NEW APPROACHES FOR TESTING FIRE HISTORY HYPOTHESES IN THE CANADIAN ROCKIES

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SUMMARY

Historically, wildland fires were frequent in the montane ecoregion of the Canadian Rockies. Recent analyses of historic fire patterns have been limited by a lack of *a priori* hypotheses and predictions, the use of spatially auto-correlated observations from single study areas, and a failure to integrate heterogenous fire history evidence such as time-since-fire, fire intervals, and tree-ring position of fire-scars. We describe a methodology to address these limitations. We tested a cultural burning hypothesis that people regularly fired montane meadows in spring. Dendrochronology was used on lodgepole pine (*Pinus contorta*) tree-disks obtained from 10 ha plots at the meadow edge, and 200 meters into the forest for 12 sectors around meadows, replicated at each of 8 meadows in different watersheds. The discrete time-since-fire, a(t), and fire interval f(t), distributions were both evaluated for variation around meadows. Fire occurrence near meadows declined after 1900, and virtually ceased after 1950. Mean fire intervals on the edge of meadows were relatively long (>30 years). Fire frequency was marginally shorter on meadow edges than in adjacent forests, on the downwind plots versus upwind plots, and on warm aspects versus cool aspects. Most fire scars on meadow edge and forest plots were in the earlywood sections of tree-rings. These results suggest that cultural burning in spring (outside the lightning season), and partially focussed on meadows, was an important component of long-term fire regimes. However, contrary to the initial hypothesis of frequent meadow burning only, it appears that people periodically burned whole valleys, predominantly on warm aspects. Future research should utilize multiple sources of fire history evidence gathered from plots on valley-wide transects, replicated both within and between watersheds.

1. INTRODUCTION

Dendrochronology, or the study of tree-rings, provides information for evaluating the frequency and timing of wildland fire (1,2,3,4). In the Rocky Mountains, numerous dendrochronology studies report that short fire cycles (<50 years) historically occurred in the montane ecoregion (5,6,7,8,9). These fires appear to be an important long-term factor in the development and persistence of montane vegetation communities dominated by grasses, Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and trembling aspen

(*Populus tremuloides*) (10,11,12). Most studies (6, 9,13) describe a major reduction in fire frequency by the year 1930. Fire occurrence may have also decreased in approximately 1800 AD (14).

Dendrochronological fire history research completed to-date for the Canadian Rockies has several limitations. Firstly, most studies have been descriptive, exploratory studies with no predefined hypotheses or treatments. Thus, statistical comparisons of observed spatial or temporal variability (4,6,14) are questionable because were not independent of the data from which they were gathered (15,16). Secondly, sampling effort has not been appropriately allocated. Most studies have focused on intensive sampling or mapping in a single watershed. Given the relatively large area burned by some Rocky Mountain fires (9,17), observations of burn years or intervals are therefore spatially autocorrelated and not independent (15,16). For example, in a Jasper National Park study, 79% and 57% of the study area was burned over by the 1847 and 1889 fires respectively (6). Thirdly, many valley-bottom areas of the Rockies have a variable regime of high, moderate and low intensity fires. The resulting heterogenous fire history evidence is difficult to analyse with traditional time-since-fire or fire interval approaches alone (16). Again using the Jasper example, Tande (6) reported that a rich mosaic of numerous small historic fires was completely burned over by the 1889 fire. A time-since-fire approach though would show only one date for most the area, 1889, and mask the region's true fire history (13). Fourthly, several fire history studies have utilized a cumulative time-since-fire (stand age) analysis (4,14) which obscures significant temporal variation in fire frequency, and can results in erroneous estimates of fire frequency (15,18). Finally, all dendrochronological approaches to-date in the Canadian Rockies have focused on spatial and coarse temporal patterns in fire frequency. Fine-scale time of burning, as inferred from the position of fire-scars within the growth rings, may be useful to understand some fire regimes (19).

