Forest Ecology and Management 256 (2008) 304–312

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Fire history and fire management implications in the Yukon Flats National Wildlife Refuge, interior Alaska

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ARTICLE INFO

Article history:
Received 2 August 2007
Received in revised form 9 April 2008
Accepted 10 April 2008

Keywords:
Fire history
Fire management
Interior Alaska
Black spruce
White spruce
Aspen
Dendrochronology

ABSTRACT

We conducted this investigation in response to criticisms that the current Alaska Interagency Fire Management Plans are allowing too much of the landscape in interior Alaska to burn annually. To address this issue, we analyzed fire history patterns within the Yukon Flats National Wildlife Refuge, interior Alaska. We dated 40 fires on 27 landscape points within the refuge boundaries using standard dendrochorological methods. Fire return intervals based on tree ring data ranged from 37 to 166 years (mean = 90 ± 32 years; $N = 38$) over the 250 year time frame covered by this study. We found no significant differences in the frequency of fire occurence over time. There was no evidence to suggest that changes in fire management policy have significantly altered the fire regime in the Yukon Flats area. However, the lack of significant differences over time may be due in part to the relatively short time period that fires were actively suppressed in Alaska. The full suppression era (1939–1984) may have been too short to significantly alter the fire regime in all areas of interior Alaska.

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1. Introduction

Wildfires have long been known to play an important role in the development of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and mixed spruce-hardwood (*Betula-Populus* spp.) forests in interior Alaska (Lutz, 1956; Viereck, 1973, 1983; Foote, 1983). Yet, between 1939 and 1984 federal policy for interior Alaska mandated that all wildfires be suppressed whenever possible (Gabriel and Tande, 1983; Norum et al., 1983; Vanderlinden, 1996; Roessler, 1998). While this policy was in force, fire suppression organizations intended to limit the occurrence and growth of all wildfires. However, all wildfires were neither actively suppressed nor controlled; some wildfires escaped notice while others were not attacked due to a lack of suppression resources (Norum et al., 1983).

From 1982 through 1984 a series of 13 interagency fire management plans were implemented (Vanderlinden, 1996; Roessler, 1998). Combined into the current Alaska Interagency Fire Management Plan (AIFMP) in 1998, these plans effectively altered and prioritized fire suppression responses across the landscape. Since this change in policy, the total area burned annually in Alaska has increased. For example, two of the three largest fire years on record for Alaska occurred in 2004 and 2005 with 707 fires burning approximately 2.7 million hectares in 2004 and 625 fires burning approximately 1.8 million hectares in 2005 (Rogers, 2005). In contrast, during the latter period of active fire suppression (1964–1984) approximately 246,000 hectares were burned annually by wildfire (Hess et al., 2001).

The main impetus for the AIFMP was to reduce fire suppression costs (Haggstrom, 1994; Roessler, 1998), however there is some debate as to the ecological desirability of the corresponding increase in wildfire activity (Roessler, 1998). Critics of the current fire management policies argue that too much land is burning in these large fires within a single fire season. They feel that some areas in Alaska are burning more frequently and more contiguously than sound ecosystem management policies necessitate. To many, the crux of the problem with the current AIFMP is that it is based on economic realities rather than on a scientific management decision matrix (Roessler, 1998). However, supporters of the present AIFMP argue that the current level of fire in the landscape is natural and provides an essential ecosystem process (DeWilde and Chapin, 2006); any subsequent planning or further study is unnecessary (Roessler, 1998).

The social and economic effects of past and present fire suppression policies have been discussed elsewhere (Natcher, 2004; DeWilde and Chapin, 2006). However, an evaluation of the influences of fire suppression policies on fire frequencies over time

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0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2008.04.040

was lacking. Our study was conducted to investigate potential changes in fire frequency over time and to provide more basic fire history information for interior Alaska. Information on where, when, and how often fires occurred in the past is necessary to evaluate the efficacy of the present AIFMP in a historical context. Specifically, we compiled fire histories on a range of forest types within the Yukon Flats National Wildlife Refuge (YFNWR). Our objectives are to identify the years when fires occurred, the stand ages when fires occurred, and the time intervals between successive fires over a range of past and current fire suppression policies in the YFNWR.

