Fire regimes of ponderosa pine communities in the Black Hills and surrounding areas 2017

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Abstract— Wildfire is an important disturbance in ponderosa pine communities in the Black Hills and surrounding areas. Effective management of these communities requires an understanding of historical fire regimes. This review provides a synthesis of the available scientific literature on historical patterns and contemporary changes in fuels, stand structures, and fire regimes in these woodlands and forests. Twelve fire history studies covering 27 sites indicate that historical mean fire-return intervals for low-severity fires ranged from about 5 to 33 years in these communities, and that fire frequency generally increased and fire severity was more variable with increasing elevation and moisture availability. Low-severity surface fires were most frequent in low-elevation ponderosa pine savannas, somewhat less frequent in low- to mid-elevation ponderosa pine woodlands and forests, and least frequent in high-elevation ponderosa pine and white spruce forests in the Black Hills region. Occasional mixed-severity fires likely occurred in the two higher elevation community types when, during low-severity surface fires, small patches (<250 acres (100 ha)) sometimes burned with high-severity. Frequent fire in ponderosa pine forests and woodlands maintained considerable structural and spatial heterogeneity. After the late 1800s, fires became less frequent due to increased settlement, logging, altered grazing patterns, and fire exclusion. These changes contributed to changes in stand structure and fuel characteristics in ponderosa pine communities which grew more dense and expanded into surrounding prairies and savanna openings. Presettlement fire sizes are difficult to estimate, so it is uncertain whether contemporary fire sizes differ from historical ones on average. Fire records from the Black Hills National Forest indicate that about half of the fires since 1910 were small (<988 acres (400 ha)); however, most very large fires (>10,000 acres (4,046 ha)) occurred since 2000. This is likely due to increased tree density and fuel continuity, along with increasing temperatures and incidence of drought. Future climate changes will likely result in earlier snowmelt and longer fire seasons, and may increase the likelihood of large, high-severity fires.

Whaley Prescribed Fire in the Black Hills National Forest north of Hill City, South Dakota, October 28, 2016. Photo credit: U.S. Forest Service.

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INTRODUCTION

This Fire Regime Synthesis brings together information from two sources: the scientific literature as of 2017, and the Biophysical Settings (BpS) models and associated Fire Regime Data Products developed by LANDFIRE. This synthesis:

- provides information on historical fire regimes and contemporary changes in fuels and fire regimes,
- identifies areas lacking fire history data,
- supplements information provided by FEIS Species Reviews, and
- assists LANDFIRE with data revisions.

As of 2017, most of the literature used to describe fire regimes in these communities was comprised of fire history studies that used composite fire-scar data from locations in the Black Hills; only a few of these fire history studies were conducted in ponderosa pine communities in the surrounding areas. None of the available studies used soil or sediment charcoal to reconstruct longer fire histories. Consequently, this review describes fire regimes during the past several centuries rather than millennia.

The term “presettlement” is typically used to refer to the period prior to substantial European-American settlement and development (e.g., logging, mining, and railroad construction), which began around 1890 in the Black Hills region [8,43,91]. Because fire history studies do not consistently use this year as a cut-off date, and because we are interested in the potential effects of fire suppression and exclusion on fire regime characteristics, in this synthesis we use presettlement to refer to the time before fire suppression efforts were effective, which varied throughout the region, but was generally during the early 1900s.

Common names are used throughout this synthesis. For a complete list of common and scientific names of important plant species found in these plant communities and links to FEIS Species Reviews, see table A3.

DISTRIBUTION AND PLANT COMMUNITIES

Geography and Climate

This review describes ponderosa pine communities in the Black Hills region of South Dakota and Wyoming and surrounding areas. The Black Hills are an isolated mountain range in the Great Plains of southwestern South Dakota and northeastern Wyoming. They cover an uplifted area of more than two million acres (800,000 ha) extending roughly northwest to southeast [73]. From north to south, the uplift is about 124 miles (200 km) long and from east to west, it is 62 miles (100 km) wide [52,73]. The Black Hills rise more than 3,280 feet (1,000 m) above the surrounding, relatively flat Great Plains [25,52]. The surrounding areas covered by this synthesis include portions of southeastern Montana; southwestern North Dakota; northeastern Wyoming; and northern Nebraska, including the Pine Ridge escarpment and the canyon of the central Niobrara River (figure 1).

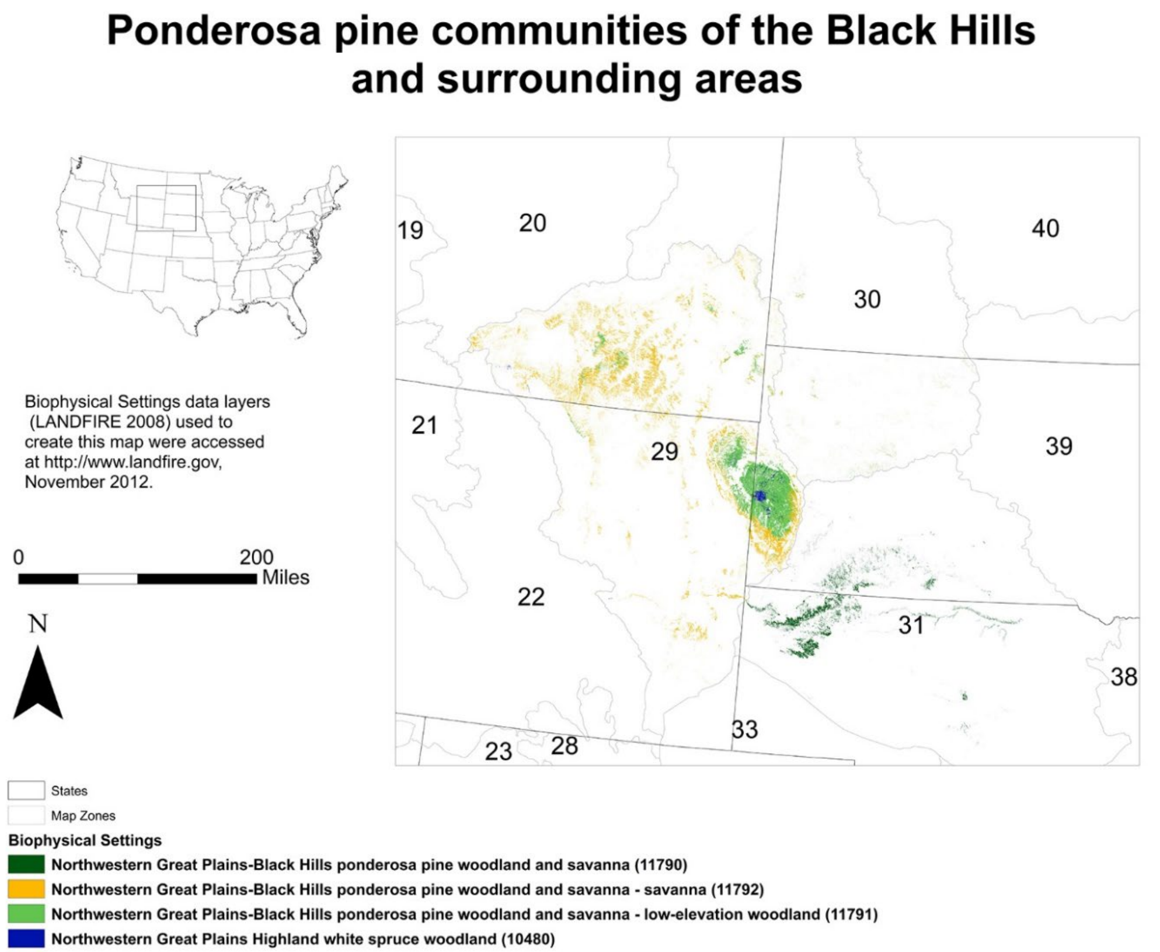


Figure 1—Land cover distribution of ponderosa pine communities of the Black Hills and surrounding areas based on the LANDFIRE Biophysical Settings (BpS) data layer [68]. Numbers indicate LANDFIRE map zones. LANDFIRE did not map every BpS in this group. Click on the map for a larger image.

The Black Hills uplift is a unique mountain range jutting out of the surrounding Great Plains. Elevations in the Black Hills range from around 2,900 to 7,200 feet (900-2,200 m) [52,73]. The Black Hills are wetter and cooler than the surrounding Great Plains and support extensive coniferous forests that contrast with the adjacent mixed-grass prairies [52,73]. Across the Black Hills there is a gradient of decreasing moisture from north to south [37,52,73]. From 1961 to 1990, mean annual precipitation ranged from more than 29 inches (740 mm) in the north-central area to less than 16 inches (400 mm) in the southeastern portion of the Black Hills [33]. Air temperatures follow a similar pattern with cooler temperatures in the north and warmer temperatures in the south [37]. Based on long-term climatic records for Rapid City (representative of the middle climate range for the Black Hills region), the average high temperature in August is 86 °F (30 °C) and the average low temperature in January is 11 °F (-12 °C) [82]. Temperature fluctuations are less extreme in the Black Hills than in the surrounding plains [37,73,75].

Plant Communities and Site Characteristics

Rocky Mountain ponderosa pine (hereafter, ponderosa pine) dominates many plant communities in the Black Hills region [28,36,73,86,117]. See the FEIS Species Review of Rocky Mountain ponderosa pine for detailed information on the natural history and fire ecology of this species. Ponderosa pine grows prolifically [14], particularly at mid to high elevations [73], and dominates 95% of the Black Hills' forests and woodlands [87,108] (figure 2). Favorable moisture conditions and frequent seed crops help ponderosa pine grow very densely in many areas of the Black Hills if not thinned by disturbance [80]. Grasslands are extensive at low elevations and include both dry and mesic mixed-grass and mesic tallgrass prairies [48,72,83].

Figure 2—Rocky Mountain ponderosa pine grows prolifically and regenerates abundantly in the Black Hills. Photo Credits: US Forest Service [42].

Tree cover generally increases with increasing elevation and moisture in the Black Hills. Ponderosa pine communities with 10% to 25% tree cover are referred to as savannas, 25% to 60% tree cover as woodlands, and those with >60% tree cover as forests [72]. Ponderosa pine savannas occur on dry, low-elevation sites in the Black Hills region in the prairie-woodland ecotone [48,72,73] and often include a robust grass layer [73]. At the highest elevations, woodlands and forests may be dominated by ponderosa pine or by white spruce on mesic sites [73]. Woodlands and forests in this region grow primarily on sandy loam to clay loam soils [52].

An endemic grassland community, the Black Hills montane grassland, occurs at elevations above 5,100 feet (1,500 m) throughout the Black Hills, but it is best developed on the Limestone Plateau in the high western Black Hills above 5,900 feet (1,800 m) [72]. This community intersperses with some of the upper elevation ponderosa pine communities discussed in this synthesis. Prairie dropseed, Richardson's needlegrass, and timber oatgrass dominate this community [72]. Marriot and others [72] provide detailed descriptions of grassland types. Fire regimes for grasslands are not specifically addressed in this synthesis.

This synthesis groups Black Hills ponderosa pine communities by elevation and moisture gradients, and by plant community structure and composition into three types: 1) ponderosa pine savanna, 2) low- to mid-elevation ponderosa pine woodland and forest, and 3) high-elevation ponderosa pine and white spruce forest. These types are derived from NatureServe's Ecological Systems [83] and LANDFIRE's BpSs [66]. Ponderosa pine community type for each study site was assigned based on location, elevation, and/or aspect if the plant community was not adequately described.

Ponderosa pine savanna (includes NatureServe Ecological Systems: Northwestern Great Plains Canyon and the savanna variant of the Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna; and BpS series: 11790 [65],11792 [64]).

Ponderosa pine savanna is widely distributed and occurs mostly between 3,200 and 4,400 feet (900-1,300 m) on relatively dry sites where mean annual precipitation is approximately 15 to 18 inches (380-460 mm) [33,48]. In the southern Black Hills it also occurs on southern aspects at elevations up to 5,700 feet (1,700 m) [64]. Along the Nebraska and South Dakota border, in areas like the Pine Ridge Ranger District of the Nebraska National Forest and the Niobrara River valley, ponderosa pine savannas occur at elevations as low as 2,000 feet (600 m) [47,65]. In northwestern Nebraska, ponderosa pine savannas are bordered by Sandhill prairie to the south and mixed-grass prairie to the north [47].

Ponderosa pine trees in savannas are often stunted [48,75] and grow in scattered patches [72] in a mosaic with surrounding grasslands [48,72,75]. Savannas typically have a dense herbaceous layer characteristic of the surrounding mixed-grass and tallgrass prairies [64,72]. Commonly associated trees include bur oak and Rocky Mountain juniper; common shrubs are common juniper, fringed sagebrush, skunkbush sumac, and true mountain-mahogany; and common graminoids include bluebunch wheatgrass, little bluestem, sideoats grama, sun sedge, and western wheatgrass [64,65,72]. In the Pine Ridge and Niobrara River valley areas of Nebraska, additional common tree species may include eastern cottonwood, eastern redcedar, and green ash; and big bluestem is a common grass [65,83].

Low- to mid-elevation ponderosa pine woodland and forest (includes NatureServe Ecological Systems: Northwestern Great Plains Canyon and the woodland variant of the Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna; and BpS series: 11790 [65],11791 [63]).

Low- to mid-elevation ponderosa pine woodland and forest occurs in the northern and central Black Hills on all aspects, above ponderosa pine savannas and below high-elevation ponderosa pine and white spruce forests. Elevation typically ranges from about 4,000 to 6,000 feet (1,200-1,800 m) [72]. Ponderosa pine grows more densely and continuously than in the savanna community. These woodlands and forests also occur in areas surrounding the Black Hills, including southeastern Montana, northcentral Wyoming's Bighorn National Forest, the Pine Ridge in northwestern Nebraska, the central reaches of the Niobrara River, and small portions of southwestern North Dakota and northwestern South Dakota [65,79,83].

Historically, ponderosa pine woodlands occurred in open, park-like stands with an understory of shrubs and/or grasses in areas where mean annual precipitation is about 20 to 22 inches (500-560 mm) [33,39,48,76]. In the northern Black Hills, where mean annual precipitation is about 24 inches (600 mm), ponderosa pine grows in dense forests with fewer shrubs and a more herbaceous understory [48]. Marriott and Faber-Langendoen [72] classify these plant communities as part of the 'Dry Coniferous Forests and Woodlands' ecological group. Other commonly associated trees include bur oak and Rocky Mountain juniper. Common shrubs include chokecherry, common juniper, common snowberry, creeping barberry, kinnikinnick, Saskatoon serviceberry, and white spirea. Common graminoids include poverty oatgrass, sedges, and roughleaf ricegrass [63,65,72]. In the southern extent of this ecosystem (in the Pine Ridge and Niobrara River valley areas of Nebraska), additional common tree species may include:

eastern cottonwood, eastern redcedar, green ash, and paper birch; and big bluestem is a common grass [65,83].

High-elevation ponderosa pine and white spruce forest (includes NatureServe Ecological System: Northwestern Great Plains Highland White Spruce Woodland; and BpS series: 10480 [62])

This plant community represents a small fraction of the total forested area of this region [52,83]. It occurs at the highest elevations (generally above 5,700 feet (1,740 m)) in the central and northern Black Hills [72] and occasionally in the subalpine zone of the Bighorn Mountains of north-central Wyoming and south-central Montana [79,83]. At lower elevations, this community is restricted to north-facing slopes or mesic areas where snow is retained for long periods [83].

Ponderosa pine or white spruce dominate this community on relatively cool and wet sites [52,72], and ponderosa pine is seral to white spruce [52]. Paper birch and quaking aspen are common associates, particularly on cool, moist sites throughout the northern part of the Black Hills, often as early successional species after fire [87]. High-elevation ponderosa pine and white spruce plant communities are included in Marriott and Faber-Langendoen's 'Mesic Coniferous Forests and Woodlands' ecological group, and generally have more than 60% tree canopy cover [72]. Common shrubs include common juniper, common snowberry, creeping barberry, grouse whortleberry, kinnikinnick, and twinflower. Common forbs include northern bedstraw, roughleaf ricegrass, and Virginia strawberry [62,72]. The Black Hills montane grassland community and adjacent ponderosa pine woodlands intersperse with this forest community and may influence fire patterns [62,72,75,83].

Table A1 lists the Biophysical Settings (BpSs) covered in this synthesis, provides links to their descriptions, and summarizes data generated by LANDFIRE [66] models.

HISTORICAL FUELS AND FIRE REGIMES

Historical fire regimes of ponderosa pine communities in the Black Hills region varied depending on climate, elevation, topography, plant community composition, and forest structure. The fire history studies reviewed for this synthesis generally show evidence of frequent surface fires prior to the 20th century, with a pattern of decreasing fire frequency with increasing latitude and elevation in these communities, as well as a greater incidence of mixed-severity fires on mesic sites where relatively long fire-free intervals were part of the record. Historical mean fire-return intervals (MFRIs) reported for low-severity surface fires ranged from 5 to 33 years in Black Hills ponderosa pine communities. This range is similar to MFRI estimates for ponderosa pine communities in the northern Rocky Mountains, but longer than those for ponderosa pine communities in the Southwest and southern Rocky Mountains [19,20,23]. Estimates of historical fire frequency likely varied depending on the proportion of trees and grasses as well as variations in microclimate, topography, and fire reconstruction sampling methods and analyses [16,17,19,22,24-26,34,35,88,89,100,103,122].