In this paper, we describe a methodology that addresses many of these limitations. We formulate an *a priori* fire history hypothesis from independent data, and make predictions for subsequent testing with dendrochronological data. Study areas are independent, and tests of predictions make full use of heterogenous time-since-fire, fire interval, and fire-scar position data.

1.1 Hypothesis and Predictions

Isolated grasslands and shrublands, often ringed with aspen and Douglas-fir stands, lie in a matrix of lodgepole pine, white spruce (*Picea glauca*), and Engelmann spruce (*Picea engelmannii*) in many valley bottoms in the Canadian Rockies (20). Previous evidence that humans fired these meadows comes from several anecdotal sources (13). An aboriginal informant explained why his people once burned bighorn sheep (*Ovis canadensis*) habitat in the Canadian Rockies (21, p.44).

> See, mountain [bighorn] sheep aren't like domestic sheep. Mountain sheep prefer only the tips of green grass; they don't like to graze an area more than once. When the burning stopped there were fewer grassy areas than before, so the sheep came back again and again...Maybe one sick animal, like one

> with lungworm would pass its sickness on to all the others. When we used to burn there was always plenty of fresh grass and they didn't have to do that [graze the same areas twice].

Apparently, spring may have been the favoured season for burning. For instance, in 1906, J.E. Stauffer, a forest ranger in southern Alberta noted that

> I always understood that Indians would never set out fires in the forests, but this year I was convinced that they do; for hunting purposes, in season or out, in the Banff Park and out of it. They set out fires in the spring on their fishing or hunting trips in order to draw deer later for grazing. [20, p.29]

Lewis (21, p. 27) interviewed a Cree-Metis elder living near Grand Cache, Alberta on spring burning techniques. The elder reported that

> We'd always wait until the late afternoon and the fire was set at the upper end [of the meadow]. It would burn down to the low, damp places where the really wet grasses grow. That's the way we burned mountain meadows. See, you have to know the wind; you have to know how to use it.

Rylatt (23, p 163-164) spent the winter of 1873 near Jasper House. Based on after the fact observations, he provided his viewpoint on how native people once hunted bison (*Bison bison*) in Jasper's Athabasca Valley.

> The cunning savage year after year crept past the herds as they fed, and attained the upper end [of the valley], then fired the long grass during the heated term, driving a thundering living mass in terror to the only Outlet at the end of the Valley, where the main body of their enemy waited to destroy as many as opportunity offered.

The practice of burning meadows may have even extended into the early 20th century by the Dominion Forestry Branch rangers experienced with burning on forest reserves east of the mountains (24). Abraham Knechtel , inspector of forest reserves described this technique (25):

> Last year we began a practice which we know saved the reserves several fires. It is a well-known fact that, early in the spring, the fields become bare and the grass dry before the snow is all gone from the woods. While such conditions existed the forest rangers burned the meadows along the reserve boundaries. Fires, coming in from the praires, met this wide fire line and died out for want of fuel.

The anecdotal information provided the background for us to postulate that valley bottom meadows in the Canadian Rocky Mountains were routinely fired in spring by native peoples to improve wildlife habitat and hunting conditions. We reasoned that this could be tested with dendrochronological evidence gathered from lodgepole pine around meadows. Variable fire intensities caused by meadows and adjacent aspen stands (26) result in even-aged lodgepole pine after intense fires, or multi-aged, with fire-scarred boles on older trees, after lower intensity fires (6). We made four specific predictions from the hypothesis:

Prediction 1. Historic fires should have occurred frequently in meadows and less frequently in surrounding forests. If native peoples and early settlers routinely fired meadows during periods when adjacent forests were too moist to burn, as per sources in Lewis (21), meadow edges should have high fire frequencies (e.g., <10 year intervals) and nearby forests much lower fire frequencies (>50 year intervals). Alternatively, under a mid-summer lightning fire hypothesis, all areas would burn only infrequently (e.g., >50 years) (14, 17).