2. Background

2.1. Fire history in interior Alaska

Detailed information on fire history in interior Alaska is lacking. The fire regime of the boreal forest is characterized by stand-replacing fires (Johnson, 1992), which do not leave trees with records of multiple fires as occur in other forest types (Dieterich and Swetnam, 1984). Moreover, the few existing fire history studies in Alaska may have limited application to interior white and black spruce forests. For example, Alaskan fire history studies based entirely on documentary fire records (Barney, 1969; Gabriel and Tande, 1983; Kasischke et al., 2002) tend to be limited by multiple missing records, the possibly inaccurate and/or incomplete reporting of fires, and the relatively short time period covered by historical records (1950 to present). Fire history studies based on charcoal and pollen analysis have provided much needed temporal depth to the fire record in Alaska (Lynch et al., 2003, 2004; Anderson et al., 2006; Berg and Anderson, 2006), but these studies tend to lack annual precision. Fire history studies based on tree rings where individual fires can be dated precisely exist (Mann et al., 1995; DeVolder, 1999; Mann and Plug, 1999; Fastie et al., 2003). However, these studies tend to be located near large settlements (Fastie et al., 2003), in a more maritime climate such as the Kenai Peninsula (DeVolder, 1999), and/or lacked spatial extent (Mann et al., 1995; Mann and Plug, 1999; Fastie et al., 2003). Yarie (1981) provided information on fire occurrence in interior Alaska forests. However, the lack of fire scar evidence to precisely date fires, and the exclusive use of standing age distributions to estimate fire return intervals in Yarie's study may have resulted in inaccurate estimates of fire history (Huggard and Arsenault, 1999).

2.2. Wildfire and climate relationships in Alaska

Variation in the amount of area burned annually in boreal forest ecosystems may be related to climate variability (Skinner et al., 1999; Hess et al., 2001; Duffy et al., 2005). Wildfire statistics for Canada have been used to relate annual increases in area burned to circulation anomalies that create above normal temperature and below normal precipitation conditions during the fire season (Skinner et al., 1999, 2002). For Alaska, large wildfire years (defined by increased area burned) have been positively correlated with the El Niño Southern Oscillation (ENSO; Hess et al., 2001). El Niño events may be conducive to wildfire as temperatures tend to be warmer than average and precipitation levels are below average (Hess et al., 2001). Duffy et al. (2005) provide additional evidence linking annual area burned in Alaska to global circulation patterns. Positive phases of the East Pacific teleconnection were related to surface high-pressure systems that block westerly flows causing warmer temperatures, lower precipitation, and above average area burned (Duffy et al. 2005). Duffy et al. (2005) also found connections between the Pacific Decadal Oscillation (PDO) and annual area burned in Alaska. The cool phase of the PDO potentially influences winter and summer precipitation levels creating conditions conducive to fire ignition and spread but the mechanisms for these connections are unclear (Duffy et al., 2005). In our study, we investigate potential relationships between fire occurrence and the El Niño Southern Oscillation to clarify the influences of climate versus fire suppression policies.

2.3. The Alaska Interagency Fire Management Plan (AIFMP)

The AIFMP prioritizes fire suppression responses based on the proximity of urbanized areas, presence of private property, presence of high-value natural resources, and the economic and ecological consequences of fire suppression (Roessler, 1998). The AIFMP places all lands in Alaska into one of four broad wildfire response categories: critical, full, modified, and limited. All wildfires are aggressively suppressed on lands designated as warranting critical and full suppression. Wildfires on lands designated as modified are attacked early in the fire season, but after a predetermined date, usually July 10 for interior Alaska, they are commonly monitored. Fires on limited lands are monitored and allowed to burn unchecked as long as life and property are not threatened. As of 1996, approximately 65% of the fire-prone acreage on state and federal lands in Alaska was in the limited action suppression category (Vanderlinden, 1996).

3. Study area

3.1. Physiography

The Yukon Flats National Wildlife Refuge is located in northeast interior Alaska (Fig. 1). The refuge is approximately 4.5 million hectares in area with boundaries that extend 192 km from north to south (67 30′N to 65 45′N) and 352 km east to west (142–150° W). Enclosed within the refuge boundaries are portions of four topographic regions: the Yukon Flats (the largest interior basin in Alaska) which comprises most of the central portion of the refuge; the Kokrine-Hodzana Highlands in the refuge's northwestern portion; the Yukon-Tanana Uplands that make up its southern portion; and the Porcupine Plateau in the eastern portion of the refuge (Selkregg, 1976).

3.2. Climate and vegetation

Climate within the Yukon Flats National Wildlife Refuge is classified as continental (Gallant et al., 1995). Winters are cold with daily temperatures averaging from −34 to −24 °C (Gallant et al., 1995). Summers are warm (although below freezing temperatures may occur during any month) with daily high temperatures averaging around 22 °C. Total precipitation averages 16.7 cm annually at Fort Yukon (located centrally within the refuge boundary) with most of the precipitation that falls as rain occurring in July (2.4 cm) and August (3.1 cm). Summer precipitation often falls episodically in thunderstorms and rain showers which results in very localized rainfall patterns. Snow covers the ground from October to May and the average snowfall each winter is approximately 1.1 m.