Frequent, low-severity surface fires at intervals of about 5 to 25 years maintained the open, park-like structure of ponderosa pine savannas and minimized establishment of trees and shrubs in the surrounding grasslands [21,25,34,35,43]. Fire regimes of savannas are influenced by frequent fires in surrounding grasslands, which often carry into adjacent savannas and woodlands [25,103]. Fires were somewhat less frequent and severity more variable in low- to mid-elevation ponderosa pine woodland and forest communities, where low- to moderate-severity surface fires occurred at approximately 11- to

27-year intervals, and infrequent high-severity fires occurred at intervals exceeding 100 years [19,22,24,26,122]. Forests at the highest elevations and on cool, mesic sites in the northern Black Hills generally had longer historical fire-return intervals ($\geq$20 years), and likely burned with mixed-severity, with a greater proportion of stand-replacing fires [19,43,101]. Few fire history studies were available for these forest types, and fire regime estimates are based primarily on anecdotal historical accounts and inferred from forest structure.

LANDFIRE models estimate presettlement MFRIs of 13 to 28 years for the BpSs covered by this synthesis; these fires were mostly low severity but included a small proportion of mixed and replacement severity fires (table 1, table A1).

Table 1—Modeled fire intervals and severities in ponderosa pine communities of the Black Hills and surrounding areas [68].

Fire interval[a] (years)	Fire severity[b] (% of fires)			Number of Biophysical Settings (BpSs) in each fire regime group					
	Replacement	Mixed	Low	I	II	III	IV	V	NA[c]
13-28	3-11	0-28	61-96	6	0	0	0	0	0

[a]Average historical fire-return interval derived from LANDFIRE succession modeling (labeled "MFRI" in LANDFIRE).

[b]Percentage of fires in 3 fire severity classes, derived from LANDFIRE succession modeling. Replacement-severity fires cause >75% kill or top-kill of the upper canopy layer; mixed-severity fires cause 26%-75%; low-severity fires cause <26% [9,67].

[c]NA (not applicable) refers to BpS models that did not include fire in simulations.

The following sections provide discussions and documentation of historical fire regimes in ponderosa pine communities of the Black Hills and surrounding areas. Table A2 summarizes results of the fire history studies discussed below.

- **Stand Structure**
- **Fire Ignition and Seasonality**
- **Fire Frequency**
- **Fire Type and Severity**
- **Fire Pattern and Size**

Stand Structure

The ponderosa pine forests and woodlands of the Black Hills historically had considerable structural and spatial heterogeneity. The drier and warmer ponderosa pine forests and woodlands, particularly in the southern region of the Black Hills, grew in large, relatively open, park-like stands [20,21,39,48,75]. Areas of even-aged and occasionally dense forest were also present historically [19-21,26,43,101], especially in the central and northern Black Hills [101]. Brown and Cook [21] estimate that ~35% of 112 study plots throughout the Black Hills National Forest historically had a low large-tree basal area (0-44 ft^2/acre (0-10 $m^{2/}$ha)), and 7 plots (~6%) had a large-tree basal area >175 $feet^2$/acre (40 m^2/ha). They often found relatively dense stands within 300 feet (~100 m) of relatively open stands [21]. The range of stand structures across the region created variation in fuel characteristics. See the Fire Type and Severity section for information on how stand structure affects fire severity.

The historical extent of dense, even-aged forests is not known, and there is disagreement over what processes created these stands. Some researchers conclude that large cohorts of trees established after extensive crown fires in the 1700s and 1800s [101]. Others hypothesize that these cohorts established after several types of disturbances (e.g., drought, wind, insect outbreaks, crown fires) opened the canopy, and extended wet conditions during long intervals between surface fires promoted abundant ponderosa pine recruitment and fast growth [18-21]. The age of some tree cohorts in the Black Hills coincides with abundant tree establishment in the Bighorn Mountains in Wyoming, supporting the theory of synchronized tree recruitment during periods of favorable climate across the northern Great Plains [19,20].

Fire Ignition and Seasonality

Presettlement fires in the Black Hills region were started by either lightning strikes or American Indians [10,51,90,91,106]. Lightning-ignited wildfires were common and frequent in the summer months [24,25,39,50,60,88,89,103,122]. In ponderosa pine savannas of northwestern South Dakota and southeastern Montana, an average of 91.7 lightning fires occurred per year per 3,800 miles^2 (10,000 km^2) between 1940 and 1981 [50]. During this period, 73% of lightning fires in the northern Great Plains occurred in July and August, but some occurred as early as April and as late as September [50]. Records from Wind Cave National Park, South Dakota, indicated at least one spring wildfire in March 1910 – a year when fires were widespread throughout forests in the West [25,90].

Researchers have determined with dendrochronology that historical fires typically occurred in the late-growing to dormant season (i.e., summer-fall) [17,23-25,88]. This seasonal pattern was found in 84% of fires from 1565 to 1940 in ponderosa pine savannas and woodlands of the Rochelle Hills area of the Thunder Basin National Grassland, Wyoming [88], and in over 87% of fires in the ponderosa pine woodlands and forests of both Jewel Cave National Monument, South Dakota, and Wind Cave National Park [24,25]. From the Rocky Mountains of Colorado north to central Wyoming, seasonality of fires varies from predominantly early season fires in the south to late season fires in the north ($P < 0.001$), presumably because fuels dry earlier at southern latitudes than at northern ones [23].

American Indians contributed to frequent presettlement burning in the Black Hills region [10,51,106], but may have done little burning in ponderosa pine woodlands and forests [2,39]. They used fire seasonally, mostly in the surrounding Great Plains, to manage vegetation and drive game [51,106]. Fisher and others [34] report a higher frequency of fires at Devils Tower National Monument from 1770 to 1900 (MFRI = 8) compared to the period from 1600 to 1770 (MFRI = 15). They attribute the increased frequency to an increase in American Indian populations in the region during that period [34,35]. Records from 1630 to 1920 indicate that American Indians burned primarily in two seasonal periods in the northern Great Plains: March through May with a peak in April; and July through early November with a peak in October [51]. Higgins [51] concluded that these burning patterns were synchronized with bison herd movements. Evidence suggests that anthropogenic fires were frequent and widespread, and most were small to moderate in size and of short duration [51]. It is unlikely that American Indians burned the denser Black Hills forests at all [39]. Accounts suggested that American Indians were superstitious of the Black Hills and may have avoided the dense portions because game was scarce, hunting and navigating were difficult, and rain and lightning were frequent [2,39].

Fire Frequency

Methods: Locations of the fire history studies reviewed in this synthesis are shown in figure 3, and summary data from these studies are shown in table A2. Study sites were assigned to one of the three ponderosa pine community types using plant community descriptions when available, and using location, elevation, and/or aspect information when plant community descriptions were not given. We analyzed composite MFRIs from each study site to reveal fire frequency patterns (figures 4 and 5); only one MFRI was assigned to each study site (i.e., when multiple studies used the same fire-scar data from the same sites, only one MFRI was included in our analyses). For example, Brown [19] compiled fire chronologies from over 1,000 trees collected at over 50 locations throughout the Black Hills and calculated MFRIs between 1700 and 1900 at 19 intensively sampled sites. Fire history data from some of these sites are referenced and analyzed in other studies by Brown and others (e.g., [18,20,22,24,25]), as noted in table A2. For each site included in table A2, the MFRI from the longest time period studied was used in the analyses. Sites that did not report MFRIs were excluded from fire frequency analyses.

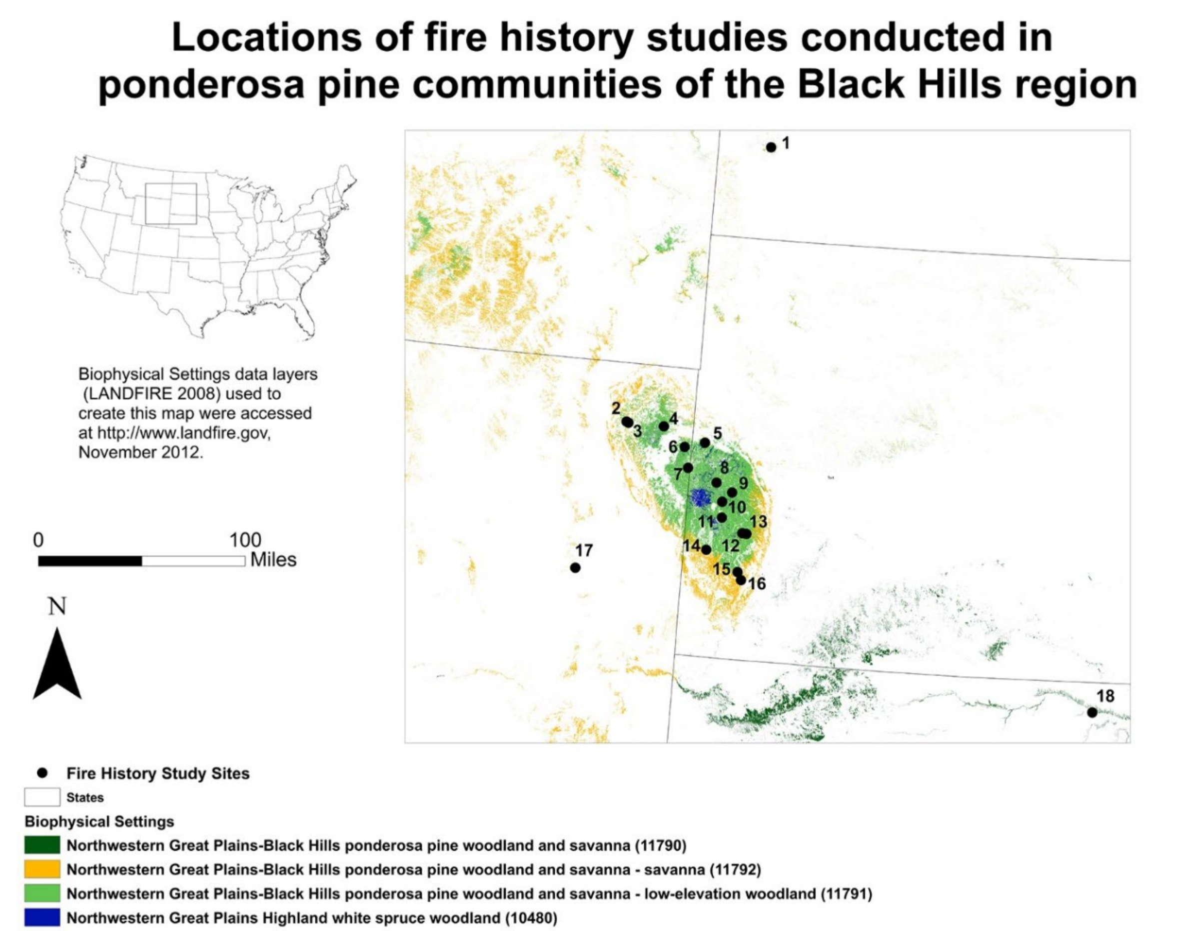


Figure 3—Locations of fire history studies conducted in ponderosa pine communities of the Black Hills region. See table A2 for study details. Some site locations are approximate and based on study descriptions. Click on the map for a larger image and zoom in to see details.

Our analyses are based on 'unfiltered' composite MFRIs, which include all fire years recorded on any tree in a given site. Several studies reviewed here [17,24,26,34,122] also reported 'filtered' composite

MFRIs, which provide a more conservative estimate of fire frequency by including only fire years in which a minimum number of trees (usually 2) and a minimum percentage of trees (usually 10% or 25%) were scarred. Analysis of both unfiltered and filtered composite chronologies provides a range of MFRI estimates and enables interpretation of fire frequency at multiple spatial scales. MFRIs are typically shorter when unfiltered analyses are used, because they include all fires, even those that may have burned very small areas. MFRIs are typically longer for highly restrictive filters because they include only fires that scar multiple trees, and therefore typically reflect larger or widespread fires.

Results: Low-severity wildfires were frequent in Black Hills ponderosa pine communities from the late 1300s to the late 1800s. Fire-scar records from 27 sites indicate that historical MFRIs ranged from about 5 to 33 years and varied among locations and community types. Sampling methods and length of historical records also affected MFRI estimates (table A2) [16,17,19,22,24-26,34,35,88,89,100,103,122].

Historical fire frequency generally decreased with increasing latitude and elevation [19,23] (figure 4). At northern latitudes and higher elevations, shorter growing seasons and generally cooler conditions reduced fire likelihood, resulting in longer intervals between fires [18,23]. Longer intervals between fires provided more time for fuels to build up and denser stands to form, resulting in a greater potential for high-severity crown fires [18]. In a widespread study throughout the Black Hills, researchers found that surface fires burned at 10- to 12-year intervals in low-elevation ponderosa pine savannas, and at about 20- to 33-year intervals in high-elevation, mesic forests in the northern and central Black Hills [19]. In the central Rocky Mountains of Colorado and Wyoming, fires became less frequent with increasing latitude from 1600 to 1800 ($P < 0.0001$), but not from 1700 to 1900 ($P = 0.21$), suggesting that fire frequencies vary through time as a result of long-term climate variation [23].

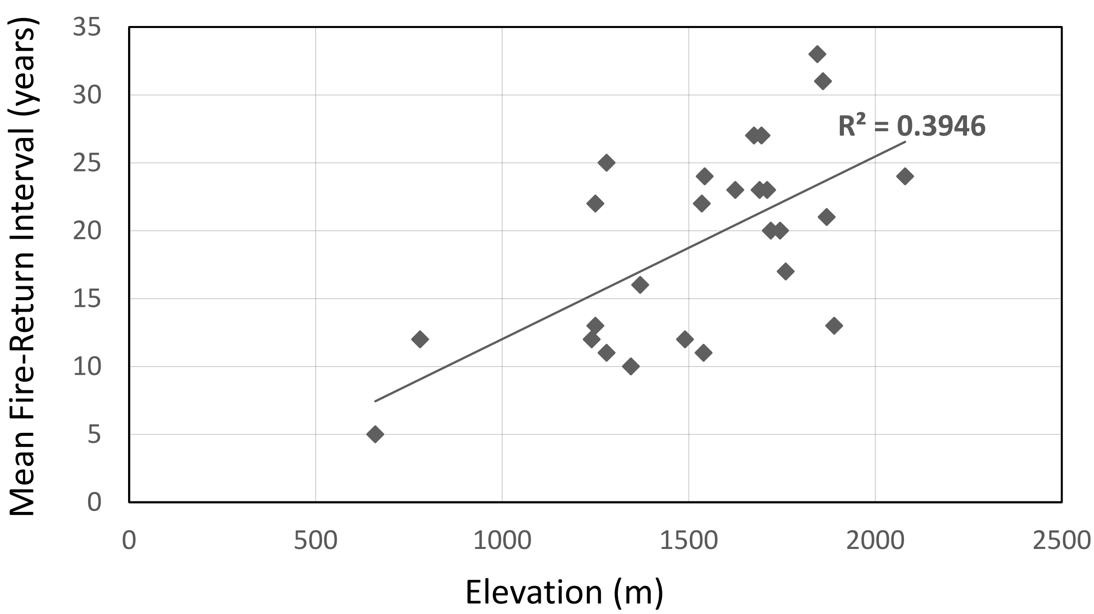


Figure 4—Relationship between mean fire-return interval and elevation for all study sites (n = 26) (table A2). The MFRI from the longest time period studied for each site was used in this analysis.

Although historical MFRIs in Black Hills ponderosa pine communities tend to be relatively short (<35 years), several studies documented fire-free periods much longer than average. These were attributed to variability in fuels, frequency and severity of non-fire disturbances, climate, and recruitment patterns [18,19,24,88]. At four sites in low- to mid-elevation ponderosa pine woodlands and forests at Jewel Cave National Monument, the longest fire-free periods between 1663 and 1890 ranged from 45 to 79 years [24]. In ponderosa pine savanna in the Rochelle Hills Area of Thunder Basin National Grassland, fire-free intervals as long as 40 to 56 years occurred during each of the 16th, 17th, and 18th centuries [88,89]. Between 1724 and 1753 and between 1785 and 1822 few fires occurred in any of the three Black Hills ponderosa pine community types. The latter interval may have enabled the survival of large, even-aged tree cohorts that established in the 1770s [19]. These longer than average fire-free intervals within the historical record suggest that both periods of frequent fire and fire absence may be climatically driven.

To include all available fire-scar studies, we used unfiltered composite MFRIs in our analyses; however, several studies calculated both unfiltered and filtered composite MFRIs [17,24,26,34,122]. Filtered MFRIs are expected to be longer than unfiltered MFRIs (i.e., not all fires are counted). This pattern was observed at some sites in our study area [17,24,34], but was not consistent on others [24,26,122]. At Mount Rushmore National Memorial in South Dakota, MFRIs differed depending on the type of interval calculated (point versus composite) and the size of the sampled area (table 2), but did not differ substantially at the landscape scale with a more restrictive data filter. The landscape composite MFRI was 16 years (SD 8) when fire dates were restricted to those recorded on 2 or more plots, and 17 years (SD 10) when fire dates were restricted to those recorded on at least 25% of plots [26].

Table 2—Comparison of MFRI data from 1529 to 1893 at Mount Rushmore National Memorial calculated at different spatial scales or with different filters [26].

Type of interval	Sampling area	Mean fire-return interval (years)
Scar-to-scar intervals found on individual trees (i.e., point fire-return intervals)	1 m^2	34
Plot composite intervals based on fire-scar dates from plot trees	266–2,075 m^2	27
Polygon composite intervals based on fire-scar dates from both plot and polygon trees	4.77–39.28 ha	24
Landscape composite fire intervals based on fire-scar dates recorded in at least two plots	517 ha	16
Landscape composite fire intervals based on fire-scar dates recorded in at least 25% of plots	517 ha	17

A similar comparison in ponderosa pine forests in northern Arizona, revealed that unfiltered MFRIs varied with sample size and area sampled, whereas MFRIs calculated using a 25% filter were fairly constant when sample size or area sampled varied. This suggests that frequency estimates for large or widespread fires are more consistent than those for all fires [118].