Prediction 2. Historic fires should have occurred more frequently on downwind areas of meadows compared to upwind areas. Prevailing westerly and south-westerly winds during periods of weather conducive to burning meadows (9,27) should carry fires started in meadows downwind in an eastward direction. This should result in higher fire frequencies on the downwind (east) edges of meadows compared to the upwind (west) edges.

Prediction 3. Fires should have burned more frequently on warm aspects around meadows than on cool aspects. Valley-bottom meadows are usually bordered on their north and east sides by south-facing slopes that become snow-free early in spring. If humans burned meadows in spring, south facing slopes near meadows should have higher fire frequencies than cool and moist aspects on the opposite sides of meadows. If mid-summer lightning fires predominate in the fire regime, there should be no difference in fire frequency between aspects (17,27).

Prediction 4. If humans burned meadows in spring, fire scars should be located mostly in the dormant (early spring), or early wood (spring and early summer) sections of annual tree-growth rings (3,19) in trees near meadows. Under the lightning fire hypothesis, most fire scars should occur later in annual growth ring (latewood) when lightning-caused fires are most common (28,29), and weather conditions are most favorable for large fires (17).

2. METHODS

2.1 Gathering Fire History Evidence

The study followed a replicated block design. We selected 8 sample meadows in main valley bottoms along the Rocky Mountain eastslope in Alberta (Table 1) based on several criteria. First, we dispersed the meadows in separate valleys to provide independence. Secondly, we selected meadows that had evidence of historical human use such as trails or campsites. This was not limiting because many valley-bottom meadows in the Rocky Mountains appeared to have been favoured occupation sites for native peoples (30) and were also used by early settlers and outfitters (31). Further, we selected meadows of >50 ha whenever possible. This was difficult because there are few large meadows in most valleys (20). Finally, we avoided areas where historic logging and recent development appeared to have removed almost all fire-scarred trees.

Disks were collected from 1 to 4 trees from each of 24-10 ha sample plots, with 2 plots in each of 12 sectors surrounding each meadow (Figure 1). A meadow edge plot (<100m from perimeter of the meadow), and a forest plot (200 to 400 m into the adjacent forest) were sampled in each sector. Similar to other fire history studies in the Canadian Rockies (6,14,32), fire-scars and pith dates from lodgepole pine were the primary sources of tree-ring evidence. Crews ring-counted disks in the field as sampling proceeded to obtain an approximate record of burn years. For each field-determined burn year, crews attempted to collect evidence of at least 2 fire-scars or pith years within the plot, or in an adjacent plot.

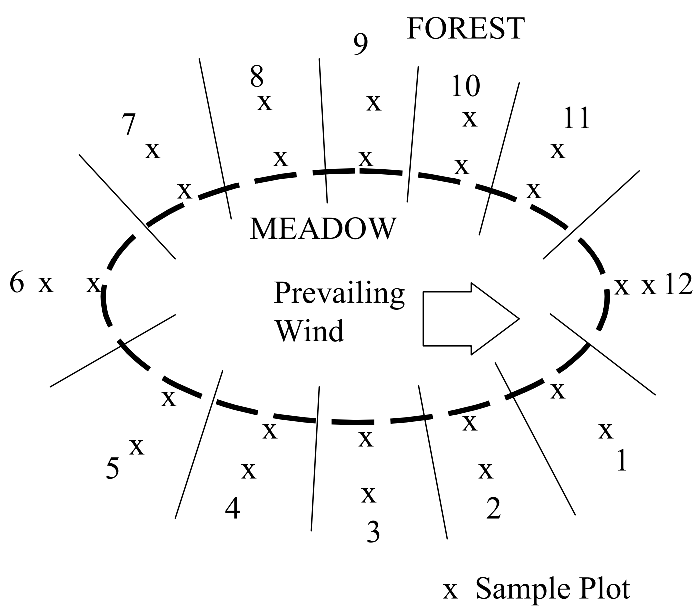

Figure 1. Standard plot layout around meadows of 24 plots at the edge of meadows and 200-400 m into the surrounding forest. Tree disks were obtained within a 200m radius of the plot centre.