Vegetation patterns are quite diverse within the Yukon Flats National Wildlife refuge. Conifer, broadleaf, and mixed species forests form a heterogeneous patchwork of multiple-aged forests that occupy individual sites depending on soil characteristics and wildfire disturbance events (Gallant et al., 1995; Viereck, 1973; Foote, 1983). White spruce (*P. glauca*) commonly dominate well-drained conifer forests, while black spruce (*P. mariana*) are more dominant in poorly-drained, cooler forested areas (Gallant et al., 1995). Aspens (*Populus tremuloides*) tend to dominate broadleaf

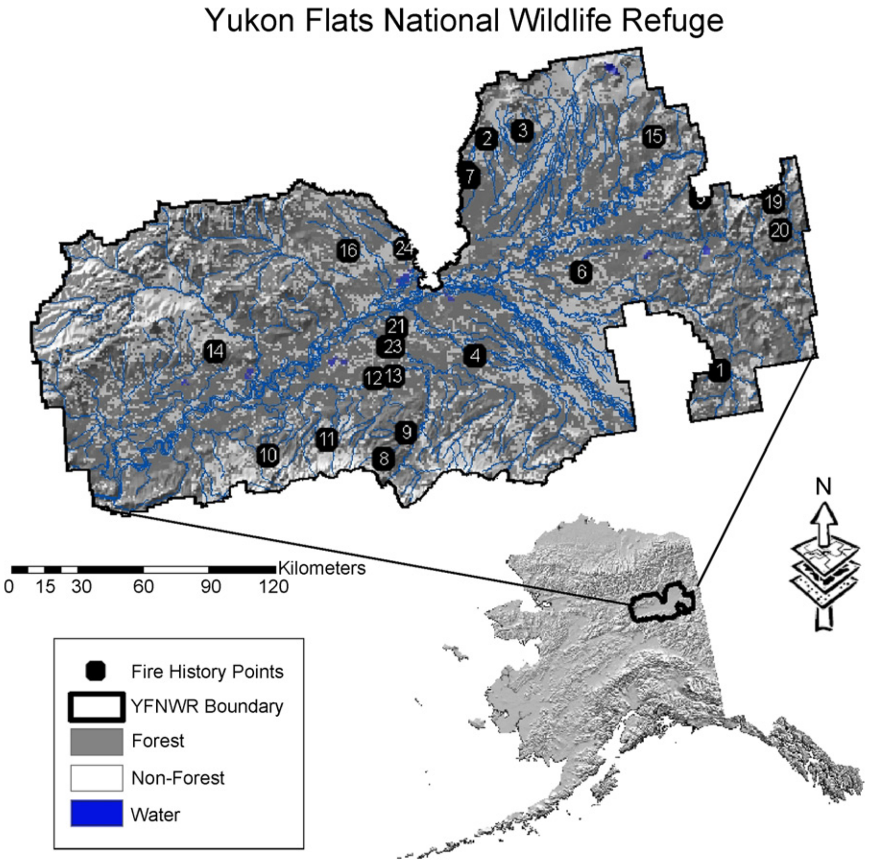

Fig. 1. Fire history locations within the Yukon Flats National Wildlife Refuge. Point 1 = site code 484; point 2 = A184; point 3 = 140; point 4 = M10; point 5 = FCM-L and FCM-U; point 6 = CIK; point 7 = CRUK; point 8 = 633; point 9 = BCF; point 10 = 043L; point 11 = 043F; point 12 = 9-MILE; point 13 = SC; point 14 = LMF; point 15 = GL; point 16 = VZL, VZLH and VZLM; point 17 = A324; point 18 = B313-N; point 19 = B313-M; point 20 = B313-S; point 21 = B9M; point 22 = CVB-W; point 23 = CVL-E; and point 24 = VBA.

forests while mixed forests consist of varying compositions of white spruce, aspen, black spruce and paper birch (*Betula papyrifera*) depending on soil drainage (Gallant et al., 1995) and wildfire.

3.3. Yukon Flats National Wildlife Refuge (YFNWR) management objectives

The YFNWR is currently managing wildfires on more than 75% of the refuge by allowing naturally ignited wildfires to burn under a wide range of environmental conditions. The goal is to use wildfire as a management tool to maintain the natural diversity of wildlife habitat as long as life, property, and ecosystem health are not threatened (USDOI, 1998; USFWS, 2001). Wildfires may be better at maintaining or restoring ecosystem health than prescribed fires as they burn under the full range of environmental conditions, including severe conditions that produce very large, intense fires (Baker, 1994; USFWS, 2001).

4. Methods

4.1. Field methods

The field methods used in this study were largely dictated by the stand-replacing fire regime characteristic of boreal forests where much of the evidence of prior fire is removed by subsequent fires. Study areas were initially selected based on the following: (1) spatial distribution across the refuge, (2) the presence or absence of historic fires, (3) vegetation type and (4) accessibility by helicopter (Fig. 1). Study areas were selected across a range of forest types and forest ages to capture as much of the spatial heterogeneity as time and resources allowed. Once selected, areas of interest were traveled to by helicopter during June, July and August of 1997. At each designated study area, a landing spot near possible fire boundaries was selected to provide access to study areas that potentially contained fire scars. On the ground, study sites of approximately 1–5 ha in area were designated and described by vegetation type and structure. The number of study sites within a study area depended on how many different vegetation types or apparently different fire events were present within an area. Each study site was then viewed as a point on the landscape since accurate fire size estimates were beyond the scope of this study.