Several studies found evidence of more frequent fire just before and during the settlement period (circa 1850-1900) in both forests and savannas within the region [16,34,35,100,103]. At Devils Tower National Monument, Wyoming, the MFRI was 25 years between 1312 and 2002, but only 6 years between 1850 and 1880 [103]. At Wind Cave National Park, the MFRI was 22 years between 1780 and 1910, but only 13 years between 1850 and 1910 [100]. In ponderosa pine savanna in the Niobrara Valley, the MFRI was 5 years between 1850 and 1900 [16]. Fire chronologies from other studies in the Black Hills region (e.g., [24,25,122]) recorded frequent fire in the mid- to late 1800s but did not calculate intervals for these short periods. Increased fire frequency during this period is attributed to drier climatic conditions or increased ignitions by American Indians and early Euro-American settlers [24,25,34,35,100,122].

Guyette et al. [45] developed a model to estimate MFRIs for the presettlement period from about 1650 to 1850 for National Park units throughout the Great Plains region using fire history, temperature, and precipitation datasets. We report their results for individual National Park units that fall within the geographic range covered by this synthesis in the sections below. The 95% confidence intervals were 2.3 years for all MFRIs. Because no empirical data were collected for this model, it was not included in the fire history summary table A2.

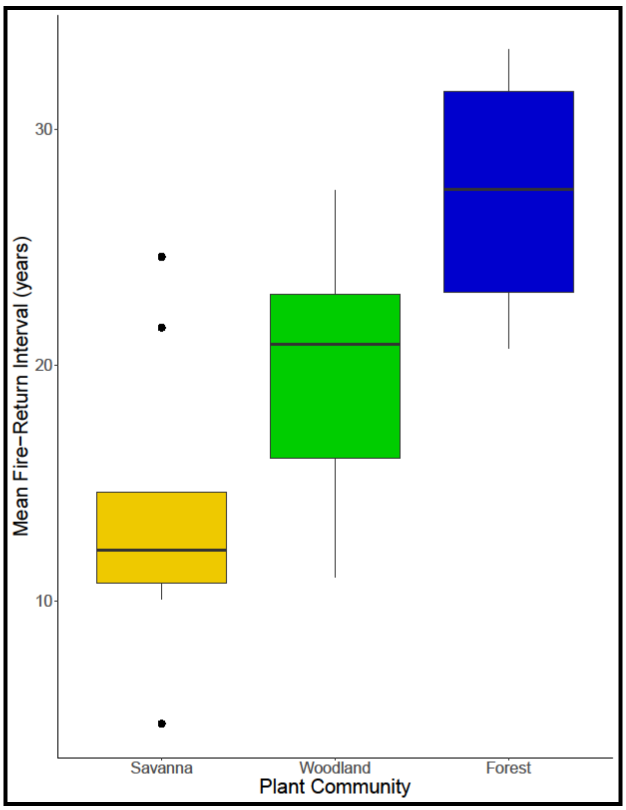


Figure 5—MFRI data reported for fire history study sites in ponderosa pine communities covered by this synthesis: Savanna (*n*=8 sites), low- to mid-elevation woodland and forest (Woodland, *n*=14), and high-elevation forest (Forest, *n*=4). Box plots show median MFRIs (horizontal line), MFRI ranges (whiskers), and outliers (black dots). For each site included in table A2, the MFRI from the longest time period studied was used in these analyses.

The following discussion of historical fire frequency is organized by three general northwestern Great Plains and Black Hills ponderosa pine community types: 1) ponderosa pine savanna; 2) low-elevation ponderosa pine woodland and forest; and 3) high-elevation ponderosa pine and white spruce forest. Based on the fire history studies reviewed here, MFRIs in these communities increase with increasing elevation from the savanna (median MFRI=12 years), to the low- to mid-elevation ponderosa pine woodland and forest (median MFRI=21 years), to the high-elevation ponderosa pine and white spruce forest (median MFRI=28 years) (figure 5).

Ponderosa pine savanna

Historical records and fire scar studies from nine sites in Black Hills ponderosa pine savannas indicate that low-severity surface fires burned frequently during much of the past 500 years. The study at the Rochelle Hills Area reported median FRIs and was not included in figure 5. Historical MFRIs at savanna sites ranged from about 5 to 25 years, with a median of 12.2 years (table A2, figure 5). Presettlement MFRI estimates were similar, ranging from 5 to 22 years [16,17,19,25,34,35,88,89,100,103]. Wildfire was historically more frequent in ponderosa pine savannas than in ponderosa pine woodlands and forests likely due to differences in ignition frequency, microclimate, fuel characteristics, and topography [24,25,103]. Ponderosa pine savannas are warmer, drier, and more open than woodlands and forests, and therefore contain more continuous fine surface fuels (graminoids) [25], making them more likely to ignite and carry fire [25,103]. Fires can occur in ponderosa pine savannas even during wet years because fine fuels can quickly dry and become flammable. Additionally, fires were likely more frequent in ponderosa pine savannas than in other Black Hills ponderosa pine communities because they are adjacent to and intermixed with grasslands that burn frequently, and grassland fires are likely to spread into adjacent communities as long as there are fuels to carry them [19,25].

Studies in ponderosa pine savanna at Wind Cave National Park, (locations 15 and 16 from figure 3), estimate relatively short presettlement MFRIs, consistent with other savanna sites. Brown and Sieg [19,25] estimated MFRIs of 10 to 12 years for surface fires from about 1528 to 1912, and Guyette et al. [45] modeled a MFRI of 9 to 11 years between 1650 and 1850. The 1980 Wind Cave National Park Fire Management Plan [100] (location 16 from figure 3) documented a MFRI of 22 years between 1780 and 1910. It is not clear why this MFRI was longer than other estimates from Wind Cave (e.g., [19,25,45]), but may have been due to the shorter time period studied. Brown [19] notes that few fires occurred in the Black Hills region between 1785 and 1822; this 37-year relatively fire-free period may have contributed to the longer MFRI reported in the management plan [100].

MFRI estimates for Devils Tower National Monument (locations 2 and 3 from figure 3) range from 11 to 19 years during the presettlement period [34,35], and a MFRI of 25 years (Weibull median fire interval (WMFI) of 20 years) was calculated using data that included intervals from 1312 to 2002, which included a 119-year fire-free interval from 1876 to 1995 [103]. Researchers calculated a presettlement MFRI of 11 years between 1600 and 1900 by using fire dates recorded on any tree in the Monument area; this unfiltered estimate includes all fires, even those that only scarred one tree [34]. When calculated using fire dates recorded on trees throughout the Monument (i.e., area-wide, or regional fire years), they calculated a MFRI of 19 years for the same period [34,35]. Guyette et al. [45] modeled a MFRI of 10 to 12 years between 1650 and 1850 for the monument.

Historical MFRIs from outlying ponderosa pine savanna sites including Little Missouri National Grassland in North Dakota, Rochelle Hills Area, and the Niobrara River Valley in Nebraska, range from about 5 to 20 years and are consistent with those from savannas in the Black Hills [16,17,88,89]. In the Little Missouri National Grassland (location 1 from figure 3), for the period from 1598 to 1936 a MFRI of 12 years (SD 10) was calculated by including fire dates recorded on any of the 18 trees sampled (i.e., unfiltered mean), and a MFRI of 20 years (SD 24) was calculated by including only fire dates recorded on two or more trees [17]. At the Rochelle Hills Area (location 17 from figure 3), researchers calculated a Weibull Median Probability Interval (WMPI) of about 8 years between 1565 and 1940, when fire exclusion became effective in this area. They calculated a WMPI of about 7 years when including intervals from 1565 to 1988 [88,89], suggesting that fire exclusion practices did not decrease fire frequency in that area. A study in the ponderosa pine woodland bluffs of the Niobrara River Valley, adjacent to the northern Sandhills Prairie region in Nebraska (location 18 from figure 3), found a MFRI during the settlement period (1850-1900) of about 5 years (SE 0.56) [16]. This unusually short interval is similar to what other researchers [24,25,34,35,100,103,122] found during the settlement period. Guyette et al. [45] modeled a MFRI of 7 to 10 years for the Niobrara National Scenic River between 1650 and 1850.

Low- to mid-elevation ponderosa pine woodland and forest

During the past several centuries, fires burned slightly less frequently in low- to mid-elevation ponderosa pine woodlands and forests than in savannas. Five studies at 14 sites in the Black Hills found that low- to moderate-severity surface fires occurred at approximately 11- to 27-year intervals (table A2) [19,22,24,26,122], with a median MFRI of 20.9 years (figure 5). Brown et al. [26] also found evidence of occasional (>100-year intervals) crown fires that burned small patches (<250 acres (100 ha)) in some stands at Mount Rushmore National Memorial. Guyette et al. [45] modeled MFRIs of 11 years for Jewel Cave National Monument and 10 to 15 years for Mount Rushmore National Memorial between 1650 and 1850.

Studies in low- to mid-elevation ponderosa pine woodlands and forests reported historical MFRIs between 16 and 24 years at 9 of 14 sites (table A2). Somewhat shorter MFRIs of 11 to 13 years were reported at two sites in the northern and one site in the central Black Hills (locations 4, 5 and 8 from figure 3) [19,122], and longer MFRIs of 27 years were reported at two sites (location 12 from figure 3) in the central Black Hills [19]. Sites with relatively short MFRIs include the Badger Game Production Area, which occurs at the lower elevational range for this community type [122], and the Spearfish Canyon site, which was at a high elevation, but located on a southeasterly aspect [19]. However, the shortest reported MFRI for this community type (11 years) was in Bear Lodge, Wyoming, on a northern aspect, where the MFRI on a nearby site with a southern aspect was 22 years [19]. The two sites with longer than average MFRIs (27 years) are in the Upper Pine Creek Research Natural Area of the Black Elk Wilderness (location 12 from figure 3) in the central Black Hills [19]. A study that reported median FRIs for these sites over a longer historical period found that return intervals range from 11 to 74 years and medians were 22 and 23 years at the two sites [22] (table A2). Although this site is not at the upper end of the elevation range for this community type, the presence of white spruce in the area suggests that it may have characteristics similar to high-elevation ponderosa pine forests, which have longer MFRIs [93].

A study at Mount Rushmore National Memorial (location 13 from figure 3) included a variety of historical fire and forest structure information based on extensive sampling [26]. Modal fire intervals in this study ranged from 11 to 15 years and did not vary across spatial scales; however, MFRI did vary across spatial scales (table 2). Between 1529 and 1893, the estimated MFRI was 24 years (SD 14) using all fire dates, 16 years (SD 8) using fire dates recorded in at least two plots, and 17 years (SD 10) using fire dates recorded in at least 25% of the plots. Point fire-return intervals from individual trees were the longest (34 years), which may reflect long fire-free intervals at individual sites or possibly missing scars. Composite fire-return intervals were shorter as the area of analysis increased, because more small fires were detected. Brown et al. [26] suggest that the landscape MFRI calculated using the 25% filter (17 years) was the most robust estimate for how often fires burned somewhere in the 1280-acre (517-ha) Mount Rushmore landscape. Fire reconstructions there are unique because the park contains some of largest and last contiguous stands of unharvested ponderosa pine, and two-thirds of the forest is classified as old growth [26], which may provide more evidence of historical fires than heavily managed stands. Guyette et al. [45] modeled a similar MFRI of 10 to 15 years for Mount Rushmore between 1650 and 1850.

In a high-density (1,300 to 4,700 stems/ha) ponderosa pine forest at the Badger Game Production Area (location 5, figure 3), researchers calculated an unfiltered MFRI (including all fire dates) of 13 years (SD 10) between 1450 and 1879. When including only fire dates recorded on more than three trees, the MFRI was 15 years (SD 11), and when including only fire dates recorded on more than six trees the MFRI was 11 years (SD 8) [122], suggesting that years with widespread fires occurred at a frequency similar to years with smaller fires. However, sample size was limited for the most restrictive filter, which likely affected these results.

High-elevation ponderosa pine and white spruce forest

Limited fire history information was available for high-elevation ponderosa pine and white spruce forests; however, researchers surmised that this community burned less frequently than lower-elevation communities [19,62] because it is cooler and wetter. Brown [19] sampled four sites in this community (locations 7 and 11 from figure 3); we classified these sites as this community type based on elevation and location rather than from specific vegetation descriptions. Brown [19] calculated MFRIs for low-severity fires ranging from about 21 to 33 years (median MFRI=27.5 years (figure 5)); however, he suggested that 30 to 33 years was a good estimate for MFRIs in the mesic interior forests in the northern and central Black Hills, even though sampling was limited, and trees on mesic sites were difficult to adequately cross-date because tree rings were difficult to distinguish. Brown has extensively sampled throughout the Black Hills and noted that this forest community is rare, and that it was difficult to locate older white spruce that would provide a discernible or adequately long fire record. Most individuals are less than 150 years old and many established since fire exclusion began [27]. LANDFIRE models estimate a MFRI of 28 years for Northwestern Great Plains highland white spruce woodland BpS (2910480) [62], which falls within the range estimated by Brown [19] for these four sites.

Fire Type and Severity

The abundance of trees throughout the Black Hills region with multiple fire scars that clearly survived many fires provides strong evidence for fire regimes dominated by frequent, low-severity surface fires [16-20,22,24,25,122]. However, evidence also suggests that fire regimes varied spatially and temporally depending on climate, elevation, topography, and plant community composition and structure. Cool, moist, woodlands and forests at middle and high elevations likely had occasional mixed-severity fires, when during low-severity surface fires, small patches (<250 acres (100 ha)) sometimes burned with high-severity, passive crown fires [19,20,26,101]. In other words, surface fuels dominated fire spread, but individual or patches of trees were sometimes killed by crown fire in areas with high tree density or fuel loads [19-21,26]. Researchers at Mount Rushmore National Memorial estimated that 3.3% of the area burned in crown fires between 1529 and 1893 and calculated a crown fire rotation of 846 years, compared to a surface fire rotation of 30 years for the 1,277-acre (517 ha) landscape during that period [26]. NatureServe [83] suggests that in high-elevation forests, stand-replacing fires were likely more common on cool, moist sites dominated by white spruce, and surface fires were more common on sites dominated by ponderosa pine.

While most researchers agree that a low-severity surface fire regime was dominant throughout the region, and that crown fires were infrequent (>100 years) and affected only small patches [19-21,26], there is disagreement in the scientific literature regarding the proportional role of mixed-severity and stand-replacement fires in presettlement ponderosa pine fire regimes in the Black Hills and throughout the West [6,18-20,26,85,101,105]. Some researchers speculate that the historical range of variability of fire regimes in the Black Hills included common, large, high-severity fires [7,101]. Extensive even-aged stands of ponderosa pine are considered by some as evidence for large, stand-replacing fires [43,101,110]. Surveys and anecdotal historical accounts of widespread fire years during certain periods in the Black Hills (e.g., around 1730 to 1740, 1785, 1790 to 1800, and 1842) are used to support this conjecture [43,101,110]. However, many studies identify trees within and nearby even-aged stands that established prior to and lived beyond some of these widespread fire years [18-20], indicating that stand-replacing fires were not homogenous on those sites.

While large, even-aged stands of ponderosa pine may have established after stand-replacing fires, some researchers suggest that they may have established when disturbances other than fire were followed by conditions favorable for recruitment [18-21]. Many canopy-opening disturbances are well documented in the Black Hills including extreme weather and windfalls [43,98,110], drought [1,20], diseases [98,123], and insects [42,52-54,97,98,101]. For example, a major drought in the Black Hills region from about 1752 to 1762 may have created openings caused by both drought-stress and bark beetle mortality (i.e., beetles often invade drought-stressed trees [97,98]) [18-20]. Once disturbances opened the canopy, periods of above-average precipitation coinciding with large seed crops likely resulted in large pulses of even-aged ponderosa pine establishment [18-21]. Distinct pulses of trees established in the Black Hills from 1730 to 1745, in 1785, from 1790 to 1800, and in 1845. These recruitment pulses coincided with periods of high precipitation [18,19] and some of the longest fire-free intervals on record [18,24,25]. Several studies documented historical fire-free periods in Black Hills ponderosa pine communities that were much longer than average [19,24,88,89]. These intermittent, long fire-free intervals helped create a course-scale mosaic of dense to open stands with variable fuel characteristics, fire frequency, and fire behavior [7,19-21,26,101], and enabled the survival of seedlings establishing during those periods [19].

Fire Size and Pattern

Although little has been published detailing historic fire sizes because we lack methods to precisely estimate them, spatial data beginning in 1880 from the Black Hills National Forest indicate that during the settlement period (i.e., 1880-1909) fires ranged from 180 acres (73 ha) to 19,159 acres (7,760 ha) (figure A1) [115]. Historical forest surveys in the Black Hills [43,110] describe large, dense, even-aged tree stands, which Shinneman and Baker [101] interpreted as evidence of large presettlement fires up to 148,200 acres (60,000 ha). Estimates of fire size from early spatial data and historical forest surveys may overestimate historical fire size because these methods may not account for or be able to detect evidence of small fires.

