RESTORING PONDEROSA PINE FORESTS IN THE BLACK HILLS, SOUTH DAKOTA

by

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ABSTRACT

Ponderosa pine (*Pinus ponderosa* Laws.) forests have changed considerably during the past century, partly because recurrent fires have been absent for a century or more. In dense stands of ponderosa pine in the Black Hills of South Dakota, a layer of pine needles has replaced understory vegetation. I examined the disturbance history, soil seed bank, and effects of prescribed burning and overstory reduction on understory vegetation in a ponderosa pine stand in the northern Black Hills. Cessation of fires, prolific ponderosa pine regeneration, and logging led to a dense, even-aged stand with very little understory vegetation and few viable seeds in the soil seed bank. Understory vegetation did not respond to restoration treatments the first growing season, but did respond the second growing season. Paucity of viable seeds in the soil seed bank does not appear to constrain recruitment of understory vegetation in dense ponderosa pine forests of South Dakota.

Key words: *Black Hills*; *fire history*; *overstory*; Pinus ponderosa *Laws.*; *prescribed fire*; *soil seed bank*; *stand age*; *understory*

CHAPTER 1

Introduction

Ponderosa pine (*Pinus ponderosa* Laws.) forests are widely distributed across western North America, covering about 16 million hectares from southern British Columbia to Durango, Mexico and California to north central Nebraska (Wright and Bailey 1982, Arno et al. 1995). Historically, disturbances such as fire were frequent in ponderosa pine forest and played an important role in shaping the ponderosa pine ecosystem (e.g. Weaver 1951, Cooper 1960, Wright and Bailey 1982, Swetnam and Baisan 1996). Frequent fires resulted in a forest comprised of discontinuous, distinct groups of even-aged trees with a wide range of size classes represented (Biswell 1972, Biswell et al. 1973).

During the past century, forests of western North America have experienced changes in structure and function that include increases in dense thickets of small, young trees, increased frequency and severity of insect and disease epidemics, increased severity of wildfires, and decreased number of large, old trees and understory herbaceous production (Weaver 1943, Wright 1978, Covington and Moore 1992, Arno 1996). These changes are most often attributed to the interactive effects of active fire suppression, logging, livestock grazing, and geographic fragmentation (Cooper 1960, Covington and Moore 1994, Swetnam and Baisan 1996, McPherson 1997).

In the Black Hills of South Dakota, nearly monotypic stands of ponderosa pine cover almost 95% of the area (Wright and Bailey 1982). Black Hills forests are dynamic and have evolved with a variety of natural disturbances including variable and sometimes extreme weather, periodic fires, and insect and disease epidemics. Of these disturbances, fire was one of the most prevalent (Sieg and Severson 1996). These disturbances limited the density and extent of ponderosa pine trees across the landscape (Parrish et al. 1996, McPherson 1997).

Before Anglo settlement, lightning and American Indians were the ignition sources for fires in the Black Hills (Sieg and Severson 1996). On average, fires burned every 20 to 24 years in interior ponderosa pine stands of the Black Hills and about every 10 to 12 years in foothills stands (Brown and Sieg 1996, Brown and Sieg 1999). Frequent, low-intensity fires thinned dense stands of young pines and kept pine forests open and park-like with an understory of herbs and shrubs (Cooper 1960, Wright and Bailey 1982).

Large-scale, anthropogenic changes in the Black Hills began with the discovery of gold in 1874, after which Anglo populations increased sharply and large quantities of timber were harvested to support growing towns and mining activities (Progulske 1974). Frequent, low-intensity fires also ceased in the late 1800s and early 1900s, probably the result of active fire suppression, logging, geographic fragmentation, and livestock grazing (Brown and Sieg 1996, Brown and Sieg 1999). The combination of intensive silvicultural management and suppression of fires has resulted in increased density and extent of ponderosa pine stands (Progulske 1974, Progulske and Shideler 1983). This has led to decreases in understory productivity, extent of interior prairies and meadows, and species diversity (Parrish et al. 1996), all of which have likely caused a decrease in available forage for big game species such as white-tailed deer (*Odocoileus virginianus*) and Rocky Mountain elk (*Cervus elaphus*).