At each landscape point we destructively sampled 5 or 6 individuals of each tree species within each post-fire tree cohort present. Cross-sections of the destructively sampled tree boles were collected within 4 cm of the base and returned to the lab for analysis where individual tree ages and establishment dates were determined (see Section 4.2). Tree ages were used to determine stand ages when fires occurred, post-fire tree cohort ages, and post-fire stand origin dates. When available, five to six samples from fire killed dead-standing snags or downed dead woody material were collected from each point to provide death dates, tree ages when killed, and stand origin dates. In addition, the boundaries between fire events were searched for fire scars. If present, up to 6 fire-scarred tree cross-sections were collected from each point to accurately date the occurrence of past fires using the fire scar methodology discussed below. Only fires that were recorded by at least two individual fire-scarred trees were included as precisely dated fires.

4.2. Lab methods

Each tree cross-section was sanded with progressively finer grits of sandpaper until individual cells were clearly visible using a dissecting microscope (McBride, 1983). Annual rings were counted and visually cross-dated using the list or pointer year method (Yamaguchi, 1991). The accuracy of the visual cross-dating process was confirmed by measuring ring-widths to the nearest 0.01 mm on a sliding Velmex micrometer bench on approximately 30% of the tree cross-sections. The measured ring-width series were compared with a previously dated tree-ring chronology for the Christian River region of the YFNWR (Drury unpublished data) using the computer program COFECHA (Holmes, 1986). Tree cross-sections that did not cross date were not included in future analysis. For dead trees, annual rings were counted and measured on each dead tree sample and cross-dated using COFECHA and the on-site chronologies from the dated living trees. These procedures resulted in individual tree establishment dates for living trees, death dates for fire-killed trees, tree establishment dates, and tree ages for fire-killed trees, and accurate dates for rings containing fire scars.

Fire return intervals were calculated two ways: (1) once fires were accurately dated using fire scars (precise fire dates, two scar minimum per fire), a fire return interval was calculated using the time interval from one dated fire to a successive dated fire. (2) When no fire scars were available the death dates of fire-killed trees were used to establish fire dates. Subsequently, fire return intervals were compiled using the death dates of the fire-killed trees, the ages of the fire-killed trees, and mean post-fire tree establishment dates as tree regeneration tends to occur within 1–10 years after fire in boreal forests (Foote, 1983). Post-fire tree establishment lag times were identified by determining the time interval from when the fire occurred to the establishment date of the first individual of an identifiable tree cohort on each site with precise fire dates determined from fire scars. No ages of existing unburned stands were used to calculate fire return intervals. Fire dates and fire return intervals from fire-killed trees were combined with the fire scar data to compute a second set of mean fire return intervals which are referred to as stand age based fire dates.

4.3. Data analysis

Fire and climate relationships for dated fire years were investigated using the computer program FHX2 (Grissino-Mayer, 1995). FHX2 can be used to analyze fire-scar data and to provide graphical and statistical descriptions of fire history information (Grissino-Mayer, 1995). We used the Superposed Epoch Analysis (SEA) module within FHX2 and the tree-ring chronology for the Christian River region (Drury unpublished data) to test for significant differences in climate between fire-event years and non-fire years (Grissino-Mayer and Swetnam, 2000). The climatically sensitive Christian River chronology (based on 18 white spruce tree-ring records) is significantly correlated (correlation coefficient $R = 0.67$, total variance explained = 45%) with temperature and precipitation from the Fort Yukon Weather Station. Tree-ring growth is positively related to above average precipitation and below average temperatures during summer months and negatively related to below average precipitation and above average temperature during summer months. Using this chronology as a climate proxy, average climate conditions during widespread fire years (years when fires were recorded in at least 25% of the sample sites) were compared with the average climate for each of the 5 years before a fire year, and the average climate for each of the 4 years after the fire year (−5, +4).

SEA was also used to test for relationships between the El Niño Southern Oscillation using the Southern Oscillation Index (SOI) and widespread fire years. We used Stahle et al.'s (1998) tree-ring reconstruction of winter (December–February) SOI to determine if fire years were influenced by the negative (El Niño years) phase or positive phase (La Niña years) of the southern oscillation from 1750 to 1977.

4.4. Temporal and spatial differences in fire occurrence

Student's *t*-tests were used to test for species specific differences in stand age when fires occurred, and ANOVA was used to test for stand age differences among topographic regions when fires occurred. In addition, fire return intervals were compared by species using Student's *t*-tests and by region using ANOVA. Fire return interval variation over time was compared for four distinct time periods: 1847–1892, 1893–1938, 1939–1984, and 1985–1999 using ANOVA and the stand age based fire return intervals. Stand age based fire return intervals were used in this analysis due to the larger sample size. These time periods were chosen to compare the 46-year time period of most aggressive fire suppression within the refuge (1939–1984) with two 46-year time periods before 1939 and the 15-year time period after the implementation of the AIFMP. Ideally, identical time periods would be compared, however the short period of time covered by aggressive fire suppression, the short time period since the implementation of the AIFMP, and the long fire return intervals representative of the boreal forests precluded comparing identical time periods. To compensate for this, the time intervals for the return of fire were compared based on when the fire that closed the interval occurred. For a point that burned in 1843 and then reburned in 1936 the fire return interval would be 93 years and this interval would be placed into the 1893–1938 time period for analysis.