While it is difficult to precisely estimate fire size using fire scar data because not all fires scar trees, and it is difficult to determine if fire scars formed in the same year are from one or more fires, we can infer some general fire patterns from fire scars. Fires scar trees only where ample fuel has accumulated to enable fires to burn long and hot enough to create a scar. Consequently all fire years may not be recorded, and fire size and frequency may be underestimated, especially in communities where fuels are more limited (e.g., savannas) [17,88]. Based on fire scars recorded before 1900 in ponderosa pine savannas, several authors identified fire scars in the same fire years with patchy spatial patterns [17,25,88]. Fire years recorded on only one or a few trees in near proximity may indicate relatively small fires [17,88]. Fire years recorded on trees large distances from one another—without fire-scarred trees in between—may indicate a single large fire that burned with such low severity that it did not leave many fire scars [17,88].

The fire-scar record indicates several years when fires were widespread throughout the region. Fire-scar records showed synchronous fire dates in three or more studies in 1580, 1591, 1684, 1706, 1743, 1753, 1785, 1807, 1822, 1845, 1863, 1864, 1879, and 1890 [19,22,24-26,34,35,103,122]. All studies recorded fires in 1785, including the region-wide study [19] that recorded fires at 80% of sites, indicating fires were prevalent and widespread that year. Although fire dates were often synchronous across a widespread area, we cannot determine whether these were from separate fires that occurred in fire prone years, or from a single large fire, or a complex of merged fires. Large fire years (i.e., multiple trees scarred) in the Rochelle Hills area were typically preceded by above average precipitation, leading to fine fuels build-up, followed by drought [89]. This area is primarily grassland with small woodland patches, so increased dry fine fuels would help fire carry farther and more continuously across the landscape.

CONTEMPORARY CHANGES IN STAND STRUCTURE, FUELS, AND FIRE REGIMES

Contemporary Changes in Stand Structure and Fuel Characteristics

Forests in the Black Hills region have been intensively managed for more than 140 years, which has greatly altered forest structure and fire patterns. Large-scale timber harvesting began in the late 19th century [43], concurrent with the 1876 Black Hills gold rush [8,91], and the first managed timber sale from the (now) national forest system came from the Black Hills Forest Reserve in 1899 [8]. Nearly every harvestable hectare in the Black Hills has been cut at least once [8,14,76].

Grazing animals influenced fuel characteristics and forest structure before and after European settlement of the region. Large herds of native ungulates in the Great Plains, which sometimes completely denuded the prairies of grass, were largely decimated by the late 1800s [5,25,51]. The demise of these large herds likely led to increases in fine fuel loads, and may have temporarily contributed to more frequent fire (e.g., [5,51]). These migrating herbivores were replaced by abundant and more range-limited livestock populations, which reduced fine fuels that were necessary for fire spread and subsequently reduced fire occurrences, particularly in the lower elevation ponderosa pine woodland and savanna communities [5,21,25,29]. Selective removal of grasses and reduced fire frequency favor establishment and spread of woody species into grasslands [5,7,25].

Due to increased settlement in the late 1800s, along with the establishment of the Black Hills Forest Reserve in 1897 and greater concern for high-severity fire potential, fire exclusion became standard practice throughout the region in the early 1900s [39,100]. Organized fire protection began in the Black Hills in 1909 with aggressive fire exclusion by 1942 [70]. Fire exclusion became effective in the Rochelle Hills area around 1940 [89]. Fire exclusion became the dominant fire management practice during the 20th century throughout Black Hills region (e.g., [111-113]). However, several national forest management plans permit fires to burn in wilderness areas unless they threaten lands or resources outside wilderness boundaries [112,116].

The absence of frequent surface fires and the selective harvesting of large, older trees, have contributed to a shift in ponderosa pine forest structure from open-canopy stands composed of mostly large trees, to closed-canopy stands of smaller trees [19,21,26,74,76,122]. Forest structure data show that stem density and often basal area have significantly increased in current forests compared to historical ones [21,26,74]. This density increase has led to substantial loss in the diversity and biomass of understory species (e.g., [12,13,39,109,122]). Researchers have noted that after more than a century of fire exclusion, white spruce has established in ponderosa pine forests where it was not present historically [27,113].

Large trees used to account for most of the basal area in Black Hills forests, whereas currently, most of the basal area is comprised of small- to medium-size trees [21,26]. From 1874 to 1994, both density and basal area of small (< 8 inch (1-20 cm) size class) ponderosa pines in the southern Black Hills increased along with a more than 5-fold increase in density overall ($P < 0.03$) [74]. There was a similar increase in density and basal area from 1870 to 2005 in the ponderosa pine forests at Mount Rushmore National Memorial. Average basal area increased by 30% and tree density increased more than 4-fold mainly due to a large increase in trees less than 8 inches (20 cm) in diameter ($P < 0.01$) [26]. On average, ponderosa pines throughout the Black Hills were larger in 1900 (20-24 inches (51-61 cm) DBH) than in contemporary forests (14-17 inches (36-45 cm) DBH) ($P < 0.05$) [21].

Dense forests comprised primarily of small trees are at greater risk of disturbances than forests with more variability in forest structure. The simplification of forest structure (e.g., many trees of similar size) has contributed to greater fuel continuity both horizontally and vertically and thus increased the likelihood of high-severity crown fire in this area [21,113]. Additionally, high density forests with basal areas over 120 feet^2 per acre (27 m^2/ha) and trees 8 to 12 inches or larger in diameter are most at risk for mountain pine beetle infestation [42,95-98]. While bark beetle outbreaks were historically common in these forests (figure 6) [42,43,98,113], some large and lethal outbreaks have occurred recently, particularly in the past two decades [42]. Extensive bark beetle outbreaks may alter fuels and create conditions conducive to large, severe wildfires. For example, Lessard [70] noted that the two 'worst' fires years on record before 1986 (i.e., 1911 and 1985) occurred shortly after two large mountain pine beetle infestations in the Black Hills. These events could be related, but the forest may have been predisposed to high fire risk by other stress factors (e.g., drought stress or reduced vigor from high tree density). Furthermore, recent research has not shown a consistent link [77] and some research suggests that insect outbreaks may actually dampen post-outbreak wildfire severity [78].

Studies from this region show increased density and expansion of ponderosa pine woodlands into surrounding prairies and savannas [13,25,34,35,39,59,74,89,91,98,100,104,122]. In particular, photographic studies visually show this trend [57,59,91]. One such study in the Black Hills compared historical photographs from an 1874 expedition to photographs of the same sites 100 years later [91]. Historical photographs document many more openings, more extensive meadows, and larger areas of ponderosa pine savannas than are present today [19,91].

Forest expansion into grasslands in the West is often attributed to reduced fire frequency [25,34,35,39,61,104,106], although changes in climate and/or increased livestock grazing may also have contributed to these modifications [3,58,104]. Brown and Sieg [25] found that fire exclusion was likely the major driver of forest expansion into grasslands in the southern Black Hills and that grazing and climate had minimal impact.

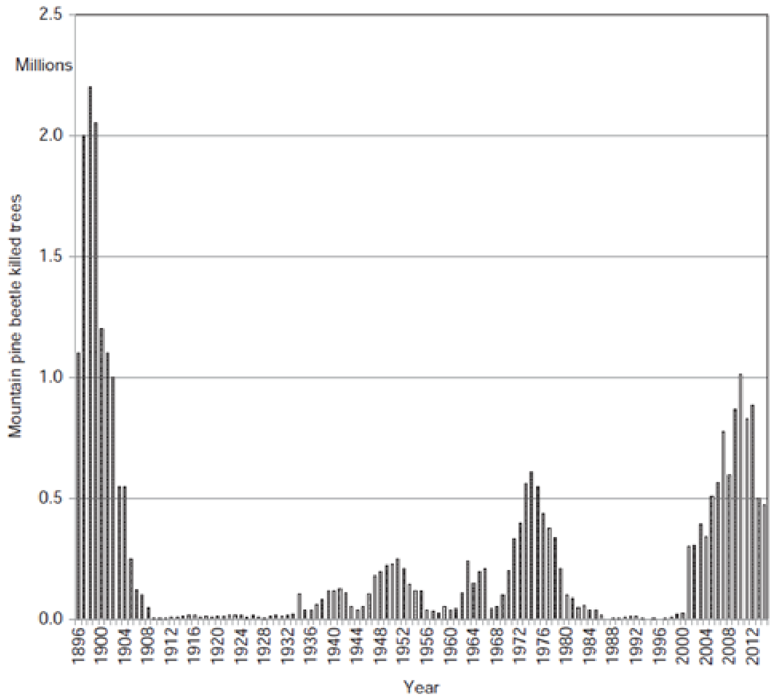


Figure 6—Estimated trees killed annually by mountain pine beetles in the Black Hills since 1896 illustrating several large epidemics over time [42].

Contemporary Changes in Fire Ignition and Seasonality

While lightning continues to be the primary ignition source, human-ignited fires increased by the late 1800s, as Euro-American settlement increased in the Black Hills region [98]. After gold was discovered in 1874, railroad development expanded in the region [91]. After 1900, railroad ignitions along with brush burning and campers (i.e., unintentional human-causes from recreation, mining, and hunting) became major sources of fire ignitions in Montana, Wyoming, and South Dakota [90]. Records of over 4,200 fires in those states between 1900 and 1911 showed 17.1% of forest fires were caused by railroad ignitions, compared to 7.8% started by lightning and 7.5% by campers [90]. Of the 152 recorded fires in the Black Hills National Forest in 2012, 66% were lightning-caused and the remaining 34% were human-caused [114]. In north-central Nebraska between 2000 and 2013, almost 60% of recorded National Forest fires were human-caused [11].

Fire seasonality also began to shift in the postsettlement period. A study from the Rochelle Hills area determined that the proportion of late-season fires decreased from 84% before 1940 to 57% between 1940 and 1988, and early-season fires increased from 16% during the historic period to 43% during the postsettlement period [88]. The shift in seasonality could indicate more human-caused ignitions, possibly in part due to prescribed burning in these forests and woodlands in the latter part of that period [12,15,56,92,124]. Prescribed burning is often conducted during spring or late fall, when risk of fire spreading to non-target areas is reduced [55]. An FEIS Fire Study Effects of fall and spring fires on Rocky Mountain ponderosa pine on the pine-grassland ecotone of the southern Black Hills [55] examines effects of cool-season prescribed fires on woody vegetation at Wind Cave National Park and adjacent Black Hills National Forest lands in Custer County, South Dakota.

Contemporary Changes in Fire Frequency

Studies throughout the region clearly identified long fire-free periods and reduced fire frequency after Euro-American settlement [16,19,22,24-26,34,35,103,122]; however, fire frequency may be increasing in recent decades [115]. Several studies recorded fire-free intervals of over 100 years since the late 1800s or early 1900s [19,22,24,25,103,122]. No fires were recorded at sites sampled at Jewel Cave from 1890 to 1994 [24], in the northern Black Hills from 1879 to 1998 [122], and in Devils Tower from 1876 to 1995 [103]. A study from Devils Tower reported a MFRI twice as long after 1900 than before [34,35]. In the Rochelle Hills area, however, researchers found that fire was slightly more frequent (6.7 years versus 7.9) but not significantly different ($P = 0.69$) in the exclusion period (1940-1988) compared to the historical period (1565-1939) [88,89]. This may be due to differences in the lengths of time periods studied, inadequate sample size during the exclusion period, or the late start of the exclusion period (1940). Fire records from the Black Hills National Forest show more than twice as many fires from 1970 to 2014 than from 1880 to 1969, although most of these contemporary fires were small [115] (see Contemporary Changes in Fire Size and Pattern, below).

Contemporary Changes in Fire Type and Severity

Fire type and severity have changed since Euro-American settlement due to fire exclusion and subsequent increased fuels and forest density. Researchers suggest that in ponderosa pine forests of the Mount Rushmore National Memorial, the dominant fire type has shifted from surface to crown fire during the period of fire exclusion from the late 19th to early 21st centuries [26]. They compared surface and canopy fuel structures between historical forests (circa 1870) and contemporary forests (2005) and found that very few plots with historical forest stand structure were likely to fuel crown fires, whereas most plots in the contemporary forest could burn with crown fires under moderate to severe weather conditions. Increased tree density and greater abundance of young trees with lower crown base heights increased the likelihood of both passive and active crown fires in contemporary forests [26].

In the absence of frequent fire over the last century, large, mixed-severity fires may help restore historical forest structure in some instances. The largest modern fire in the Black Hills—the 2000 Jasper Fire—was a mixed-severity wildfire that burned 83,510 acres (33,795 ha) in six days. Although the dense forest burned quickly during extremely dry and windy conditions, fire severity varied throughout the burned area, and patches of trees survived [69,98]. Remotely sensed imagery and field sampling indicated that the burned area was 25% low-severity, 48% moderate-severity, and 27% high-severity. Patches of different burn severities were distributed in a heterogeneous mosaic across the landscape, and low-severity patches averaged 25 acres (10 ha), moderate-severity patches averaged 60 acres (24 ha), and high-severity patches averaged 20 acres (8 ha) [69]. Despite the high-density of contemporary forests, 25% of the Jasper Fire burned at low-severity, suggesting that mixed- and low-severity fires are possible in contemporary stands. Stand density, the number of large trees, and average tree diameter best predicted burn severity in the Jasper Fire. Stands with high tree densities were most likely to burn with high severity. Despite extreme weather conditions, subtle variations in forest structure and topography influenced fire severity. The authors concluded that fuel treatments that alter forest canopy and structure as well as natural disturbances may help reduce future fire severity and help promote low- to moderate-severity fires [69]. Similarly, a large crown fire in 1988 in the Rochelle Hills area burned extensive areas, however isolated pockets of trees survived in the burned area matrix and created a contemporary vegetation mosaic (as of 1994) that resembled the estimated vegetation mosaic of 1800 [89].

Contemporary Changes in Fire Size and Pattern

Fires during the postsettlement period likely burned differently than presettlement fires. Whereas presettlement fires could burn unhindered as long as fuels were available, postsettlement fires burned in a landscape that was increasingly altered and fragmented, and many fires were rapidly suppressed. This suggests that presettlement fires were larger, on average, than contemporary fires; however, data and estimates for presettlement fire size are limited, and data from the early 2000s indicates an increase in mean area burned per fire per year, largely due to an increase in very large fires (>10,000 acres (>4,046 ha)) (table 3) [115].

The increased frequency of small fires (<988 acres (400 ha)) in the Black Hills region since 1910, and especially since 1970, suggests that mean fire size may have decreased during the postsettlement and fire exclusion periods [79,115]. For example, between 1970 and 1996 in the Bighorn National Forest, 93% of all low-elevation fires were less than 12 acres (4 ha), and no fires were larger than 988 acres (400 ha) [79]. Fire records from the Black Hills National Forest show that about half (51%) of the fires reported from 1910 to 2014 were small, compared to only one (8%) of the fires reported from 1880 to 1909 (table 3, figure A1) [115]. However, because small fires were more likely to go unreported during the early years of record keeping, it is unclear whether mean fire size changed during the early postsettlement period.

Table 3—Fire size records between 1880 and 2014 for the Black Hills National Forest, comparing the first 30 years of recorded data to data from subsequent 30-year periods and a 15-year period from 2000-2014. Data compiled from figure A1 [115].

Time period	Number of fires	Mean fire size (ha)	Mean area/fire/ year (ha)	Number of small fires (<400 ha)	Number of large fires (400-4,046 ha)	Number of very large fires (>4,046 ha)
1880-1909	12	1,648	55	1	9	2
1910-1939	13	1,956	65	7	4	2
1940-1969	13	1,520	51	5	6	2
1970-1999	30	1,326	44	16	11	3
2000-2014	49	2,636	176	26	13	10

A comparison of 30 years of data from 1880 to 1909 (i.e., prior to fire effective exclusion) to subsequent 30-year periods on the Black Hills National Forest suggests that the number of fires, mean fire size, and the mean area burned per fire per year were similar between 1880 and 1970. From 1970 to 2014, the number of fires of all size classes increased substantially; and from 2000 to 2014 the mean area burned per fire per year increased more than three-fold, and the number of very large fires (>10,000 acres (>4,046 ha)) increased five-fold compared to the pre-exclusion period. Of the 19 very large fires recorded over the 135-year period, most (53%) occurred since 2000, and only two (11%) occurred before 1910 (table 3). Two of the largest fires, the Jasper (2000) and Oil Creek (2012) fires, burned a combined 144,850 acres (58,600 ha) and accounted for 25% of recorded acreage burned in the Black Hills since 1880 (figure A1) [115]. The pattern of a few large fires accounting for most of the acreage burned is consistent with trends across the western United States in recent decades. On federally managed forests, both the frequency ($P < 0.0001$) of large wildfires (>988 acres (400 ha)) and total area burned in all fires ($P = 0.002$) have increased each decade since 1973. Although only 1% of all fires were larger than 988 acres (400 ha), they accounted for 75% of the total burned area between 1970 and 2012 [120]. This pattern may be partially explained by improvements in measurements and records for contemporary fires, but is also likely due to higher tree density (i.e., increased horizontal and vertical continuity of fuels), warmer temperatures, more frequent drought (i.e., longer fire seasons and increased flammability of fuels), or a combination of these factors. See the Climate Change section, below, for more information on those topics.

Fires started by humans are often larger than natural fires. Fire records from Wind Cave National Park show that while 27% of fires between 1910 and 1979 were human-caused, these accounted for nine times as many acres burned as lightning-caused fires [100]. Accidental, human-caused fires often occurred under severe fire conditions and were therefore more likely to spread and be difficult to control, whereas lightning-ignited fires may start under higher moisture conditions (i.e., with rain events) or in areas with sparser vegetation (e.g., ridge tops) resulting in smaller fires [100].