The negative impacts of forest management practices of the last century on ponderosa pine forests were recognized several decades ago (Weaver 1943, Cooper 1960). Many observational studies have been carried out since that time to assess the effects of wildfire, prescribed burning, and silvicultural treatments on the ponderosa pine ecosystem. However, very few experimental studies have been completed to identify the mechanisms underlying changes in ponderosa pine forests. This lack of experimental studies is particularly evident in the ponderosa pine forests of the Black Hills.

The goal of this study was to address an issue, within an experimental framework, that was relevant to the management of ponderosa pine forests of the Black Hills. Winter ranges of deer and elk in the Black Hills have been identified as "the most critical areas requiring management emphasis" (Sieg and Severson 1996). Therefore, the objectives of this study were: 1) document the condition of the ponderosa pine stand before restoration treatments were applied, 2) examine the disturbance history of the stand and how it relates to the pre-treatment condition of the stand, 3) address the role of prescribed burning and overstory reduction in restoring understory production on deer and elk winter ranges in the northern Black Hills, and 4) examine to what extent a lack of soil seed bank constrains understory recruitment following disturbance.

Chapter 3 addresses the first two objectives, and the third and fourth objectives are addressed in Chapter 4.

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CHAPTER 2

Study Area

This study was conducted in Lawrence County, South Dakota, in the northern Black Hills. The study area is located on the South Dakota Game, Fish & Parks Badger Game Production Area (GPA) west of Spearfish, South Dakota (Fig. 1). Climate and soil information are summarized from Meland (1979). Average annual precipitation in Lawrence County is 61 cm, of which 43 cm (70%) of the yearly precipitation usually falls between April and September. Average winter temperature is -3 C with a record low of -34 C. Average summer temperature is 18 C with an average daily maximum near 27 C. The growing season is approximately 140 days and extends from early May until late September.

Soils on the site are of the Vanocker series (loamy-skeletal, mixed, superactive, frigid Hapludalfs). Soils of the Vanocker series are formed from limestone and calcareous sandstone parent materials (Ensz 1990). This soil series is common on the Badger GPA and is relatively common on the Black Hills portions of Lawrence County (Meland 1979). It is found extensively on the lower limestone plateau and is similar to soils found on the upper limestone plateau (Ed Ensz *pers. comm.*). Elevation of the site ranges from approximately 1220 m to 1280 m.

Ponderosa pine (*Pinus ponderosa* Laws.) is the dominant overstory species. At experiment initiation, the understory was sparsely vegetated and generally characterized by a layer of pine needles 5 to 7 cm thick. Understory species included *Apocynum*