5. Results

5.1. Fire years and stand characterizations

A total of 27 study areas, or landscape points, were located within the confines of the YFNWR (Fig. 1). At these locations, 40 fires were identified and dated to the year of fire occurrence (Table 1 and Fig. 2). Nine landscape points were located in the Hodzana Highlands where 11 fires were encountered; 4 landscape points were classified as white spruce stands, black spruce stands occupied 3 landscape points, while 2 landscape points had significant aspen components (Table 1). The earliest fire date identified in this region were in 1872 at Vunzik Lake (Table 1 and Fig. 1); the most recent fire investigated in this region occurred in 1998 at the Alaska Fire Service (AFS) Fire #324 point.

Eight landscape points were located within the Porcupine Plateau in the eastern portion of the refuge (Table 1). Seven of these landscape points possessed a significant black spruce component while two points were characterized as either mixed aspen–white spruce sites or mixed aspen, black spruce, and white spruce landscape points (Table 1). As in the Hodzana Highlands, a total of 13 fires were encountered within this area with the oldest fire in 1872, Frozen Calf Mountain-lower, and the most recent fire in the last year covered by this study, 1999, AFS Fire B313 (Table 1).

We located 4 landscape points within the Yukon/Tanana uplands where seven fires were identified and dated (Table 1). Two of the 4 landscape points were classified as black spruce points while the remaining two points were a mixed black spruce/

Table 1
Summary information on fire occurrence and location within the Yukon Flats National Wildlife Refuge (*indicates a historical record exists of this fire). Each fire date below is a known fire date or is recorded by 2–11 fire scarred trees, or both (number of fires scars recording fire enclosed within parentheses)

Site name	Fire scar dates	Stand type
Hodzana Highlands		
Vunzik Lake (VZL)	1872/1950 (2)*	White spruce
Vunzik Lake H (VZLH)	1881 (2)	Black spruce
Vunzik Lake M (VLM)	1885/1950 (6)*	Black spruce
Christian River (CRUK)	1903 (5)	White spruce
Venetie Burn Area (VBA)	1922 (6)	White spruce
AFS Fire #140 (140)	1959 (3)*	White spruce
Lone Mountain Fire (LMF)	1979*	White spruce/aspen/birch
AFS Fire #A184 (A184)	1986*	White/black spruce
AFS Fire #A324 (A324)	1998*	White spruce/aspen
Porcupine Plateau		
Frozen Calf Mtn—Lower (FCM-L)	1872 (3)/1936[a]	Black spruce
Frozen Calf Mtn—Upper (FCM-U)	1880 (5)/1936[a]	Black spruce
AFS Fire #B313—North (B313-N)	1895 (2)/1986*	Black spruce
AFS Fire #B313—Middle (B313-M)	1920 (2)/1999*	Black spruce
AFS Fire #B313—South (B313-S)	1947 (2)/1999*	Black spruce
AFS Fire #484 (484)	1898 (2)/1943 (11)/1997*	Black/white spruce/aspen
Chalkyitsik Burn Area (CIK)	1969 (3)*	Aspen/white spruce
Graphite Lake (GL)	1988*	Black spruce
Yukon/Tanana uplands		
Beaver Creek Burn Area (BCF)	1894 (2)/1967*	Black/white spruce
AFS Fire #633 (633)	1902 (4)/1996*	Black spruce
AFS Fire #043 Lake (043L)	1950 (7)*	White/black spruce/aspen
AFS Fire #043 JC (043F)	1988*	Black spruce
Yukon Flats		
Meadow 10 (M10)	1843 (2)/1943 (3)	White spruce/aspen
Beaver 9 Mile (B9M)	1872 (2)/1922 (2)	White spruce/aspen
Canvasback Lake—East (CVL-E)	1919 (2)	White spruce
9 Mile (9-MILE)	1920 (4)	White spruce/aspen
South of Canvasback Lake (SC)	1920 (5)	White spruce/aspen
Canvasback Lake—West (CVB-W)	1941 (3)	White spruce/aspen
Total	40 dated fires (90)	

[a] Fire in 1936 on Frozen Calf Mountain recorded by the death dates of 12 cross-dated trees.

white spruce landscape point and a white spruce/black spruce/aspen point (Table 1). The earliest fire encountered occurred in 1894 at the 1967 Beaver Creek Fire point and the most recent fire, 1996 AFS Fire #633, occurred in 1996 (Table 1).