Climate Change

Observed changes and effects

Observed climate changes in the western United States include warmer than average temperatures and increased incidence of drought in recent decades. A 2010 report documented a regional trend of a 2 °F (1.1°C) increase in temperature across the northern Great Plains and a 5.5 °F (3°C) increase in temperature in parts of Montana, North Dakota, and South Dakota over the 20th century [38]. During the same period, precipitation decreased by 10% in Montana, North Dakota, and eastern Wyoming [38]. South Dakota experienced extreme drought several times in the 21st century, particularly in 2002, 2003, 2006, 2012, and 2013 [81]. High temperatures and low relative humidity caused an extremely dry year in the Black Hills in 2012 [114].

Increasing temperatures and drought are affecting fire regimes and fire seasons across the West, including the Black Hills. Based on numerous studies from shortgrass and tallgrass ecosystems primarily in the Great Plains region, historical MFRIs got shorter by approximately two years with each 1 °C increase in annual mean maximum temperature [103]. More frequent fire in grasslands would increase the likelihood of fires moving into adjacent woodlands and forests, like those in the Black Hills. Warmer winter and spring temperatures result in either less winter precipitation overall or more precipitation falling as rain rather than snow and earlier spring snowmelt [103,119]. This leads to longer growing seasons, which leads to more fuel accumulation, shorter fuel drying times, and potentially longer fire seasons [103,119]. These changes—together with denser forests—are generally shifting fire regimes to larger, longer burning, and potentially more severe fires sometimes occurring outside the historical fire season [84,114,119,120]. In the Black Hills, an extremely dry and warm year in 2012 contributed to fires starting as early as February, and the fire season continued into January of 2013 [114]. In 2012, the Oil Creek Fire burned 61,340 acres (24,823 ha), which is the second-largest fire on record for the Black Hills [115]. Similarly, in 2016 and 2017 several fires started atypically early (in early spring) in multiple locations of the Black Hills (figure 7) [44]. A high fire danger warning was issued in early March 2017 for the entire Black Hills region [40,44].

Throughout the West, wildfire activity has increased in conjunction with warmer spring temperatures and earlier snowmelt [119,120]. A study that examined large wildfire activity on federal lands in the western United States from 1970 to 2003 found that earlier spring snowmelt dates strongly correlated with increased annual wildfire frequency and area burned, especially in mid- to high-elevation forests [119]. They found that most areas, including the Black Hills, were vulnerable to warmer spring temperatures and thus earlier snowmelt dates, which lead to greater cumulative moisture deficit (i.e., drier fuels). Overall, 56% of wildfires and 72% of area burned occurred in early snowmelt years (versus 11% and 4% respectively in late snowmelt years) [119]. In the Middle Rockies Ecoregion (which includes the Black Hills), earlier spring snowmelt was correlated with above-average annual area burned between 1984 and 2012 [84]. On western federal forest lands, both wildfire frequency and area burned increased (>500% and >1200%, respectively) between 2003 and 2012 compared to 1973 to 1982 [120]. A substantial increase in wildfire frequency and area burned was observed in all decades since the 1970s when compared to the preceding decade. Ongoing increase in large wildfire frequency, longer fire seasons and fire duration, and earlier snowmelt are contributing to the overall increase in area burned [120].

Figure 7—The human-caused Storm Hill Fire burning in April 2016 east of Hill City, SD. Photo Credit: Jim Burk, SDWF, from Great Plains Fire Information blog.

Historically, regional fire years in the Black Hills were strongly associated with droughts and climate circulation patterns in both the Great Plains and Bighorn Basin, rather than antecedent moist conditions [19,20]. Linkages between past climate variations, fire years, and tree recruitment patterns suggest that wet conditions did not precede large fire years in the Black Hills, although this pattern is often observed in the Southwest [19,20]. Because fire was generally less frequent in the Black Hills than in the Southwest, longer fire-free intervals, rather than increased antecedant moisture, may contribute to fuel accumulation. With sufficient fuel, a dry year was the only condition needed for widespread burning to occur [19,20]. Regional fire years were strongly associated with climate circulation patterns including La Niña years (often associated with dry summers in the Northern Plains region), cool phases of the Pacific Decadal Oscillation, and warm phases of the Atlantic Multidecadal Oscillation [20].

Predicted changes and effects

There is widespread agreement that temperatures will continue to rise, but less certainty about precipitation projections. With continued rising temperatures leading to hotter and potentially drier summers and falls, precipitation will likely shift to more rain and less snow throughout the northern Great Plains. Warmer temperatures are predicted throughout the region for the 21st century, with the largest increases in the western parts of the Great Plains and more warming in winter and spring than summer and fall [38]. In the northern Great Plains, climate models predict that over the next 25 to 50 years maximum air temperatures will rise 2.7°F to 8.1°F (1.5-4.5°C) in all seasons, with more pronounced increases during the summer and fall [71]. At Wind Cave National Park in the southern Black Hills, mean temperatures are projected to rise 7.2 °F (4 °C) over the 21st century [5]. Relative humidity is predicted to decrease by about 4% to 6% in the summer and fall [71]. Precipitation projections vary. One model predicts increased precipitation throughout the region, another predicts increases only across northern portions, and a third predicts decreases on the eastern side of the Rocky Mountains [38].

Predicted future climate changes may result in larger, more severe fires and even longer fire seasons. Liu et al. [71] predict that temperature increases and relative humidity decreases, particularly in the summer and fall, would increase fire potential. They project future wildfire potential (using the Keetch–Byram Drought Index) to substantially increase in the northern Great Plains region in all seasons [71].

Climate change will likely have direct and indirect impacts on vegetation distribution, composition, and structure. Vegetation responses to climate variations, especially drought, tend to be most rapid and pronounced in forests and woodlands at semiarid ecotones [1], such as those discussed in this synthesis. More climate variability could result in other stresses including greater temperature extremes, more irregular freeze/thaw patterns, acceleration of tree growth (i.e., leading to increased forest density and competition for nutrients), or more turbulent and violent weather events (e.g., [1,30,38]). All of these stressors could lead to both direct and indirect mortality (e.g., from bark beetle or disease outbreaks). Increased mortality may not only change the distributions of these vegetation communities over time but could also lead to changes in fire regimes.

A dynamic vegetation model predicts somewhat contradicting outcomes for woody plant establishment in Wind Cave National Park and similar Black Hills ponderosa pine communities [5]. The model predicts that increasing temperatures would constrain tree growth due to reduced water availability, favor shrub and grass development, and promote a shift from forests to woodlands. A warmer climate may also lead to increased drought, which may increase fire frequency and, in turn, limit woody shrub and tree establishment. On the other hand, potential increased precipitation may allow forests to survive large temperature increases [5].

More information and syntheses on relationships between climate change and fire can be found in these reviews [41,49,102,107,121].

MANAGEMENT CONSIDERATIONS

Forest management practices that aim to reconstruct a mosaic of age and structural classes on the landscape could help achieve numerous management objectives including: reduced fire hazard, increased habitat diversity for understory plant and wildlife species, improved watershed function, increased productivity, and improved resilience to disturbances (e.g., bark beetles) [21,42,56,113]. It is well documented that stand structure of contemporary Black Hills ponderosa pine communities differ from their presettlement condition due to timber harvest, altered grazing regimes, and fire exclusion during the past century or longer (e.g., [19,21,26,57,59,74,91]). The contemporary forest lacks the heterogeneous structure that was present in presettlement forests, including varied canopy openings, stand ages, and densities, as well as patches of large and old trees [20,21,56,113]. These changes have altered fuel characteristics and may alter the behavior and effects of contemporary fires [56].

There is evidence of extended historical periods of both frequent [19,24-26,122] and infrequent fire [19,88] in all three Black Hills ponderosa pine community types. These were attributed to variability in fuels, frequency and severity of non-fire disturbances, climate, and recruitment patterns [18,19,24,88]. Recognizing the natural variability in historical fire frequency within and among ponderosa pine community types emphasizes the importance of targeting a range of fire-return intervals in fire management plans aimed at reconstructing a mosaic of age and structural classes on the landscape.

Prescribed fire and mechanical thinning may be used to abate the compounding effects of past management practices, increase forest structural heterogeneity, reduce forest density, reduce fuel loads, and improve wildlife habitat in these Black Hills plant communities (e.g., [5,12,13,15,20,39,56,92,99,100,111,124]). As of 1994, managers at Wind Cave National Park burned about 2,001 acres (810 ha) every year, with grasslands burned on a 6- to 7-year rotation and forests on a 15- to 25-year rotation [5]. However, these practices do not entirely mimic broad ecological effects that a functioning natural fire regime would provide. For example, prescribed fires are typically conducted in spring or fall, when the risk of escape is lower, whereas presettlement fires were most common in late summer, which may affect plant species differently [55]. Mechanical thinning may increase structural heterogeneity and reduce fuels and forest density, but may increase soil erosion or compaction [56]. Thinning also lacks some benefits to ponderosa pines and other plants that fire provides when forest litter and woody debris are burned such as nutrient release, increased pine seedling establishment and growth, and possibly improved water absorption into the mineral soil (e.g., [31,32,46,94]). In 2006, the Black Hills National Forest adopted an aggressive program to thin mature stands of ponderosa pine to reduce the risk of severe fire and vulnerability of stands to the mountain pine beetle [114]. For more information on ecological, silviculture, and fuels management in the region see these publications by Hunter et al. [56] and Shepperd and Battaglia [98].

Forest managers in the Black Hills should in all likelihood plan for increased fire activity (i.e., longer fire seasons, larger fires, and increased fire severity). By knowing the range of variability and possible extremes, managers can adapt practices to promote resilient ecosystems to withstand future impacts of potential extreme disturbance events.

LIMITATIONS OF INFORMATION

Fire history information was limited in both high-elevation, mesic ponderosa pine and white spruce forests and parts of the ponderosa pine savanna. Only four study sites— three at Riflepit Canyon, Wyoming in the northwestern Black Hills and one at Gillette Prairie, South Dakota in the central Black Hills—were sampled in what we presumed to be high-elevation ponderosa pine and white spruce forest community based on them having elevations above 6,000 feet (1,830 m), and all were from one region-wide fire history study [19]. Two geographical areas of this region were poorly represented in the fire history literature. The area along the Nebraska and South Dakota border, including the Pine Ridge Ranger District of the Nebraska National Forest and the Niobrara River valley, had only one fire history study, published only as an abstract in a 1989 conference proceedings [16]. No fire history studies were available for the ponderosa pine communities of southeastern Montana. More fire history information for these areas might add useful insights for managers.

Fire frequency analyses in this synthesis are based on composite fire intervals because that is what is most often reported in the literature. Readers are cautioned to consider the following limitations of these analyses.

Methodology affects estimates of fire-return intervals. Point fire intervals, which are based on fire scars from individual trees or small areas, generally under estimate fire frequency because some low-severity surface fires do not leave fire scars and some fire scars may be lost due to weathering, decay, or overburning of an older scar [102]. Composite fire intervals, which are based on master fire chronologies of individual fire-scarred trees over a designated area, are highly dependent on the size of the study area. Composite fire intervals tend shorten as the study area increases and more trees are sampled because more fires are detected. The size of the area was not always reported in fire history studies, making comparisons among studies somewhat tentative. Arno and Peterson [4] caution that for fire-return intervals calculated from a master chronology, "it must be remembered that the data (including mean fire intervals) represent only the occurrences of fire somewhere in the fire area".

In their review, Baker and Ehle [6] discuss several uncertainties and biases that may occur when fire scar data are used to estimate mean fire-return intervals or other characteristics of historical fire regimes:

- Not all fires are recorded in the fire scar record, in part because fire scar development requires a fire severe enough to damage the cambium without killing the tree. This may not occur early in the history of a stand, so the time between the origin of a tree and the development of the first fire scar is a fire-free interval that is often omitted in fire-return interval calculations.
- Even in a stand with fire-scarred trees, some fires may be of such low severity that they do not reburn existing fire scars.
- The tendency to focus on multiple-scarred trees and areas of stands where there are higher densities of scarred trees biases calculations toward shorter estimated fire-return intervals.
- The composite fire interval becomes shorter as the size of the study area or the number of sampled trees increase, both of which results in more fires being recorded [6].

As of 2016, no sedimentary charcoal fire history studies were available for the Black Hills region. This information might provide a broader perspective regarding the range of variability in fire frequency and climatic relationships in these ecosystem by extending information to cover longer time periods than the fire-scar record.

APPENDICES

- **Table A1: Summary of fire regime information for Biophysical Settings covered in this synthesis**
- **Table A2: Summary of fire history studies**
- **Table A3. Common and scientific names of dominant, codominant, or important plant species in the Black Hills area and links to FEIS Species Reviews**
- **Figure A1: Black Hills National Forest Area Large Fire History Map (1880-2014)**

Table A1—Biophysical Settings (BpS) included in ponderosa pine communities in the Black Hills and surrounding areas
Data are derived from LANDFIRE succession modeling. Fire regime groups I-V describe a pattern of fire frequency and severity for historical fire regimes. Fire interval refers to average historical fire-return interval. Percent of fires is listed by severity class: Replacement-severity fires cause >75% kill or top-kill of the upper canopy layer; mixed-severity fires cause 26%-75%; and low-severity fires cause <26%. Terms are defined in the FEIS Glossary.

Region	Biophysical Setting name	BpS code	Link to BpS and model description	Fire regime group	Fire interval (years)	Replacement severity fires (%)	Mixed severity fires (%)	Low severity fires (%)
Northern and Central Rockies	Northwestern Great Plains Highland white spruce woodland	2910480	http://www.fs.usda.gov/database/feis/pdfs/BpS/2910480.pdf	I	28	11	28	61
Northern and Central Rockies	Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna - low-elevation woodland	2911791	http://www.fs.usda.gov/database/feis/pdfs/BpS/2911791.pdf	I	18	6	6	88
Northern and Central Rockies	Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna - savanna	2911792	http://www.fs.usda.gov/database/feis/pdfs/BpS/2911792.pdf	I	14	4	0	96
Northern Great Plains	Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna - low-elevation woodland	3011791	http://www.fs.usda.gov/database/feis/pdfs/BpS/3011791.pdf	I	18	6	6	88
Northern Great Plains	Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna - savanna	3011792	http://www.fs.usda.gov/database/feis/pdfs/BpS/3011792.pdf	I	14	4	0	96
Northern Great Plains	Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna	3111790	http://www.fs.usda.gov/database/feis/pdfs/BpS/3111790.pdf	I	13	3	13	84

Table A2—Summary of fire history studies

Details from fire history studies in ponderosa pine communities of the Black Hills and surrounding areas. Cells are blank where no information was available.

See Table A1 for further information about the associated BpSs.

See Figure 3 for map of study site locations. Some study site locations were approximated.

Location (Fig 3. Map Number)	Elevation[a] meters (Aspect)	Study Details	Period studied	MFRI[b] years (SD)	Range of FRIs	WMFI[c] years	MFRI from LANDFIRE models[d]	Contemporary findings	Citation
Ponderosa pine savanna sites (BpS series 11790, 11792)[e]									
Little Missouri National Grassland, ND (1)	780	BCF site: CFIs[f] from 18 ponderosa pines across 50 ha area	1598-1936	12 (10)	2-36		14	only 4 fires were recorded on 3 trees after 1900	[17]
Devils Tower National Monument, WY (2)	1,280	CFIs[f] from 91 trees along 10 transects ranging from 250-2500 m long throughout the 545 ha park	1600-1770	15			14	since 1900 MFRI=28 years	[34]
			1770-1900	8					
			1600-1900	11					
Devils Tower National Monument, WY (3)	1,280	CFIs from 37 dead ponderosa pines; sampled in northern, northeastern, and southwestern portions of 545 ha park	1312-2002	24.6	4-119	20.2	14	frequent fires until 1876; 119 year fire-free interval from 1876-1995	[103]
			1850-1880	5.7		5.8			

Table A2—Summary of fire history studies (continued)									
Location (Fig 3. Map Number)	**Elevation[a] meters (Aspect)**	**Study Details**	**Period studied**	**MFRI[b] years (SD)**	**Range of FRIs**	**WMFI[c] years**	**MFRI from LANDFIRE models[d]**	**Contemporary findings**	**Citation**
***Ponderosa pine savanna sites (BpS series 11790, 11792)[e]* (continued)**									
Wind Cave National Park, SD (15a[g])	1,470-1,510 (E)	WCN site: CFIs from 12 ponderosa pine trees, stumps, logs, or snags across 20-25 ha area; selectively sampled fire scarred trees; savanna-woodland site	1564-1896	12.3 (6.9)	3-32	WMPI[h] =11.6; WEPR[i]= 3.5-22.7	14	no fires recorded after 1896	[25]
	1,340-1,350 (E)	PIG site: CFIs from 14 ponderosa pine trees, stumps, logs, or snags across 20-25 ha area; selectively sampled fire scarred trees; savanna-woodland site	1528-1912	10.1 (5.8)	2-23	WMPI[h] =9.3; WEPR[i]= 2.3-20.3		only 2 fire scars recorded after 1912	
	1,220-1,260 (N)	GOB site: CFIs from 16 ponderosa pine trees, stumps, logs, or snags across 20-25 ha area; selectively sampled fire scarred trees; savanna site	1652-1910	12.3 (7.2)	3-34	WMPI[h] =11.5; WEPR[i]= 3.5-22.6		only 2 fire scars recorded after 1910	
Wind Cave National Park, SD (15b[g])	1,470-1,510 (E)	WCN site: CFIs from 12 ponderosa pine trees across 17.0 ha area	1700-1900	10.7 (6.5)	3-29	9.9	14	fires scars were generally absent from all stands after 1890	[19]
	1,340-1,350 (E)	PIG site: CFIs from 14 ponderosa pine trees across 10.0 ha area	1700-1900	9.8 (5.4)	2-18	9.1			
	1,220-1,260 (N)	GOB site: CFIs from 16 ponderosa pine trees across 11.7 ha area	1700-1900	12.0 (7.9)	3-34	10.9			
Wind Cave National Park, SD (16)	1,250	CFIs from 33 dead or stunted ponderosas from scattered stands in mostly prairie throughout park	1780-1910	21.6			14		[100]
			1820-1910	16.6					
			1850-1910	13.5					