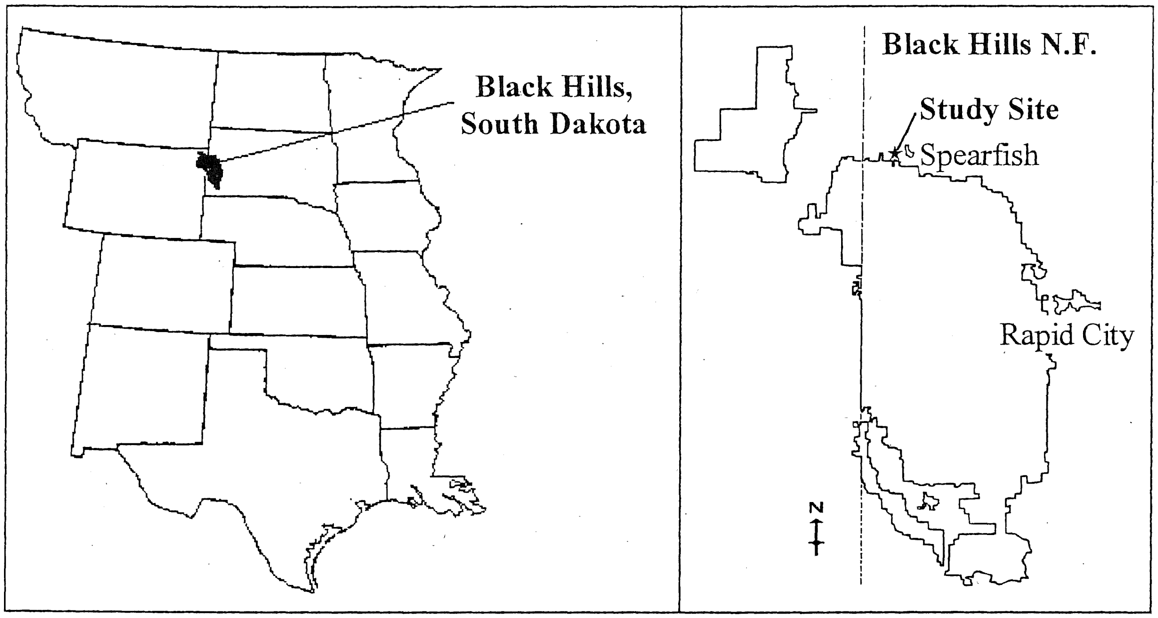

FIG. 1. Location of study site, west of Spearfish, South Dakota.

androsaemifolium L., *Anemone patens* L., *Poa pratensis* L., *Carex* sp. L., *Amorpha canescens* Pursh, *Juniperus communis* L., *Prunus virginiana* L. and others in very small amounts.

Eighteen, 45-m X 45-m research plots were established in 1998 in a relatively even-aged, high density (1300-4700 trees/ha) and basal area (50-80 m^2/ha) ponderosa pine stand representative of ponderosa pine stands in the Black Hills. Plots were placed on western and southwestern aspects (Fig. 2). This west/southwest aspect was chosen for all plots because these slopes are most likely to provide accessible winter forage for deer and elk in the northern Black Hills. Six, 15-m transects were established in the center of each plot, leaving a 15-m buffer zone of the same treatment around the transects (Fig. 3). Transects were perpendicular to the slope contour and were spaced 3 m apart.

A completely randomized design was used with three replications of two treatments in a factorial arrangement: three levels of overstory removal (clearcut, basal area thinned to about 12 m^2/ha, and uncut) and two levels of burning (burned and unburned). Treatments were randomly assigned to the plots, and plots were experimental units for all analyses. The cutting treatment was applied during the autumn and winter of 1998-1999. Both trees and slash were removed from plots to simulate whole-tree harvest. A strip-headfire technique was used to burn the buffer zones and the research plots in May 1999.