In the laboratory, disks were dried and sanded with progressively finer sandpaper (to 600 grit). For cross-dating, a master tree-ring chronology (1) was made for each meadow with approximately 10 trees that did not contain scars. Ring counts and widths were measured on computer-scanned images of tree disks (32). The program COFECHA (33) was used to cross-date the master chronology samples, identify any possible dating or measurement problems, and maintain accuracy in the assignment of calendar years. Distinct and consistent marker years identified in the master chronologies provided a basis to cross-date piths and scars on the remaining disk samples. All cross-dated pith and scar information for each meadow was compiled on the same graph-sheet for cross-checking between plots (2).

Season of burn was estimated by using a binocular microscope to determine the position of the fire-scar within annual tree-growth rings (3,19), classed as follows: D, dormant season; E, earlywood; or LW, latewood. When possible, earlywood scars were further broken down in EE, early earlywood, ME, mid-earlywood; and LE, late earlywood. These estimates were calibrated with fire scars collected from a series of disks collected from Banff National Park where the fire date is known from either wildfire reports (9), or prescribed fire reports (35).

2.2 Statistical Analysis

Analyses of fire frequency usually focus on either time-since-fire data (14,36), or intervals between fire-scars (5,8). The shorter the mean time-since-fire or fire interval, the higher the fire frequency (4). In this study, variable fire intensities around meadows created heterogenous fire history evidence that was difficult to interpret with either fire frequency approach alone (16). We could obtain a time-since-fire observation from almost all plots, whereas fire interval evidence was only common on meadow edge and warm aspect plots. Thus, we used the fire year data obtained from sample plots to analyse both measures of fire frequency. First, for almost all plots, the data existed to compile the discrete time-since-fire distribution (a(t)) as of 1950, the approximate year that fire suppression for Banff National Park (9) and Alberta's eastslopes (24) became highly effective. Secondly, for plots where trees had fire-scars, we calculated fire interval observations as the time between fires, or between piths and scars for plots, and compiled these individually as a fire interval distribution, f(t). Because tree regeneration near meadows has uneven ages, observations of intervals calculated from the time between fire-scars and piths were likely underestimated for many cases.

The a(t) distribution scaled to 1 at time = 0, and the f(t) distributions are equivalent, respectively, to the survivorship (l_x) and age at death (d_x) distributions used in population life table analysis (18,37). For distributions sampled from the same area and a constant hazard of burning over time for the period of recorded fire years (e.g., no long term climate, ignition or fire suppression changes to fire frequency), the fire interval distribution is related to the time-since-fire distribution by:

$$A(t) = 1- F(t) \qquad \text{(Equation 1)}$$

where A(t) and F(t) are the cumulative forms of a(t) and f(t) (4,18). Under even more constraining conditions of constant hazard of burning over time and for all stand ages (e.g., uniform sample-point flammability with time-since-fire), f(t) equals the unscaled a(t) distribution (or n_x in life table terminology). Under this unique condition, both observation sets would have the same negative exponential distribution (4,18,36) and could be combined for analysis. However, in our study, preliminary analysis of the a(t) and f(t) observations indicated variations in hazard of burning over time and with stand age, so the a(t) and f(t) distributions were evaluated individually.