Table A2—Summary of fire history studies (continued)									
Location (Fig 3. Map Number)	**Elevation[a] meters (Aspect)**	**Study Details**	**Period studied**	**MFRI[b] years (SD)**	**Range of FRIs**	**WMFI[c] years**	**MFRI from LANDFIRE models[d]**	**Contemporary findings**	**Citation**
Ponderosa pine savanna sites (BpS series 11790, 11792)[e] **(continued)**									
Rochelle Hills Area of Thunder Basin National Grassland, WY (17)	1,500	CFIs from 48 trees including live ponderosa pine (46) and Rocky Mountain juniper (2) trees across 7,000 ha park area; sampled in small patches of ponderosa pine and Rocky Mountain juniper surrounded by grasslands	1565-1940			WMPI[h] =7.9; WEPR[i]= 1.2-23	14	fires slightly more frequent during exclusion period (1940-1988), no signif diff with non-exclusion period (1565-1939 (*P* = 0.69)); WMPI[h]= 6.7; WEPR[i]=1-21	[88,89]
			1565-1988			WMPI[h] =7.4; WEPR[i]= 1.1-22			
Niobrara Valley Preserve, NE (18)	660	CFI from 25 ponderosa pine trees; only study within BpS series 11790, sampled in oak/ponderosa pine forest on southern bluffs of Niobrara River; info from abstract only	1850-1900	4.8 (SE 0.56)			13	MFRI lengthened to 7.0 (SE 1.06) years for 1900-1950	[16]
Low- to mid-elevation ponderosa pine woodland and forest sites (BpS series 11790, 11791)[e]									
Bear Lodge, WY (4)	1,520-1,550 (S)	BLN site: CFIs from 13 ponderosa pine trees across 17.6 ha area	1700-1900	21.6 (11.3)	11-41	20.8	18	fires scars were generally absent from all stands after 1890	[19]
	1,520-1,560 (N)	BLC site: CFIs from 11 ponderosa pine trees across 18.8 ha area		11.0 (7.3)	3-30	10.1			
Badger Game Production Area, SD (5)	1,220-1,280	CFIs[f] from 23 ponderosa pine trees, stumps, and snags across 6.3 ha area; even-aged, high-density, high basal area forest	1450-1879	13 (10)	1-43		18	119 year fire-free interval from 1879-1998	[122]

Table A2—Summary of fire history studies (continued)									
Location (Fig 3. Map Number)	**Elevation[a] meters (Aspect)**	**Study Details**	**Period studied**	**MFRI[b] years (SD)**	**Range of FRIs**	**WMFI[c] years**	**MFRI from LANDFIRE models[d]**	**Contemporary findings**	**Citation**
***Low-to mid-elevation ponderosa pine woodland and forest sites (BpS series 11790, 11791)[e]* (continued)**									
Cold Springs Creek, WY (6)	1,350-1,390 (E)	CSC site: CFIs from 10 ponderosa pine trees across 6.5 ha area	1700-1900	15.7 (10.4)	4-34	14.1	18	fires scars were generally absent from all stands after 1890	[19]
Spearfish Canyon North, SD (8)	1,870-1,910 (SE)	SCN site: CFIs from 9 ponderosa pine trees across 15.6 ha area	1700-1900	12.8 (4.2)	8-19	12.9	18	fires scars were generally absent from all stands after 1890	[19]
Black Hills Experimental Forest, SD (9)	1,730-1,760 (E)	BEF site: CFIs from 11 ponderosa pine trees across 11.7 ha area	1700-1900	20.2 (10.0)	7-37	19.5	18	fires scars were generally absent from all stands after 1890	[19]
Reynold's Prairie, SD (10)	1,740-1,780 (SW)	REY site: CFIs from 11 ponderosa pine trees across 16.4 ha area	1700-1900	17.1 (8.7)	2-33	16.1	18	fires scars were generally absent from all stands after 1890	[19]
Upper Pine Creek Research Natural Area, SD (12a[g])	1,660-1,690	UPC site: CFI from 9 ponderosa pine trees	1580-1887	median =23	11-74		18	110 year fire-free interval (1887-1997)	[22]
	1,670-1,720	UPM site: CFI from 10 ponderosa pine trees	1668-1890	median =22	13-72			107 year fire-free interval (1890-1997)	
Upper Pine Creek Research Natural Area, SD (12b[g])	1,660-1,690 (E)	UPC site: CFIs from 9 ponderosa pine trees across 12.9 ha area	1700-1900	26.8 (10.4)	15-42	26.7	18	fires scars were generally absent from all stands after 1890	[19]
	1,670-1,720 (S)	UPM site: CFIs from 10 ponderosa pine trees across 16.4 ha area	1700-1900	27.4 (12.0)	15-46	27.0			

Table A2—Summary of fire history studies (continued)									
Location (Fig 3. Map Number)	**Elevation[a] meters (Aspect)**	**Study Details**	**Period studied**	**MFRI[b] years (SD)**	**Range of FRIs**	**WMFI[c] years**	**MFRI from LANDFIRE models[d]**	**Contemporary findings**	**Citation**
Low-to mid-elevation ponderosa pine woodland and forest sites (BpS series 11790, 11791)[e] **(continued)**									
Mount Rushmore National Memorial, SD (13)	1,340-1,745	CFIs[f] from 907 dead mostly ponderosa pines within and near plots on 500 m grid throughout 517 ha park; calculated MFRIs at multiple spatial scales with a consistent mode (11-15 years) across most spatial scales, see study for other MFRI estimates	1529-1893	24 (14)	1-76		18	only 2 fire scars recorded from 1893 to 2005 (both in 1912)	[26]
Jewel Cave National Monument, SD (14a[g])	1,585-1,768	JCC site: CFIs[f] from 14 ponderosa pine trees	1388-1890	23 (18)	1-63		18	104 year fire-free interval (1890-1994)	[24]
		JCN site: CFIs[f] from 11 ponderosa pine trees	1576-1890	20 (14)	4-45				
		JCE site: CFIs[f] from 16 ponderosa pine trees	1591-1890	23 (22)	1-77				
		JCS site: CFIs[f] from 16 ponderosa pine trees	1591-1900	23 (23)	7-93			94 year fire-free interval (1900-1994)	
		ALL SITES: CFIs[f] calculated using all detected fire dates at all sites	1388-1900	16 (14)	1-45				
Jewel Cave National Monument, SD (14b[g])	1,670-1,710 (N)	JCC site: CFIs from 16 ponderosa pine trees across 18.8 ha area	1700-1900	20.4 (17.4)	1-47	15.4	18	fires scars were generally absent from all stands after 1890	[19]
	1,720 (flat)	JCN site: CFIs from 11 ponderosa pine trees across 10.0 ha area	1700-1900	23.0 (14.4)	6-45	21.1			
	1,680-1,740 (S)	JCE site: CFIs from 16 ponderosa pine trees across 14.1 ha area	1700-1900	20.4 (17.0)	1-47	15.7			
	1,580-1,670(SW)	JCS site: CFIs from 16 ponderosa pine trees across 10.6 ha area	1700-1900	19.4 (10.9)	7-37	18.4			

Table A2—Summary of fire history studies (continued)									
Location (Fig 3. Map Number)	Elevation[a] meters (Aspect)	Study Details	Period studied	MFRI[b] years (SD)	Range of FRIs	WMFI[c] years	MFRI from LANDFIRE models[d]	Contemporary findings	Citation
High-elevation ponderosa pine and white spruce forest sites (BpS series 10480)[e]									
Riflepit Canyon, WY (7)	1,830-1,860 (S)	RPN site: CFIs from 11 ponderosa pine trees across 7.6 ha area	1700-1900	33.4 (8.8)	22-42	35.0	28	fires scars were generally absent from all stands after 1890	[19]
	1,850-1,890 (E)	RPW site: CFIs from 10 ponderosa pine trees across 20.0 ha area		20.7 (17.5)	4-64	17.7			
	1,840-1,880 (W)	RPE site: CFIs from 13 ponderosa pine trees across 12.9 ha area		31.0 (18.1)	14-64	29.4			
Gillette Prairie, SD (11)	2,070-2,090 (S)	GIL site: CFIs from 9 ponderosa pine trees across 20.1 ha area	1700-1900	23.9 (12.6)	10-42	23.0	28	fires scars were generally absent from all stands after 1890	[19]

[a]some elevations are estimated from provided location information.

[b]MFRI=mean fire-return interval; values are unfiltered, composite mean fire-return intervals (all fire years used in calculations) and standard deviation unless otherwise noted.

[c]WMFI= Weibull median fire interval (years), values are WMFI unless otherwise noted.

[d]see Table A1 for further information on LANDFIRE BpS series [68].

[e]plant community type was not always explicit in the literature and was inferred from site info (e.g. elevation, aspect, geography).

[f]additional mean(s) (e.g., filtered or area-wide) calculated in study but not reported here.

[g]studies with same map number used the same fire scar dataset to calculate FRIs but with different time periods or metrics.

[h]WMPI= Weibull median probability interval (years).

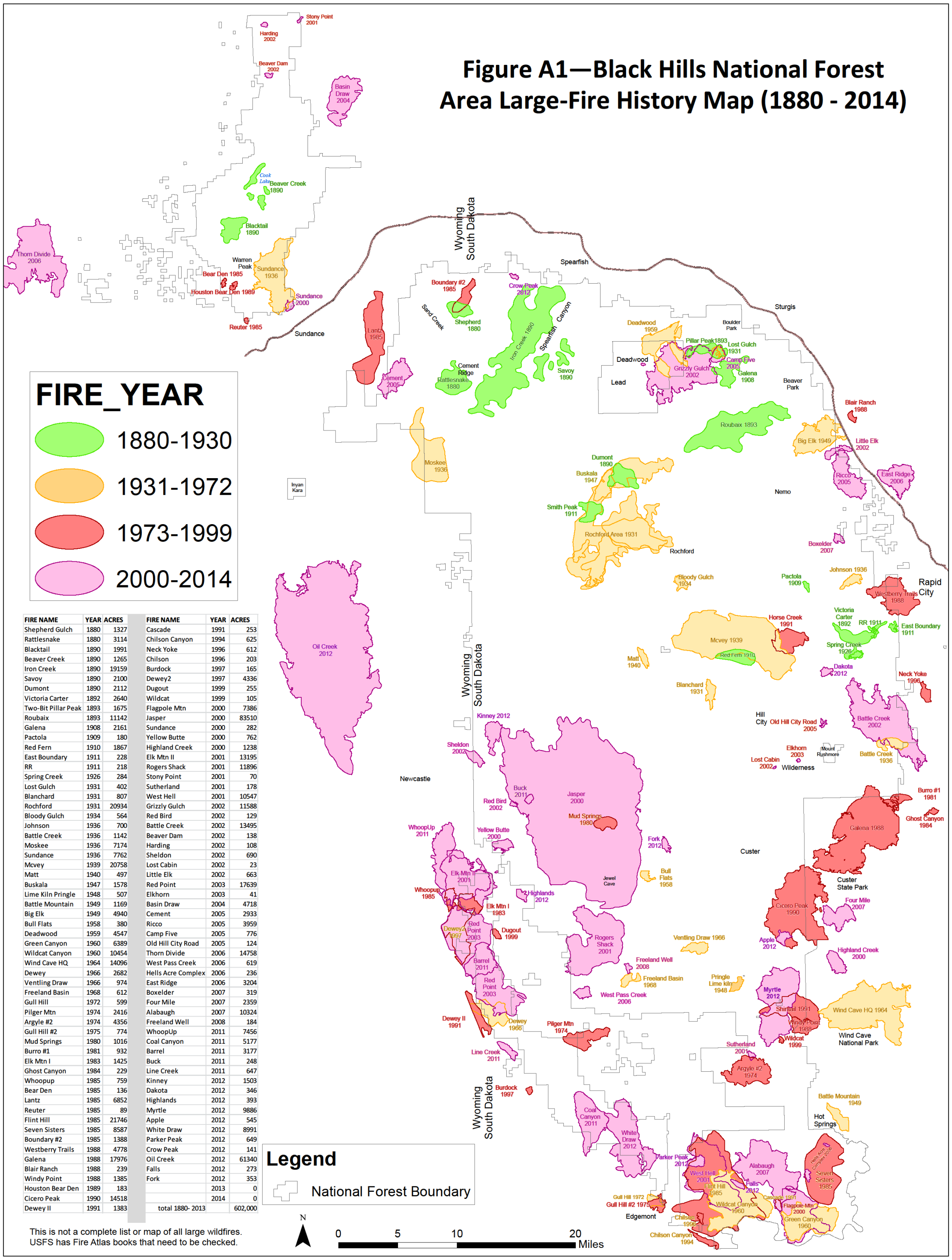
[i]WEPR=Weibull exceedance probability range is equivalent to 5% to 95% confidence interval (years).

Table A3—Common and scientific names of dominant, codominant, or important plant species in the Black Hills area and links to FEIS Species Reviews.

Common name	Scientific name
Trees	
bur oak	*Quercus macrocarpa*
eastern cottonwood	*Populus deltoides*
eastern redcedar	*Juniperus virginiana*
green ash	*Fraxinus pennsylvanica*
paper birch	*Betula papyrifera*
quaking aspen	*Populus tremuloides*
Rocky Mountain juniper	*Juniperus scopulorum*
Rocky Mountain ponderosa pine	*Pinus ponderosa subsp. scopulorum*
white spruce	*Picea glauca*
Shrubs	
chokecherry	*Prunus virginiana*
common juniper	*Juniperus communis*
common snowberry	*Symphoricarpos albus*
creeping barberry	*Mahonia repens*
fringed sagebrush	*Artemisia frigida*
grouse whortleberry	*Vaccinium scoparium*
mountain ninebark	*Physocarpus monogynus*
kinnikinnick	*Arctostaphylos uva-ursi*
prickly rose	*Rosa acicularis*
Saskatoon serviceberry	*Amelanchier alnifolia*
skunkbush sumac	*Rhus trilobata*
soapweed yucca	*Yucca glauca*
russet buffaloberry	*Shepherdia canadensis*
true mountain-mahogany	*Cercocarpus montanus*
twinflower	*Linnaea borealis*
western poison ivy	*Toxicodendron rydbergii*
white spirea	*Spiraea betulifolia*
Forbs	
bluebell bellflower	*Campanula rotundifolia*
cream pea	*Lathyrus ochroleucus*
hookedspur violet	*Viola adunca*
little false Solomon's-seal	*Maianthemum stellatum*
northern bedstraw	*Galium boreale*
prairie sage	*Artemisia ludoviciana*
pussytoes	*Antennaria species (such as A. parvifolia)*
western yarrow	*Achillea millefolium*
Virginia strawberry	*Fragaria virginiana*
Graminoids	
big bluestem	*Andropogon gerardii*

Table A3 (continued)

Common name	Scientific name
Graminoids (continued)	
bluebunch wheatgrass	*Pseudoroegneria spicata*
green needlegrass	*Nassella viridula*
Kentucky bluegrass	*Poa pratensis*
little bluestem	*Schizachyrium scoparium*
poverty oatgrass	*Danthonia spicata*
prairie dropseed	*Sporobolus heterolepis*
Richardson's needlegrass	*Achnatherum richardsonii*
roughleaf ricegrass	*Oryzopsis asperifolia*
sideoats grama	*Bouteloua curtipendula*
sun sedge	*Carex inops subsp. heliophila*
timber oatgrass	*Danthonia intermedia*
western wheatgrass	*Pascopyrum smithii*



FIRE NAME	YEAR	ACRES	FIRE NAME	YEAR	ACRES
Shepherd Gulch	1880	1327	Cascade	1991	253
Rattlesnake	1880	3114	Chilson Canyon	1994	625
Blacktail	1890	1991	Neck Yoke	1996	612
Beaver Creek	1890	1265	Chilson	1996	203
Iron Creek	1890	19159	Burdock	1997	165
Savoy	1890	2100	Dewey2	1997	4336
Dumont	1890	2112	Dugout	1999	255
Victoria Carter	1892	2640	Wildcat	1999	105
Two-Bit Pillar Peak	1893	1675	Flagpole Mtn	2000	7386
Roubaix	1893	11142	Jasper	2000	83510
Galena	1908	2161	Sundance	2000	282
Pactola	1909	180	Yellow Butte	2000	762
Red Fern	1910	1867	Highland Creek	2000	1238
East Boundary	1911	228	Elk Mtn II	2001	13195
RR	1911	218	Rogers Shack	2001	11896
Spring Creek	1926	284	Stony Point	2001	70
Lost Gulch	1931	402	Sutherland	2001	178
Blanchard	1931	807	West Hell	2001	10547
Rochford	1931	20934	Grizzly Gulch	2002	11588
Bloody Gulch	1934	564	Red Bird	2002	129
Johnson	1936	700	Battle Creek	2002	13495
Battle Creek	1936	1142	Beaver Dam	2002	138
Moskee	1936	7174	Harding	2002	108
Sundance	1936	7762	Sheldon	2002	690
Mcvey	1939	20758	Lost Cabin	2002	23
Matt	1940	497	Little Elk	2002	663
Buskala	1947	1578	Red Point	2003	17639
Lime Kiln Pringle	1948	507	Elkhorn	2003	41
Battle Mountain	1949	1169	Basin Draw	2004	4718
Big Elk	1949	4940	Cement	2005	2933
Bull Flats	1958	380	Ricco	2005	3959
Deadwood	1959	4547	Camp Five	2005	776
Green Canyon	1960	6389	Old Hill City Road	2005	124
Wildcat Canyon	1960	10454	Thorn Divide	2006	14758
Wind Cave HQ	1964	14096	West Pass Creek	2006	619
Dewey	1966	2682	Hells Acre Complex	2006	236
Ventling Draw	1966	974	East Ridge	2006	3204
Freeland Basin	1968	612	Boxelder	2007	319
Gull Hill	1972	599	Four Mile	2007	2359
Pilger Mtn	1974	2416	Alabaugh	2007	10324
Argyle #2	1974	4356	Freeland Well	2008	184
Gull Hill #2	1975	774	WhoopUp	2011	7456
Mud Springs	1980	1016	Coal Canyon	2011	5177
Burro #1	1981	932	Barrel	2011	3177
Elk Mtn I	1983	1425	Buck	2011	248
Ghost Canyon	1984	229	Line Creek	2011	647
Whoopup	1985	759	Kinney	2012	1503
Bear Den	1985	136	Dakota	2012	346
Lantz	1985	6852	Highlands	2012	393
Reuter	1985	89	Myrtle	2012	9886
Flint Hill	1985	21746	Apple	2012	545
Seven Sisters	1985	8587	White Draw	2012	8991
Boundary #2	1985	1388	Parker Peak	2012	649
Westberry Trails	1988	4778	Crow Peak	2012	141
Galena	1988	17976	Oil Creek	2012	61340
Blair Ranch	1988	239	Falls	2012	273
Windy Point	1988	1385	Fork	2012	353
Houston Bear Den	1989	183		2013	0
Cicero Peak	1990	14518		2014	0
Dewey II	1991	1383	total 1880- 2013		602,000

Figure A1—Map of fires on the Black Hills National Forest, 1880-2014 [115]. Click here for a larger image.