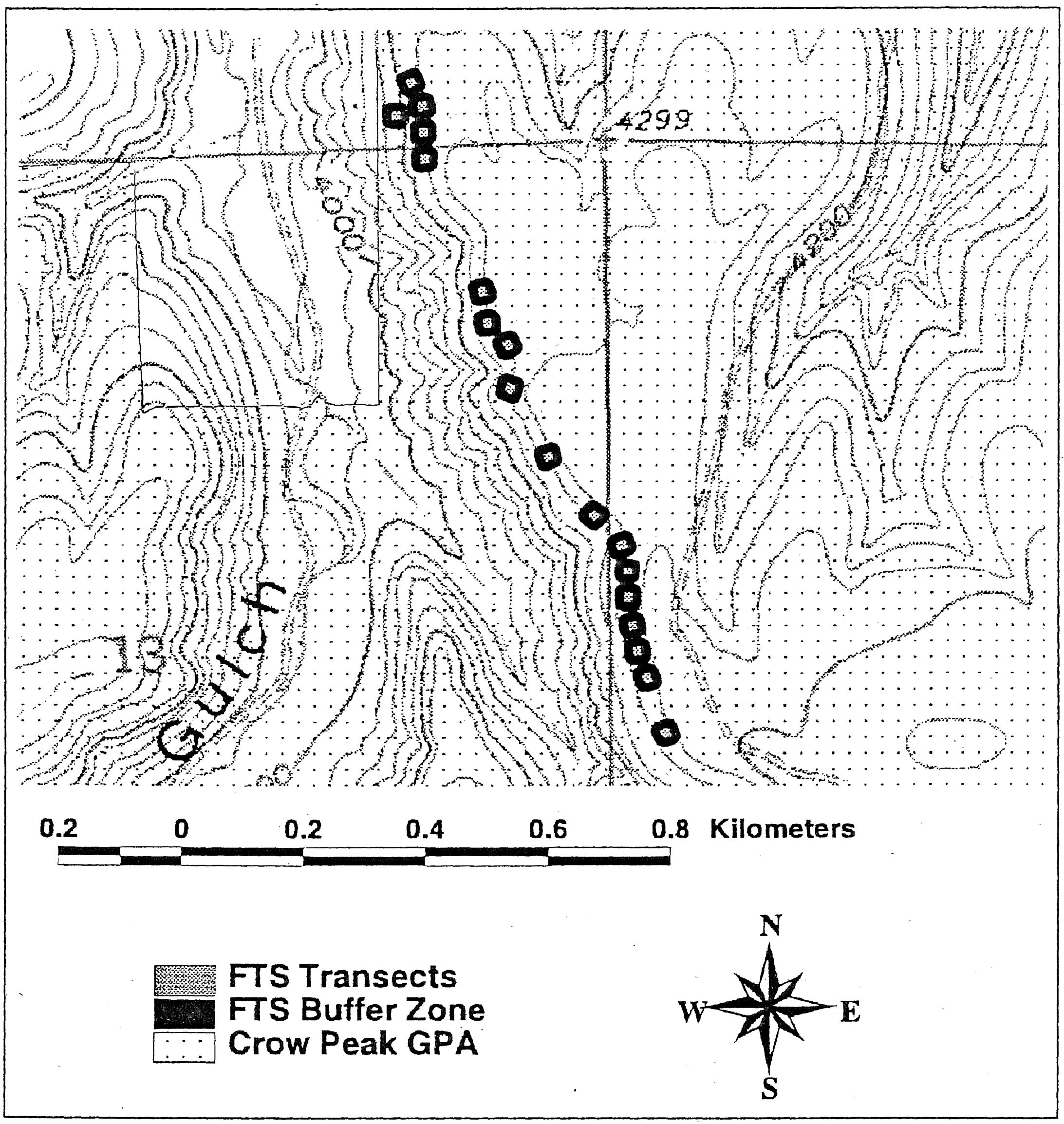

FIG. 2. Locations of plots on the South Dakota Game, Fish & Parks game production area (GPA) west of Spearfish, South Dakota. Each plot measures 15 m X 15 m with a 15-m buffer zone surrounding the plot. "FTS" (fire-thinning study) was the abbreviation used for this study.