The final area where fire occurrence was investigated was within the Yukon Flats proper. A total of six landscape points were located within this basin where eight fires were identified and dated (Table 1). The earliest fire occurred at the Meadow 10 point

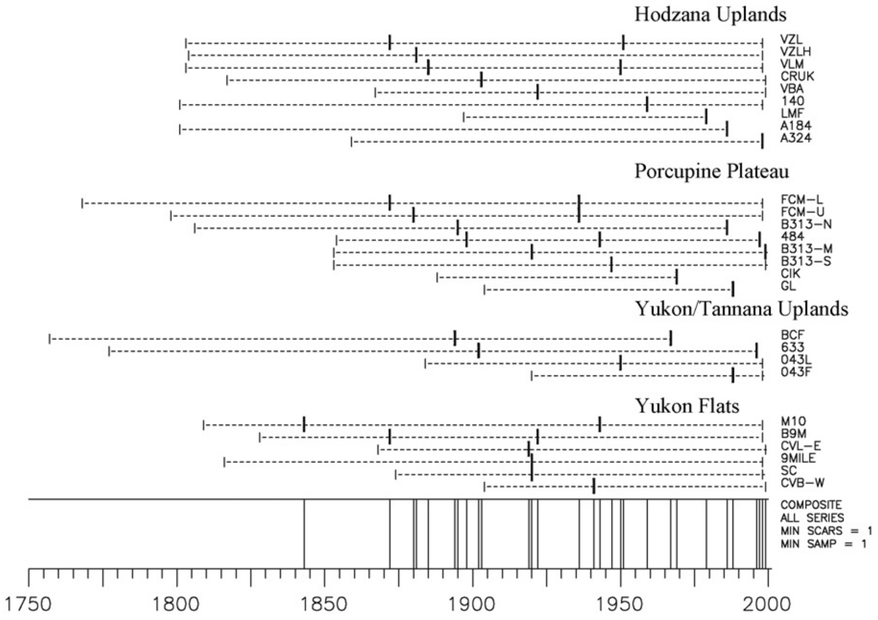

Fig. 2. Fire history summaries for the Yukon Flats National Wildlife Refuge. Vertical bars represent fires that were dated using fire scars. Only fires that were recorded by at least two trees per landscape point or historic fire dates exist are shown. The intervals between vertical bars were used to compile mean fire return intervals (see Tables 3 and 4).

Table 2

Summary table for stand ages when fires occurred on all sites within the Yukon Flats Wildlife Refuge. N = Number of landscape points

	N	Mean stand age, years (±S.D.)	Median stand age (years)	Minimum stand age (years)	Maximum stand age (years)	95% confidence interval (years)
All sites	36	81 ± 38	82	18	218	±13
White spruce sites	20	77 ± 34	69	34	159	±16
Black spruce sites	19	81 ± 41	82	18	218	±19
Aspen sites	3	60 ± 18	55	47	81	±45
Hodzana Highlands	13	99 ± 13	82	44	218	±29
Porcupine Plateau	13	69 ± 25	81	18	104	±15
Yukon-Tanana uplands	5	86 ± 25	85	63	125	±31
Yukon Flats	5	56 ± 27	47	34	104	±34

Table 3

Mean fire return intervals (MFRI) determined using precise fire dates. Precise fire dates are fire dates that were determined using fire scars except for two fire dates that were dated to annual resolution using the death dates of the pre-fire tree cohort and establishment dates of the post-fire tree cohort. Fire return intervals determined using precise fire dates are time intervals where the date of the last fire and the fire that preceded it are known to annual resolution. The time interval summarized is from 1843 to 1999

	Number of fire return intervals[a]	Mean fire return interval, years (±S.D.)	Median fire return interval (years)	Minimum fire return interval (years)	Maximum fire return interval (years)	95% confidence interval (years)
All sites	13	76 ± 27	69	45	148	±17
White spruce/aspen sites	6	82 ± 38	71	45	148	±40
Black sprucesites	10	67 ± 17	65	45	94	±12
Hodzana Uplands	3	94 ± 27	69	65	148	±116
Porcupine Plateau	7	63 ± 6	56	45	91	±15
Yukon-Tanana uplands	2	84 ± 11	84	73	94	±133
Yukon Flats	1	100	100	100	100	n/a

[a] The totals for all sites and the sum of the individual white and black spruce sites are not in agreement because three sites had both white and black spruce stands that burned at the same time.

in 1843 while the most recent fire identified and dated at these points occurred in 1943, also at the Meadow 10 point (Table 1). All six landscape points were classified as white spruce stands or white spruce/aspen stands.

5.2. Fire occurrence and climate

Twenty-eight fire years were identified as occurring from 1843 to 1999 on our landscape points within the refuge (Table 1 and Fig. 2). While these fires tended to occur more often in drier years than would be expected if fire occurrence were independent of climate conditions, the superposed epoch analysis revealed no significant relationships between climate and fire occurrence (results not shown). Moreover, there were no significant relationships between fire occurrence on our points in the refuge and SOI (1750–1977; Stahle et al., 1998).