Time-since-fire and fire intervals observations were grouped by sectors and distance from meadow (edge or forest) to test predictions of edge, wind, and aspect effect. For meadow edge effect, observations were classed as meadow edge or forest. For wind effect, sectors 3 to 9 were classed as upwind, and sectors 10 to 2 as downwind (Figure 1). For the aspect effect, plots on aspects from SSE to WNW were classed as warm, and aspects from NNW to ESE as cool. The $\log_{10}$ transformation of time-since-fire and interval observations provided reasonable fits to a normal probability distribution, and was used in factorial analyses with the linear model:

$$X_{ijk} = u + W_i + E_j + A_k + WE_{ij} + EA_{jk} + WA_{jk} + WEA_{ijk} + e_{ijk} \qquad \text{(Equation 2)}$$

Where X is the overall variance in time-since-fire or interval data, W is the 2 levels of wind effect, E denotes the 2 levels of edge effect, and A is the 2 levels of aspect effect. A model including meadows as a fully orthogonal factor could not be tested because fire intervals were not observed for all sectors in some meadows.

Further, we graphically evaluated a(t) and f(t) distributions with histograms of observation counts with sectors grouped into 4 quadrants: 1) upwind-warm aspect, 2) downwind-warm aspect, 3) downwind cool aspect and 4) upwind cool aspect. The distribution of fire-scar positions in annual growth-rings was also evaluated graphically for meadow edge and forest plots.

3. PRELIMINARY RESULTS

From sampling of eight meadows to-date (Table 1), we obtained 375 disks providing 244 scar and 368 pith dates. Fire-scarred trees were uncommon around some meadows, and particularly uncommon on cool aspects on all meadows. Plot burn years were most common after 1850 for study areas in main transportation corridors (e.g., Hillsdale and Prairie de la Vache). In more remote study areas such as Clearwater River or Willow Creek, observed burn years occurred primarily before 1850. Historic logging (<100 years) appeared to have removed some fire-scarred trees around the most southerly meadows (Sibbald Flats, Ribbon Creek, and Hillsdale).

Table 1. Description of study meadows.

Meadow	Code	Description, UTM and elevation at centre of meadow
Clearwater River	CW	Confluence of Malloch Creek and Clearwater River in Banff National Park, lower subalpine ecoregion, 80 ha area, UTM: 565200-5742500, Elevation: 1810 m
Hillsdale	HD	18 km NW of Banff in Bow River valley, Banff National Park, montane ecoregion, 40 ha area, UTM: 584900-5675200, Elevation: 1240 m
Panther River	PR	Valley bottom of Panther River, 6 to 9 km west of Banff National Park boundary, montane transitional to lower subalpine ecoregion, 170 ha area, UTM: 592500-5715300, Elevation: 1840 m
Prairie de la Vache	PV	9 km SE of Jasper, Alberta in Athabasca River valley, Jasper National Park, montane ecoregion, 30 ha area, UTM: 432300-5849600, Elevation: 1100 m
Ribbon Creek	RC	1 to 3 km north of confluence of Ribbon Creek and Kananaskis River, montane transitional to lower subalpine ecoregion, 200 ha area ,UTM: 631500-5642500, Elevation: 1450 m
Sibbald Flats	SF	Confluence of Sibbald Creek and Jumpingpound Creek, 40 km east of Calgary, montane ecoregion, 150 ha area, UTM: 650000-5656000, Elevation: 1460 m
Willow Creek	WC	1 to 3 km north of confluence of Willow Creek and Snake Indian River, Jasper National Park, montane transitional to lower subalpine ecoregion, 100 ha, UTM: 409000-581700, Elevation: Elevation: 1380 m
Ya Ha Tinda	YT	Valley bottom of Red Deer River, 4 to 20 km east of Banff National Park boundary, subalpine and montane ecoregion, 2000 ha, UTM: 599000-5734000, Elevation: 1680 m