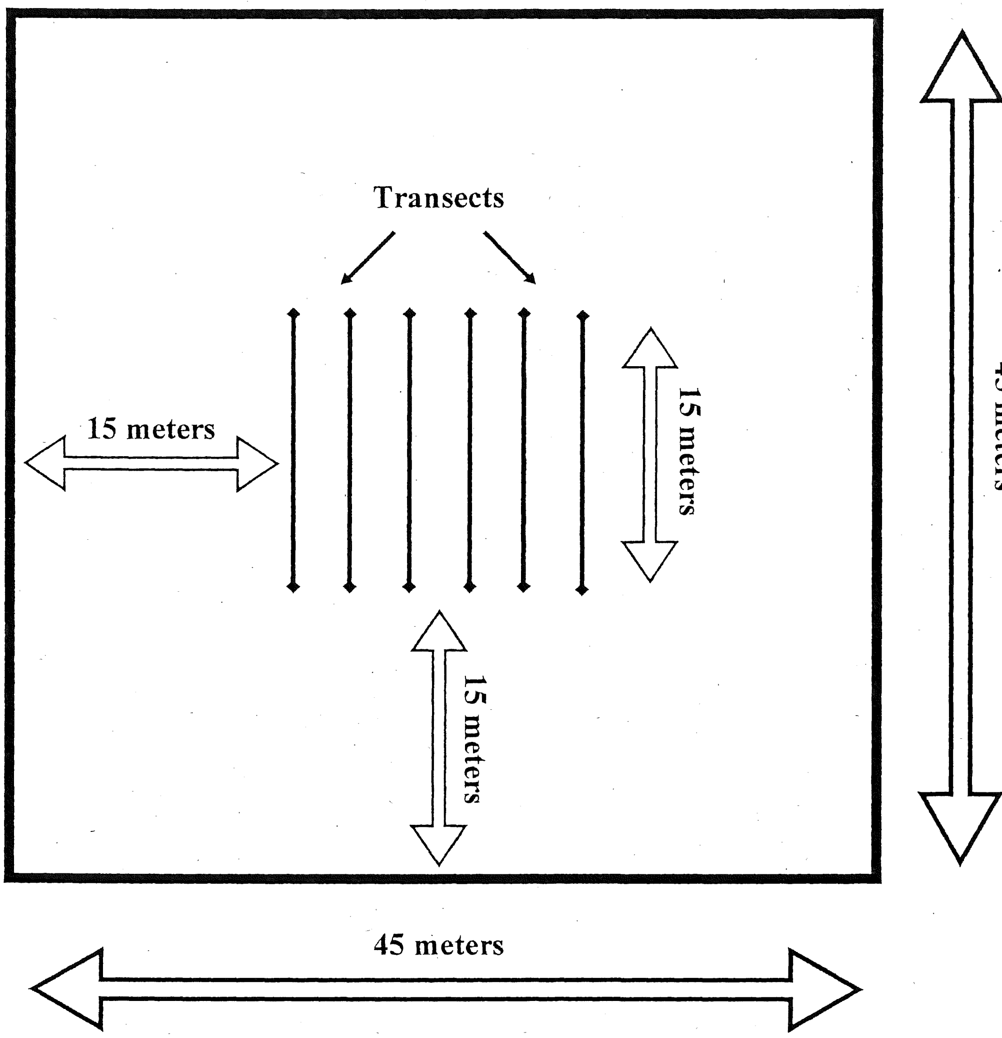

FIG. 3. Schematic of research plots. Six, 15-m transects were established at the center of each plot to leave a buffer zone of the same treatment around the transects. Transects run perpendicular to the contour of the slope and are spaced 3 m apart. The 15-m buffer zone received the same treatment as the center 15 m X 15 m plot.

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CHAPTER 3

Stand History and the Resulting Stand Conditions of a Ponderosa Pine Forest in the Black Hills, South Dakota

ABSTRACT

Ponderosa pine forests have changed considerably during the past century. Changes in stand structure and function have been attributed to fragmentation, changes in climate, logging, livestock grazing, and fire suppression. I studied the history of a ponderosa pine (*Pinus ponderosa* Laws.) stand in the northern Black Hills. Fire history, stand age, and past management of the stand were examined to develop a comprehensive history of the stand, and the current condition of the stand was assessed with tree density, basal area, overstory canopy cover, and understory production and diversity. Frequent fires burned in this stand for at least 300 years before Anglo settlement of the area. The mean fire interval was 14 years with a range of 1 to 43 years, and no fires were recorded after 1879. Cessation of fires, prolific regeneration of ponderosa pine, and subsequent logging in 1903 has led to a very dense, even-aged ponderosa pine stand with very little understory vegetation. The current stand is about 100 years old, and has a density of 2700 tree/ha, basal area of 60 m^2/ha, and overstory canopy cover of 96%. Total production of understory vegetation was 26 kg/ha, with richness and diversity (*H'*) of 3.9 and 0.6, respectively. It appears that the current conditions of this ponderosa pine stand are the result of environmental, climatic, and anthropogenic factors.