5.3. Stand ages at the time of fire occurrence

The ages of fire-killed trees across our study points varied from a minimum of 18 years to a maximum of 218 years (Table 2; N = 36 stands, mean of 81 ± 38 years, median = 82 years). Areas with existing white spruce and black spruce stands tended to be older when burned (77 ± 34 and 81 ± 41 years respectively) than areas with existing aspen stands (60 ± 18 years; Table 2). However, these differences were not significant (ANOVA; $p = 0.65$). Stands also tended to be older when fires occurred in the Hodzana Highlands or the Yukon/Tanana uplands (99 ± 13 and 86 ± 25 years) than in the either the Yukon Flats interior basin (56 ± 27 years) or the Porcupine Plateau (69 ± 25 years; Table 2). Yet, these differences were not significant ($p = 0.08$) in the ANOVA analysis.

5.4. Time intervals between successive fires (fire return intervals)

5.4.1. Precise fire dates

Fire return intervals for precisely dated fires within the YFNWR varied from a minimum of 45 years to a maximum of 148 years (mean = 76 ± 27 years, median = 69 years; based on a two scar minimum per dated fire; Table 3). Mean fire return intervals for white spruce/aspen stands tended to be longer than for black spruce stands (82 ± 38 and 67 ± 17 years; Table 3) although these differences were

Table 4

Mean fire return intervals (MFRI) determined using tree cohort ages at the time of fire occurrence. Fire return intervals dated using tree cohort ages are intervals where the stand age at the time of fire occurrence is used to determine the length of the fire return interval. For stands that are initially colonized by aspen 1 year is added to the stand age to determine the return interval. For stands colonized by white spruce eight years are added to the stand age, and for black spruce stands six years are added to the stand age to determine the fire return interval (see text and Table 6 for details on establishment rates). The time interval covered is from 1751 to 1999. White spruce and aspen data were combined for this analysis

	Number of fire return intervals	Mean fire return interval, years (±S.D.)	Median fire return interval (years)	Minimum fire return interval (years)	Maximum fire return interval (years)	95% confidence interval (years)
All sites	38	90 ± 32	89	37	166	±11
White spruce/aspen sites	24	92 ± 38	88	37	166	±16
Black spruce sites	14	87 ± 20	89	50	130	±12
Hodzana Uplands	11	101 ± 36	90	63	166	±21
Porcupine Plateau	15	93 ± 26	90	50	151	±15
Yukon-Tanana uplands	6	94 ± 36	82	54	145	±38
Yukon Flats	6	58 ± 28	49	37	112	±29

Table 5
Summary table for mean fire return intervals over time. Mean fire return intervals are based on tree ages at time when fires occurred (stand age based fire return intervals). *N* equals the number of fires per time interval

	N	Mean FRI, years (±S.D.)	Median FRI (years)	95% confidence interval (years)
1847–1892	8	81 ± 24	87	±20
1893–1938	12	90 ± 33	91	±21
1939–1984[a]	10	94 ± 35	90	±25
1985–1999	8	94 ± 38	91	±31

[a] Time period of aggressive fire suppression.

Table 6
Mean time intervals between fire occurrence and successful forest establishment

Site type	*N*	Mean interval, years (±S.D.)	Median interval (years)	Minimum interval (years)	Maximum interval (years)	95% confidence interval (years)
All sites	25	5 ± 4	4	1	22	±2
Aspen	8	5 ± 8	1	1	22	±6
Black spruce	10	6 ± 2	5	2	9	±2
White spruce	16	9 ± 8	6	1	29	±4
White spruce[a]	8	5 ± 3	5	1	10	±3

[a] Sites composed exclusively of white spruce.

not significant (alpha = 0.05, Student's *t*-test). Mean fire return intervals also tended to be longer for the upland regions of the refuge (94 ± 27 and 84 ± 11 years) than for the Porcupine Plateau (63 ± 6 years; Table 3) although these differences were also not significant. There were not enough data on precisely dated fire return intervals for the Yukon Flats interior basin for comparisons.

5.4.2. Stand age based fire return intervals

Determining fire return intervals based on stand ages when burned greatly increased the number of intervals available for testing (13 fire return intervals versus 38 fire return intervals; Tables 3 and 4). While stand age based fire intervals were longer in most cases than the fire return intervals calculated from precise fire dates (Tables 3 and 4), these differences were not significant (Student's *t*-test; alpha = 0.05).

5.4.3. Potential changes in fire occurrence over time

Mean fire return intervals based on stand ages over the four time periods tested were not significantly different (ANOVA; $p = 0.85$; Table 5). Only the 1847–1892 time period showed variation in the incidence of fire with fires occurring at slightly shorter time intervals (MFRI 81 ± 24 years). Moreover, fire return intervals during the 1939–1984 period of aggressive fire suppression were not significantly shorter than the fire return intervals within the 1985–1999 AIFMP era (MFRI = 94 ± 35 and 94 ± 38 years, respectively; Table 5).