The time-since-fire as of 1950 (a(t)) distribution (Figure 2a) followed a consistent pattern of an exponentially declining distribution that was interrupted about 50 years prior to 1950 (e.g., 1900). From 1900 to 1950, the overall number of plots burned declined sharply. The overall fire interval distribution f(t) (Figure 2b)) shows that short (< 10 years) fire intervals were either infrequent, or did not scar trees near meadows. Factorial analyses (Equation 2) of $\log_{10}$ transformed values of a(t) and f(t) by plot location (3 factors x 2 levels each) indicated that fire occurred more frequently on meadow edges than in nearby forests (fire interval 40 years versus 53 years, $P = 0.059$), more frequently on downwind ends of meadows versus upwind ends (time-since-fire 66 years versus 88 years, $P = 0.026$, Table 2), and more frequently on warm aspects than on cool aspects (fire interval 40 years versus 57 years, $P = 0.061$, Table 3). Fire-scar position in growth rings could be estimated for 191 fire-scars. Due to more frequent scars, plots on meadow edges yielded more estimates than forest plots (Figure 3). However a similar pattern of more frequent fire-scars in the early wood portion of rings was found for both forest and meadow plots. Relatively few fire-scars occurred in the latewood section of growth rings.

Table 2. Means ± standard error (years) and sample size (in brackets) for time-since-fire as of 1950 for plots from all meadows grouped by plot position. Warm is warm aspects (SEE to WNW), and cool is cool aspects (NNW to ESE). Double asterisks indicate difference between means significant at $P < 0.05$.

Aspect	Wind		Total
	Upwind	Downwind	
Cool	99±12 (57)	73±10 (34)	89±8 (91)
Warm	74±10 (44)	63±6 (70)	67±5 (114)
Total	88±8** (101)	66±5** (104)	77±5 (205)

Table 3. Means ± standard error (years) and sample size (in brackets) for fire intervals for plots from all meadows grouped by plot position. Warm is warm aspects (SEE to WNW), and cool is cool aspects (NNW to ESE). Single asterisks indicate difference between means significant at $P < 0.10$.

Aspect	Wind		Total
	Upwind	Downwind	
Cool	59±8 (41)	48±8 (15)	57±6* (56)
Warm	37±4 (52)	42±4 (101)	40±3* (153)
Total	47±5 (93)	43±3 (116)	44±3 (209)

4. DISCUSSION AND CONCLUSION

The combination of time-since-fire, fire interval, and time-of-burning data, gathered with standard plots from replicate, independent locations was essential to evaluate predictions from the cultural burning hypothesis.

Fire frequency derived from time-since-fire and fire interval data did not completely support the hypothesis that meadows were a focus for frequent cultural burning. Most importantly, meadow edges did not appear to have the short mean fire intervals (<10 years, Prediction 1) that would indicate frequent human burning. However, meadow edges (Prediction 1), downwind ends (Prediction 2), and warm aspects (Prediction 3) did burn somewhat more often which suggests that meadows were may have been partially a focus for historical burning.

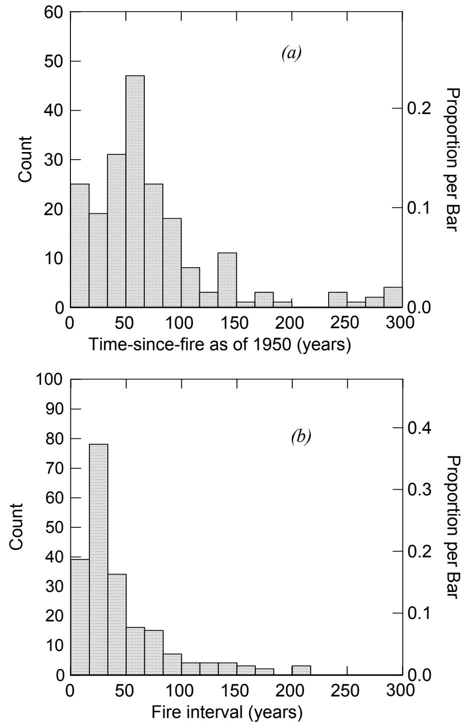

Figure 2. Time since fire as of 1950 *(a)*, and fire interval *(b)* distributions for all sample plots around meadows.