REFERENCES

1. Allen, Craig D.; Breshears, David D. 1998. Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. Proceedings, National Academy of Sciences of the United States of America. 95(25): 14839-14842. [35901]

2. Anderson, M. Kat. 2002. An ecological critique. In: Stewart, Omer C.; Lewis, Henry T.; Anderson, M. Kat, eds. Forgotten fires: Native Americans and the transient wilderness. Norman, OK: University of Oklahoma Press: 37-64. [43712]

3. Archer, Steven. 1994. Woody plant encroachment into southwestern grasslands and savannas: Rates, patterns and proximate causes. In: Vavra, Martin; Laycock, William A.; Pieper, Rex D., eds. Ecological implications of livestock herbivory in the West. Denver, CO: Society for Range Management: 13-68. [45592]

4. Arno, Stephen F.; Petersen, Terry D. 1983. Variation in estimates of fire intervals: A closer look at fire history on the Bitterroot National Forest. Res. Pap. INT-301. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p. [10336]

5. Bachelet, Dominique; Lenihan, James M.; Daly, Christopher; Neilson, Ronald P. 2000. Interactions between fire, grazing and climate change at Wind Cave National Park, SD. Ecological Modeling. 134(2-3): 229-244. [37571]

6. Baker, William L.; Ehle, Donna. 2001. Uncertainty in surface-fire history: The case of ponderosa pine forests in the western United States. Canadian Journal of Forest Research. 31(7): 1205-1226. [89414]

7. Baker, William L.; Veblen, Thomas T.; Sherriff, Rosemary L. 2007. Fire, fuels and restoration of ponderosa pine-Douglas fir forests in the Rocky Mountains, USA. Journal of Biogeography. 34(2): 251-269 [+ appendices]. [67120]

8. Ball, John J.; Schaefer, Peter R. 2000. Case no. 1: One hundred years of forest management. Journal of Forestry. 98(1): 4-10. [91206]

9. Barrett, S.; Havlina, D.; Jones, J.; Hann, W.; Frame, C.; Hamilton, D.; Schon, K.; Demeo, T.; Hutter, L.; Menakis, J. 2010. Interagency fire regime condition class guidebook (FRCC), [Online], (Version 3.0). In: Interagency fire regime condition class website. U.S. Department of Agriculture, Forest

Service; U.S. Department of the Interior; The Nature Conservancy (Producers). Available: https://www.frames.gov/partner-sites/frcc/frcc-guidebook-and-forms/. [2016, May 23]. [85876]

10. Barrett, Stephen, W.; Arno, Stephen F. 1982. Indian fires as an ecological influence in the Northern Rockies. Journal of Forestry. 80(10): 647-651. [12711]

11. Benson, Sandy. 2015. North central Nebraska community wildfire protection plan. Bassett, NE: U.S. Department of Agriculture, Forest Service, Nebraska Forest Service. 219 p. [90922]

12. Biswell, Harold H. 1973. Fire ecology in ponderosa pine-grassland. In: Komarek, Edwin V., Sr., technical coordinator. Proceedings, annual Tall Timbers fire ecology conference; 1972 June 8-9; Lubbock, TX. Number 12. Tallahassee, FL: Tall Timbers Research Station: 69-96. [8462]

13. Bock, Jane H.; Bock, Carl E. 1984. Effects of fires on woody vegetation in the pine-grassland ecotone of the southern Black Hills. The American Midland Naturalist. 112(1): 35-42. [477]

14. Boldt, Charles E. 1973. Black Hills ponderosa pine. In: U.S. Department of Agriculture, Forest Service, Division of Timber Management Research. Silvicultural systems for the major forest types of the United States. Agricultural Handbook No. 45. Washington, DC: U.S. Department of Agriculture, Forest Service. 114 p. [30809]

15. Bone, Steven D.; Klukas, Richard W. 1990. Prescribed fire in Wind Cave National Park. In: Alexander, M. E.; Bisgrove, G. F., technical coordinators. The art and science of fire management: Proceedings of the 1st Interior West Fire Council annual meeting and workshop; 1988 October 24-27; Kananaskis Village, AB. Information Report NOR-X-309. Edmonton, AB: Forestry Canada, Northwest Region, Northern Forestry Center: 297-302. [14145]

16. Bragg, Thomas B. 1991. Fire history of the northern Nebraska Sandhills Prairie. In: Proceedings, 17th Tall Timbers fire ecology conference; 1989 May 18-21; Tallahassee, FL. Tallahassee, FL: Tall Timbers Research Station: 407. Abstract. [17621]

17. Brown, Peter M. 1996. Feasibility study for fire history of the North Dakota Badlands. Final report to Theodore Roosevelt Nature and History Association and Theodore Roosevelt National Park. Fort Collins, CO: Rocky Mountain Station Tree-Ring Laboratory. [91898]

18. Brown, Peter M. 2001. Landscape age structure of ponderosa pine stands, Limestone Plateau, Black Hills National Forest: Final report. No. CCS-11020399-23. Custer, SD: U.S. Department of Agriculture, Forest Service, Black Hills National Forest; Fort Collins, CO: Rocky Mountain Tree-Ring Research, Inc. 11 p. [+ tables & figures]. [90100]

19. Brown, Peter M. 2003. Fire, climate, and forest structure in ponderosa pine forests of the Black Hills. Fort Collins, CO: Colorado State University. 103 p. Dissertation. [88621]

20. Brown, Peter M. 2006. Climate effects on fire regimes and tree recruitment in Black Hills ponderosa pine forests. Ecology. 87(10): 2500-2510. [65050]

21. Brown, Peter M.; Cook, Blaine. 2006. Early settlement forest structure in Black Hills ponderosa pine forests. Forest Ecology and Management. 223(1-3): 284-290. [61502]

22. Brown, Peter M.; Ryan, Michael G.; Andrews, Thomas G. 2000. Historical surface fire frequency in ponderosa pine stands in Research Natural Areas, Central Rocky Mountains and Black Hills, USA. Natural Areas Journal. 20(2): 133-139. [35463]

23. Brown, Peter M.; Shepperd, Wayne D. 2003. Fire history and fire climatology along a 5 degree gradient in latitude in Colorado and Wyoming, USA. Palaeobotanist. 50(1): 133-140. [43826]

24. Brown, Peter M.; Sieg, Carolyn H. 1996. Fire history in interior ponderosa pine communities of the Black Hills, South Dakota, USA. International Journal of Wildland Fire. 6(3): 97-105. [29220]

25. Brown, Peter M.; Sieg, Carolyn H. 1999. Historical variability in fire at the ponderosa pine - Northern Great Plains prairie ecotone, southeastern Black Hills, South Dakota. Ecoscience. 6(4): 539-547. [35536]

26. Brown, Peter M.; Wienk, Cody L.; Symstad, Amy J. 2008. Fire and forest history at Mount Rushmore. Ecological Applications. 18(8): 1984-1999. [74211]

27. Brown, Peter. 2017. [Personal communication to Shannon Murphy]. 16 May. Regarding fire history. Fort Collins, CO: Rocky Mountain Tree-Ring Research. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. 4 p. [91963]

28. Conkle, M. Thompson; Critchfield, William B. 1988. Genetic variation and hybridization of ponderosa pine. In: Baumgartner, David M.; Lotan, James E., compilers. Ponderosa pine: The species and its management: Symposium proceedings; 1987 September 29 - October 1; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension: 27-43. [9399]

29. Cooper, Charles F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecological Monographs. 30(2): 129-164. [3927]

30. Covington, W. Wallace; Everett, Richard L.; Steele, Robert; Irwin, Larry L.; Daer, Tom A.; Auclair, Allan N. D. 1994. Historical and anticipated changes in forest ecosystems of the Inland West of the United States. Journal of Sustainable Forestry. 2(1/2): 13-63. [45804]

31. Covington, W. Wallace; Sackett, S. S. 1992. Soil mineral nitrogen changes following prescribed burning in ponderosa pine. Forest Ecology and Management. 54: 175-191. [20230]

32. Covington, W. Wallace; Sackett, Stephen S. 1984. The effect of a prescribed burn in Southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor. Forest Science. 30(1): 183-192. [7624]

33. Driscoll, Daniel G.; Hamade, Ghaith R.; Kenner, Scott J. 2000. Summary of precipitation data for the Black Hills area of South Dakota, water years 1931-98. Open-file report 00-329. Denver, CO: U. S. Department of the Interior, Geological Survey; South Dakota Department of Environment & Natural Resources; West Dakota Water Development District. 20 p. [+ supplemental information]. [90546]

34. Fisher, R. F.; Jenkins, M. J.; Fisher, W. F. 1985. Fire and the vegetative mosaic at Devils Tower National Monument. In: Long, James N., ed. Fire management: The challenge of protection and use symposium: Proceedings; 1985 April 17-19; Logan, UT. Logan, UT: Utah State University: 11-24. [6905]

35. Fisher, R. F.; Jenkins, M. J.; Fisher, William F. 1987. Fire and the prairie-forest mosaic of Devils Tower National Monument. The American Midland Naturalist. 117(2): 250-257. [15638]

36. Flora of North America Editorial Committee, eds. 2017. Flora of North America north of Mexico, [Online]. Flora of North America Association (Producer). Available: http://www.efloras.org/flora_page.aspx?flora_id=1. [36990]

37. Froiland, Sven G. 1978. Natural History of the Black Hills. Sioux Fall, S.D.: Center for Western Studies, Augustana College. 174 p. [90556]

38. Furniss, Michael J.; Staab, Brian P.; Hazelhurst, Sherry; Clifton, Caty F.; Roby, Ken B.; Ilhadrt, Bonnie L.; Larry, Elizabeth B.; Todd, Albert H.; Reid, Leslie M.; Hines, Sarah J.; Bennett, Karen A.; Luce, Charles H.; Edwards, Pamela J. 2010. Water, climate change, and forests: Watershed stewardship for a changing climate. Gen. Tech. Rep. PNW-GTR-812. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 75 p. [90873]

39. Gartner, F. Robert; Thompson, Wesley W. 1973. Fire in the Black Hills forest-grass ecotone. In: Proceedings, annual Tall Timbers fire ecology conference; 1972 June 8-9; Lubbock, TX. No. 12. Tallahassee, FL: Tall Timbers Research Station: 37-68. [1002]

40. Geographic Area Coordination Centers (GACC). 2017. Incident information: Fuels/fire danger, [Online]. Rapid City, SD: Great Plains Interagency Dispatch Center (Producer). Available: https://gacc.nifc.gov/rmcc/dispatch_centers/r2gpc/. [2017, July 17]. [91964]

41. Gonzalez-Caban, Armando, tech. cood. 2013. Proceedings of the fourth international symposium on fire economics, planning, and policy: Climate change and wildfires. 5 November 2013; Mexico City, Mexico. General Technical Report PSW-GTR-245. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 405 p. [88502]

42. Graham, Russell T.; Asherin, Lance A.; Battaglia, Michael A.; Jain, Theresa B.; Mata, Stephen A. 2016. Mountain pine beetles: A century of knowledge, control attempts, and impacts central to the Black Hills. Gen. Tech. Rep. RMRS-GTR-353. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 186 p. [+ appendices]. [91164]

43. Graves, Henry S. 1899. Black Hills Forest Reserve. In: Walcutt, Charles D.; Gannett, Henry. Nineteenth annual report of the United States Geological Survey. Part V--Forest Reserves. Washington, DC: Government Printing Office: 67-164. [89853]

44. Great Plains Fire Information. 2017. Fire updates, [Online]. Custer, SD: U.S. Department of Agriculture, Forest Service, Black Hills National Forest; Chadron, NE: U.S. Department of Agriculture, Forest Service, Nebraska National Forest and Grasslands; Rapid City, SD: South Dakota Wildland Fire Division (Producers). Available: http://gpfireinfo.blogspot.com/. [2017, March 4]. [91967]

45. Guyette, Richard P.; Stambaugh, Michael C.; Marschall, Joseph M. 2011. A quantitative analysis of fire history at national parks in the Great Plains. Final Report for: USGS - NRPP (06-3255-0205Guyette). Columbia, MO: University of Missouri, Department of Forestry; Lincoln, NE: University of Nebraska. 78 p. [+ appendices]. [90195]

46. Harris, Gary R.; Covington, W. Wallace. 1983. The effect of a prescribed fire on nutrient concentration and standing crop of understory vegetation in ponderosa pine. Canadian Journal of Forest Research. 13: 501-507. [4699]

47. Harrison, A. Tyrone. 1980. The Niobrara Valley Preserve: Its biogeographic importance and description of its biotic communities. Unpublished report to the Nature Conservancy. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 116 p. [5736]

48. Hayward, Herman E. 1928. Studies of plants in the Black Hills of South Dakota. Botanical Gazette. 85(4): 353-412. [1110]

49. Hessl, Amy E. 2011. Pathways for climate change effects on fire: Models, data, and uncertainties. Progress in Physical Geography. 35(3): 393-407. [91214]

50. Higgins, Kenneth F. 1984. Lightning fires in North Dakota grasslands and in pine-savanna lands of South Dakota and Montana. Journal of Range Management. 37(2): 100-103. [1148]

51. Higgins, Kenneth F. 1986. Interepretation and compendium of historical fire accounts in the Northern Great Plains. Resource Publication 161. Washington, DC: U.S. Department of the Interior, Fish and Service. 39 p. [20]

52. Hoffman, George R.; Alexander, Robert R. 1987. Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: A habitat type classification. Res. Pap. RM-276. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 48 p. [1181]

53. Hopkins, A. D. 1902. Insects enemies of the pine in the Black Hills Forest Reserve: An account of special investigations, with recommendations for preventing losses. U.S. Department of Agriculture, Division of Entomology, Bulletin No. 32. Washington, DC: Government Printing Office. 24 p. [91572]

54. Hopkins, A. D. 1910. Insects which kill forest trees: Character and extent of their depredations and methods of control. U.S. Department of Agriculture, Bureau of Entomology, Circular No. 125. Washington, DC: Government Printing Office. 12 p. [91571]

55. Howard, Janet L., compiler. 2003. Effects of fall and spring fires on Rocky Mountain ponderosa pine on the pine-grassland ecotone of the southern Black Hills. In: Pinus ponderosa var. brachyptera, Pinus ponderosa var. scopulorum. In: Fire Effects Information System (FEIS), [Online]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/pinpons/all.html#1stCaseStudy. [91965]

56. Hunter, M. E.; Shepperd, W. D.; Lentile, J. E.; Lundquist, J. E.; Andreu, M. G.; Butler, J. L.; Smith, F. W. 2007. A comprehensive guide to fuels treatment practices for ponderosa pine in the Black Hills, Colorado Front Range, and Southwest. Gen. Tech. Rep. RMRS-GTR-198. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 93 p. [90262]

57. Johnson, Kendall L. 1987. Rangeland through time: A photographic study of vegetation change in Wyoming, 1870-1896. Miscellaneous Publication 50. Laramie, WY: University of Wyoming, Agricultural Experiment Station. 188 p. [2751]

58. Kaye, Margot W.; Woodhouse, Connie A.; Jackson, Stephen T. 2010. Persistence and expansion of ponderosa pine woodlands in the west-central Great Plains during the past two centuries. Journal of Biogeography. 37(9): 1668–1683. [91972]