5.5. Time interval for successful post-fire tree establishment

Post-fire time lag for successful tree establishment was determined for 25 stands where precise fire dates were determined (Table 6). Tree seedlings established rapidly after fire, usually within 10 years (Table 6). Aspen resprouts tended to be present 1 year post-fire in aspen stands (only two of eight aspen stands had post-fire seedling establishment dates longer than 1 year). Black spruce seedlings took longer to return post-fire with a mean establishment time of 6 ± 2 years, yet black spruce seedlings were present in all black spruce stands within 9 years post-fire (Table 6). White spruce seedlings were slower to establish post-fire in mixed species stands (9 ± 8 years on average; Table 6). However, in pure white spruce stands, white spruce seedlings tended to establish more rapidly post-fire (5 ± 3 years on average, 10 year maximum lag time; Table 6).

6. Discussion

6.1. Fire occurrence over time on the Yukon Flats National Wildlife Refuge

We see no sign that current fire management policies as outlined in the AIFMP are leading to greater rates of fire occurrence within the YFNWR. There were no significant differences in fire frequency or stand ages when burned between any of the time periods studied (Table 5). Moreover, fire return intervals for the 1939–1984 time period of most active fire suppression (MFRI = 94 ± 35 years) were virtually identical to the fire return intervals observed during the time period of the AIFMP (94 ± 38 years; Table 5). Only the time period from 1847 to 1892, well before active land management or the current climate warming trend, showed slightly more frequent fire occurrence (MFRI 81 ± 24 years).

We suggest that the lack of significant differences between the time periods we investigated may be due in part to the short time period that fires were actively suppressed in interior Alaska. Fires in interior Alaska are large and fairly infrequent. Subsequently, fire return intervals in Alaska tend to be much longer than intervals covered by various fire management policies. It is likely that the full suppression era (1939–1984), when all fires were actively suppressed whenever possible, was too short to significantly alter the fire regime throughout interior Alaska. For example, if fire suppression successfully lengthened a fire return interval from 60 to 100 years, the resulting interval without fire is not outside of the historic range of fire free intervals. Moreover, many fires in remote, interior locations such as the YFNWR escaped initial attack during the full suppression era and became large fires before they could be controlled, or were simply not staffed because of higher priority fires that threatened more populated areas. In essence full fire suppression may have never been in force in the YFNWR area. The relatively short time period covered by the full fire suppression era and the lack of suppression on many fires in this area during the fire suppression period suggests that the YFNWR has experienced an essentially uninterrupted, natural fire regime.

6.2. Fire occurrence and climate

The lack of significant relationships between climate and fire occurrence we observed suggests that any point on the landscape in interior Alaska may experience conditions conducive to burning during any given year. This result is not necessarily inconsistent with previous studies that related large fire years based on quantities of hectares burned to global climate anomalies (Skinner et al., 1999, 2002; Hess et al., 2001; Duffy et al., 2005), as we are discussing different aspects of the fire regime. Our goal was to extend the record of fire occurrence back in time, not to determine how much of the area burned within a given area on an annual basis. Standard fire history methods are effective at identifying the temporal aspect of fire occurrence on a given point on the landscape. However, it is virtually impossible to determine the spatial extent of past fires (pre-1950) in interior Alaska using standard fire history methods since evidence of the spatial extent of past fires is removed by subsequent fires. Therefore we incorporated all fires, regardless of spatial extents, in our study to provide a longer temporal record of fire occurrence.

In addition, our study was not designed to predict the influence of future climate warming scenarios on fire regimes. However, recent studies in North American boreal forests (Stocks et al., 2002; Duffy et al., 2005; Flannigan et al., 2005; Kasischke and Turetsky, 2006) suggest that future fire seasons in Alaska will be longer under the predicted warmer and drier climatic conditions. Potentially, more fires will occur, burn longer, and cover more spatial extent on an annual basis during longer fire seasons. More information regarding fire frequency variability under a range of climate scenarios is necessary to understand, model, and predict fire regime responses to potentially warmer climates and longer fire seasons.

7. Conclusions

We see no evidence to suggest that fire suppression activities between 1939 and 1984 had significantly changed fire frequencies over the 1750–1999 time period we studied. Our results suggest that looking at short time periods to evaluate the impacts of fire prescription policies on boreal forest ecosystems may be misleading. Fires occur over long time intervals on individual sites in boreal forests. Researchers evaluating trends in fire frequency, fire severity, and fire area need to look at long time intervals to produce accurate assessments of whether fire policy over a short term has influenced whether or not the boreal forest is burning within the range of historic variability. The pattern of fire frequency we observed since the application of the AIFMP (1985–1999) is within the historical range of fire variability for the Yukon Flats National Wildlife Refuge. We conclude that the fire management policy of allowing some fires to burn in remote areas as specified in the Alaska Interagency Fire Management Plan is prudent.

Acknowledgements

We thank Bill Gjesdahl and Tami Defries for field assistance. We thank Thomas T. Veblen, three anonymous reviewers, and the staff at the Yukon Flats National Wildlife Refuge for thoughtful reviews of the original manuscript. Larry Vanderlinden provided technical advice and support. Additional support was provided by the Yukon Flats National Wildlife Refuge, the Biogeography Lab at the University of Colorado Boulder, and the Missoula Fire Sciences Laboratory.

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