The position of the majority of fire-scars in the early wood and dormant sections of tree rings (Figure 3) clearly supported cultural burning as cause of fires. Contrary to Prediction 4, the timing of scars was similar in both meadow and forested plots, indicating that spring or dormant season fires burned not only meadows, but also major areas of forest. This evidence contradicts Johnson and Wowchuk's (17) conclusion that most forest areas of the Canadian Rockies burned historically from lightning-caused fires in July and August. However, their supporting data was written fire reports for the few burns that occurred after 1950. Near the meadows evaluated during our study, fire occurrence post-1950 was virtually non-existent, and recent burn area is reported as very low throughout the Rocky Mountains (6, 9,15). Conclusions on season-of-burn, derived solely from limited post-1950 fire data may not be applicable to earlier time-periods with different fire regimes and human land uses.

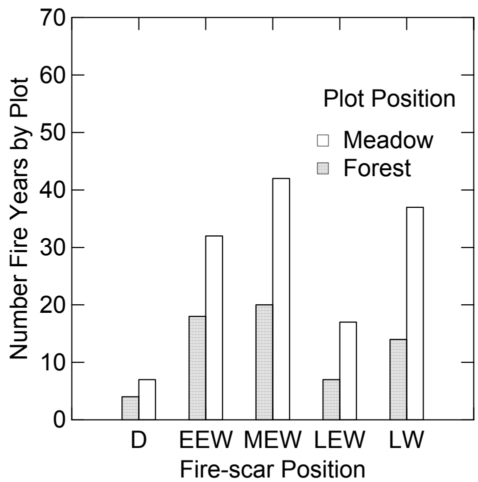

Figure 3. Position of fire-scars in annual growth rings for plots grouped by meadow edge (Meadow) or forest locations. Positions are dormant season (D), early earlywood (EEW), mid-early wood (MEW), late early wood (LEW), and latewood (LW).

The hypothesis of a human-ignition dominated fire regime for the eastern slopes of the Canadian Rockies is supported by the low occurrence and burn area of lightning fire compared to human-caused fires (9,13,29), and the predominance of fire scars in earlywood or dormant sections of tree-rings (this study). However, the pattern appears to differ from that reported by Lewis (21) for northern Alberta areas. Lewis (21) found that frequent spring burning was reported as carefully contained in meadows or narrow travel corridors. In contrast, our dendrochronological evidence indicates that human-started fires in the Rockies were probably less frequent and spread down whole valleys, burning both forests and meadows. This observation is consistent with other reports (8,9,13,24) of widespread human-caused burns in Rocky Mountain valleys and foothills during periods outside the midsummer lightning fire season. Other studies (6,9,32,40) also found that warm aspects burned somewhat more frequently than cool aspects.

The motive for this potential large-area cultural burning practice may have been maintenance of bison movement corridors from the plains into the mountains. Prior to 1880, bison are the dominant, identifiable faunal component in eastern slope archaeological sites, and were also the most commonly observed species in explorer journals (13). The relatively high abundance of bison in comparison to other ungulates likely reflects movements into the mountains of small sub-herds the separated from large, migratory herds of bison historically found on the Great Plains to the east (13). First Nations valued bison highly for food, clothing, and shelter, and people were well-skilled in using manipulation by fire and other techniques to control herd movements (e.g., 41,42). Therefore, it is possible that bison movement into the mountains was not just passively observed, but actively encouraged by hunters. Once within most eastern slope mountain valleys, bison were effectively contained in large rock-walled pounds. Escape routes across mountain passes were blocked by deep snow for over 6 months per year.

On the basis of our initial results, we recommend that future fire history research not be focussed on meadows. Rather, valley-wide transects replicated both within and between watersheds would be more useful. Predictions from hypotheses could be tested with data collected from a standard template of plot locations on transects, and should utilize time-since-fire, fire interval, and season of burn data.

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