59. Klement, K. D.; Heitschmidt, R. K.; Kay, C. E. 2001. Eighty years of vegetation and landscape changes in the Northern Great Plains: A photographic record. Conservation Research Report No. 45. U.S. Department of Agriculture, Agricultural Research Service. 91 p. [90650]

60. Komarek, E. V., Sr. 1968. The nature of lightning fires. In: Proceedings, California Tall Timbers fire ecology conference; 1967 November 9-10; Hoberg, CA. No. 7. Tallahassee, FL: Tall Timbers Research Station: 5-41. [18442]

61. Kucera, Clair L. 1981. Grasslands and fire. In: Mooney, H. A.; Bonnicksen, T. M.; Christensen, N. L.; Lotan, J. E.; Reiners, W. A., tech. coords. Fire regimes and ecosystem properties: Proceedings of the conference; 1978 December 11-15; Honolulu, HI. Gen. Tech. Rep. WO-26. Washington, DC: U.S. Department of Agriculture, Forest Service: 90-111. [4389]

62. LANDFIRE Biophysical Settings. 2009. Biophysical setting 2910480: Northwestern Great Plains highland white spruce woodland. In: LANDFIRE Biophysical Setting Model: Map zone 29, [Online]. In: Vegetation Dynamics Models. In: LANDFIRE. Washington, DC: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Geological Survey; Arlington, VA: The Nature Conservancy (Producers). Available: https://www.landfire.gov/national_veg_models_op2.php. [2017, January 10]. [88620]

63. LANDFIRE Biophysical Settings. 2009. Biophysical setting 2911791: Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna-low-elevation woodland. In: LANDFIRE Biophysical Setting Model: Map zone 29. [90545]

64. LANDFIRE Biophysical Settings. 2009. Biophysical setting 2911792: Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna-savanna. In: LANDFIRE Biophysical Setting Model: Map zone 29, [Online]. In: Vegetation Dynamics Models. In: LANDFIRE. Washington, DC: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Geological Survey; Arlington, VA: The Nature Conservancy (Producers). Available: https://www.landfire.gov/national_veg_models_op2.php. [2017, January 10]. [90534]

65. LANDFIRE Biophysical Settings. 2009. Biophysical setting 3111790: Northwestern Great Plains-Black Hills ponderosa pine woodland and savanna. In: LANDFIRE Biophysical Setting Model: Map zone 31, [Online]. In: Vegetation Dynamics Models. In: LANDFIRE. Washington, DC: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Geological Survey; Arlington, VA: The Nature Conservancy (Producers). Available: https://www.landfire.gov/national_veg_models_op2.php. [2017, January 10]. [90619]

66. LANDFIRE Biophysical Settings. 2009. LANDFIRE Vegetation Product Descriptions, biophysical settings, [Online]. In: Vegetation Dynamics Models. In: LANDFIRE. Washington, DC: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Geological Survey; Arlington, VA: The Nature Conservancy (Producers). Available: https://www.landfire.gov/NationalProductDescriptions20.php. [2017, January 10]. [86317]

67. LANDFIRE Rapid Assessment. 2005. Reference condition modeling manual (Version 2.1). Cooperative Agreement 04-CA-11132543-189. Boulder, CO: The Nature Conservancy; U.S.

Department of Agriculture, Forest Service; U.S. Department of the Interior. 72 p. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. [66741]

68. LANDFIRE. 2008. CONUS refresh (LANDFIRE 1.1.0). Biophysical settings layer, LANDFIRE data distribution site, [Online]. In: LANDFIRE. U.S. Department of the Interior, Geological Survey (Producer). Available: https://landfire.cr.usgs.gov/viewer/. [2017, January 10]. [89416]

69. Lentile, Leigh B.; Smith, Frederick W.; Shepperd, Wayne D. 2006. Influence of topography and forest structure on patterns of mixed severity fire in ponderosa pine forests of the South Dakota Black Hills, USA. International Journal of Wildland Fire. 15(4): 557-566. [71482]

70. Lessard, Gene. 1986. Mountain pine beetle mortality in ponderosa pine Black Hills of South Dakota and Wyoming. Biological Evaluation R2-86-2. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Timber, Forest Pest, and Cooperative Forestry Management. 22 p. [143]

71. Liu, Yongqiang; Goodrick, Scott L.; Stanturf, John A. 2013. Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario. Forest Ecology and Management. 294: 120-135. [86911]

72. Marriott, Hollis J.; Faber-Langendoen, Don. 2000. Black Hills community inventory. Volume 2: Plant community descriptions. Minneapolis, MN: The Nature Conservancy. 289 p. [+ appendices]. [90533]

73. Marriott, Hollis; Faber-Langendoen, Don; McAdams, Amanda; Stutzman, Diane; Burkhart, Beth. 1999. Black Hills Community Inventory: Final report. Minneapolis, MN: The Nature Conservancy. 144 p. [+ appendices]. [90200]

74. McAdams, Amanda G. 1995. Changes in ponderosa pine forest structure in the Black Hills, South Dakota, 1874-1995. Flagstaff, AZ: Northern Arizona University. 63 p. [+ appendices]. Thesis. [89964]

75. McIntosh, Arthur C. 1931. A botanical survey of the Black Hills of South Dakota. Black Hills Engineer. 19(3): 159-276. [3980]

76. Mehl, Mel S. 1992. Old-growth descriptions for the major forest cover types in the Rocky Mountain Region. In: Kaufmann, Merrill R.; Moir, W. H.; Bassett, Richard L., technical coordinators. Old-growth forests in the Southwest and Rocky Mountain regions: Proceedings of a workshop; 1992 March 9-13; Portal, AZ. Gen. Tech. Rep. RM-213. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 106-120. [19047]

77. Meigs, Garrett W.; Campbell, John L.; Zald, Harold S. J.; Bailey, John D.; Shaw, David C.; Kennedy, Robert E. 2015. Does wildfire likelihood increase following insect outbreaks in conifer forests? Ecosphere. 6(7): 1-24. [90893]

78. Meigs, Garrett W.; Zald, Harold S. J.; Campbell, John L.; Keeton, William S.; Kennedy, Robert E. 2016. Do insect outbreaks reduce the severity of subsequent forest fires? Environmental Research Letters. 11(4): 1-10. [90782]

79. Meyer, Carolyn B.; Knight, Dennis H.; Dillon, Gregory K. 2005. Historic range of variability for the upland vegetation in the Bighorn National Forest, Wyoming. Gen. Tech. Rep. RMRS-GTR-140. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 94 p. [60766]

80. Myers, Clifford A.; Van Deusen, James L. 1960. Natural thinning of ponderosa pine in the Black Hills. Journal of Forestry. 58: 962-964. [5734]

81. National Drought Mitigation Center. 2017. Maps and data. In: United States Drought Monitor, [Online]. Lincoln, Nebraska: University of Nebraska, National Drought Mitigation Center; U.S. Department of Agriculture, Farm Service Agency; National Oceanic and Atmospheric Administration (Producers). Available: http://droughtmonitor.unl.edu/MapsAndData.aspx. [2017, August 25]. [92075]

82. National Oceanic and Atmospheric Administration, National Weather Service. 2017. Black Hills climate overview, [Online]. In: NWS forecast office. Rapid City, SD: National Oceanic and Atmospheric Administration, National Weather Service (Producer). Available: https://www.weather.gov/unr/bhco. [2017, August 25] [92078]

83. NatureServe. 2013. International Ecological Classification Standard: Terrestrial Ecological Classifications of the United States and Canada. In: NatureServe Central Databases. Arlington, VA, (Producer). 1530 p. [89169]

84. O'Leary, Donal S., III; Bloom, Trevor D.; Smith, Jacob C.; Zemp, Christopher R.; Medler, Michael J. 2016. A new method comparing snowmelt timing with annual area burned. Fire Ecology. 12(1): 41-51. [91059]

85. Odion, Dennis C.; Hanson, Chad T.; Arsenault, Andre; Baker, William L.; DellaSala, Dominick A.; Hutto, Richard L.; Klenner, Walt; Moritz, Max A.; Sherriff, Rosemary L.; Veblen, Thomas T.; Williams, Mark A. 2014. Examining historical and current mixed-severity fire regimes in ponderosa pine and mixed-conifer forests of western America. PLOS ONE. 9(2): 1-14 [+ appendices]. [88228]

86. Oliver, William W.; Ryker, Russell A. 1990. Pinus ponderosa Dougl. ex Laws. ponderosa pine. In: Burns, Russell M.; Honkala, Barbara H., technical coordinators. Silvics of North America. Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 413-424. [13399]

87. Pase, Charles P. 1958. Herbage production and composition under immature ponderosa pine stands in the Black Hills. Journal of Range Management. 11: 238-243. [1823]

88. Perryman, Barry L.; Laycock, W. A. 2000. Fire history of the Rochelle Hills Thunder Basin National Grasslands. Journal of Range Management. 53(6): 660-665. [38122]

89. Perryman, Barry Layne. 1996. Fire history of the Rochelle Hills area of the Thunder Basin National Grasslands. Laramie, WY: University of Wyoming. 74 p. Dissertation. [90651]

90. Plummer, Fred G. 1912. Forest fires: Their causes, extent and effects, with a summary of recorded destruction and loss. Bulletin 117. Washington, DC: U.S. Department of Agriculture, Forest Service. 39 p. [16160]

91. Progulske, Donald R.; Sowell, Richard H. 1974. Yellow ore, yellow hair, yellow pine. Bulletin 616. Brookings, SD: South Dakota University, Agricultural Experiment Station. 167 p. [4019]

92. Roach, David. 1974. Prescribed burning in the Black Hills. South Dakota Conservation Digest. 41(5): 41-43. [1999]

93. Ryan, Michael G.; Joyce, Linda A.; Andrews, Tom; Jones, Kate. 1994. Research natural areas in Colorado, Nebraska, North Dakota, South Dakota, and parts of Wyoming. Gen. Tech. Rep. RM-251. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 57 p. [90197]

94. Sackett, Stephen S. 1984. Observations on natural regeneration in ponderosa pine following a prescribed fire in Arizona. Res. Note RM-435. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 8 p. [8093]

95. Sartwell, Charles; Stevens, Robert E. 1975. Mountain pine beetle in ponderosa pine: Prospects for silivcultural control in second-growth stands. Journal of Forestry. 73(3): 136-140. [2062]

96. Schmid, J. M.; Mata, S. A. 1992. Stand density and mountain pine beetle-caused tree mortality in ponderosa pine stands. RM-515. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p. [18637]

97. Schmid, J. M.; Mata, S. A.; Obedzinski, R. A. 1994. Hazard rating ponderosa pine stands for mountain pine beetles in the Black Hills. Res. Note RM-529. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p. [24450]

98. Shepperd, Wayne D.; Battaglia, Michael A. 2002. Ecology, silviculture, and management of Black Hills ponderosa pine. Gen. Tech. Rep. RMRS-GTR-97. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 112 p. [44794]

99. Shilts, Deane M. 1976. Experimental burning in Wind Cave National Park. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT. 6 p. [2134]

100. Shilts, Deane M.; Klukas, Richard W.; Freet, Bruce L.; Oliverius, Timothy. 1980. Fire management plan: Wind Cave National Park. Hot Springs, SD: U.S. Department of the Interior, Wind Cave National Park. 60 p. On file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 60 p. [50656]

101. Shinneman, Douglas J.; Baker, William L. 1997. Nonequilibrium dynamics between catastrophic disturbances and old-growth forests in ponderosa pine landscapes of the Black Hills. Conservation Biology. 11(6): 1276-1288. [28953]

102. Sommers, William T.; Coloff, Stanley G.; Conard, Susan G. 2011. Synthesis of knowledge: Fire history and climate change. Joint Fire Science Project No. 09-2-01-09. Boise, ID: Joint Fire Science Program. 190 p. [+ appendices]. [87582]

103. Stambaugh, Michael C.; Guyette, Richard P.; McMurry, Erin R.; Marschall, Joseph M.; Willson, Gary. 2008. Six centuries of fire history at Devils Tower National Monument with comments on regionwide temperature influence. Great Plains Research: A Journal of Natural and Social Sciences. Lincoln, NE: University of Nebraska. 18(2): 177-187. [90564]

104. Steinauer, Ernest M.; Bragg, Thomas B. 1987. Ponderosa pine (Pinus ponderosa) invasion of Nebraska sandhills prairie. The American Midland Naturalist. 118(2): 358-365. [6620]

105. Stevens, Jens T.; Safford, Hugh D.; North, Malcolm P.; Fried, Jeremy S.; Gray, Andrew N.; Brown, Peter M.; Dolanc, Christopher R.; Dobrowski, Solomon Z.; Falk, Donald A.; Farris, Calvin A.; Franklin, Jerry F.; Fule, Peter Z.; Hagmann, R. Keala; Knapp, Eric E.; Miller, Jay D.; Smith, Douglas F.; Swetnam, Thomas W.; Taylor, Alan H. 2016. Average stand age from forest inventory plots does not describe historical fire regimes in ponderosa pine and mixed-conifer forests of western North America. PLOS One. 11(5): 20 p. [90649]

106. Stewart, Omer C. 1953. Why the Great Plains are treeless. Colorado Quarterly. Boulder, CO: University of Colorado. 2(1): 40-50. [74584]

107. Swetnam, Thomas W.; Falk, Donald A.; Sutherland, Elaine K.; Brown Peter M.; Brown, Timothy J. 2011. Laboratory of Tree-Ring Research and School of Natural Resources and the Environment: Final report. Fire and Climate Synthesis (FACS) Project, JFSP 09-2-01-10. Tucson, AZ: University of Arizona. 42 p. [91347]

108. Thilenius, John F. 1971. Vascular plants of the Black Hills of South Dakota and Wyoming. Res. Pap. RM-71. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 43 p. [2319]

109. Uresk, Daniel W.; Severson, Kieth E. 1989. Understory-overstory relationships in ponderosa pine forests, Black Hills, South Dakota. Journal of Range Management. 42(3): 203-208. [6705]

110. USDA Forest Service. 1948. Black Hills National Forest, 50th anniversary. Washington, DC: U.S. Government Printing Office. 43 p. [89895]

111. USDA Forest Service. 1983. Land and resource management plan, Black Hills National Forest. Custer, SD: U.S. Department of Agriculture, Forest Service, Black Hills National Forest. 439 p. [91320]

112. USDA Forest Service. 1986. Custer National Forest management plan. Billings, MT: U.S. Department of Agriculture, Forest Service, Custer National Forest and National Grasslands. 148 p. [+ appendices]. [91321]

113. USDA Forest Service. 1994. Appendix A. The range of natural variability for the Black Hills: A first step. In: Proposed revised land and resource management plan, Draft Environmental Impact Statement, Black Hills National Forest, Appendices. 97 p. Custer, SD: U.S. Department of Agriculture, Black Hills National Forest. [90196]

114. USDA Forest Service. 2013. Black Hills National Forest: FY 2012 monitoring and evaluation report. Custer, SD: U.S. Department of Agriculture, Forest Service, Black Hills National Forest. 180 p. [90878]

115. USDA Forest Service. 2014. Black Hills National Forest area, large fire history map, 1880-2014. U.S. Department of Agriculture, Forest Service, Black Hills National Forest. 1:24,000; map, colored. Available online: https://www.fs.usda.gov/detail/blackhills/landmanagement/gis/?cid=stelprdb5112497 [2017, January 10]. [90621]

116. USDA Forest Service. 2015. Gallatin Forest Plan. Bozeman, MT: U.S. Department of Agriculture, Forest Service, Gallatin National Forest. 128 p. [91322]

117. USDA Natural Resources Conservation Service. 2017. PLANTS Database, [Online]. U.S. Department of Agriculture, Natural Resources Conservation Service (Producer). Available: https://plants.usda.gov/. [34262]

118. Van Horne, Megan L.; Fule, Peter Z. 2006. Comparing methods of reconstructing fire history using fire scars in a southwestern United States ponderosa pine forest. Canadian Journal of Forest Research. 36: 855-867. [67189]

119. Westerling, A. L.; Hidalgo, H. G.; Cayan, D. R.; Swetnam, T. W. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science. 313(5789): 940-943. [65864]

120. Westerling, Anthony LeRoy. 2016. Increasing western US forest wildfire activity: Sensitivity to changes in the timing of spring. Philosophical Transactions of the Royal Society B. 371: 20150178. [91318]

121. Westerling, Anthony; Brown, Tim; Schoennagel, Tania; Swetnam, Thomas; Turner, Monica; Veblen, Thomas. 2014. Briefing: Climate and wildfire in western U.S. forests. In: Sample, V. Alaric; Bixler, R. Patrick, eds. Forest conservation and management in the Anthropocene: Conference proceedings; 2017 September 17-18; Washington, DC. RMRS-P-71. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station: 81-102. [89335]

122. Wienk, Cody L.; Sieg, Carolyn Hull; McPherson, Guy R. 2004. Evaluating the role of cutting treatments, fire and soil seed banks in an experimental framework in ponderosa pine forests of the Black Hills, South Dakota. Forest Ecology and Management. 192(2-3): 375-393. [48628]

123. Williams, R. E.; Shaw, C. G., III.; Wargo, P. M.; Sites, W. H. 1986. Armillaria root disease. Forest Insect & Disease Leaflet 78. Washington, D.C: U.S. Department of Agriculture, Forest Service. 8 p. [90241]

124. Wright, Henry A. 1978. The effect of fire on vegetation in ponderosa pine forests: A state-of-the-art review. Lubbock, TX: Texas Tech University, Department of Range and Wildlife Management. 21 p. In cooperation with: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. [4425]