Key words: Black Hills; fire history; overstory; Pinus ponderosa *Laws.; stand age; understory*

Introduction

Ponderosa pine *(Pinus ponderosa* Laws.) is the dominant overstory species in the Black Hills of South Dakota and Wyoming, covering nearly 95% of the area (Wright and Bailey 1982). Before Anglo settlement, recurrent fires helped shape the ponderosa pine ecosystem, both in the Black Hills (Gartner and Thompson 1972, Fisher et al. 1987, Brown and Sieg 1996, Brown and Sieg 1999), and throughout its range (Cooper 1960, Wright and Bailey 1982, Swetnam and Baisan 1996, Brown et al. 2000). Fires limited the density and extent of ponderosa pine trees across the landscape (Covington et al. 1994, Parrish et al. 1996, McPherson 1997). Frequent, low-intensity fires kept pine forests open and park-like with a productive understory of herbs and shrubs by thinning dense stands of young pines (Cooper 1960, Wright and Bailey 1982). The result of these fires was a forest comprised of discontinuous, distinct groups of even-aged trees with all size classes represented (Biswell 1972, Biswell et al. 1973, Parrish et al. 1996).

Before Anglo settlement, fires in the Black Hills were started by lightning and American Indians (Sieg and Severson 1996). The mean fire interval (MFI) between 1388 and 1900 was approximately 20 to 24 years with a range of 1 to 93 years for interior ponderosa pine stands in the south-central Black Hills (Brown and Sieg 1996). More frequent fires have been reported for ponderosa pine savannas found in the foothills of the Black Hills. Fires burned approximately every 10 to 12 years with a range of 2 to 34 years in the foothills stands (Brown and Sieg 1999). Fisher et al. (1987) reported similar fire frequencies for the Devil's Tower region on the northwestern edge of the Black Hills. The MFI was 19 years before 1900, and 42 years since 1900. It also has been proposed that large, catastrophic disturbances were a part of the natural disturbance regime in ponderosa pine forests of the Black Hills (Shinneman and Baker 1997). Since Anglo settlement, fire frequencies have decreased drastically. For example, none of the trees sampled in the interior stands had any fire scars that dated to the current century (Brown and Sieg 1996). Decreases in fire frequency since 1900 have been attributed to management practices such as active fire suppression, livestock grazing, logging (e.g. Covington et al. 1994, Brown and Sieg 1996, Brown and Sieg 1999), and geographic fragmentation (McPherson 1997). Ponderosa pine populations have subsequently erupted, resulting in dense pine thickets (Progulske 1974, Arno 1996, Parrish et al. 1996). This has led to decreased understory productivity, extent of interior prairies and meadows, and species diversity (Parrish et al. 1996). In some areas covered with high densities of ponderosa pine, understory vegetation has been replaced by a thick mat of pine needles.

This study was conducted to document the conditions of this ponderosa pine stand before restoration treatments were applied. A study of the stand's history was also conducted to examine the factors that contributed to the pre-treatment conditions of this stand. Fire history, stand age, and land use history were studied to interpret the history of this stand.

METHODS

Study Area

See Chapter 2 for a detailed description of the study area and research plots.

Fire History

Twenty-four fire-scarred cross sections were collected from the study site. These samples were collected in four clusters distributed over a distance of approximately one kilometer (Fig. 4). Of these 24 samples, 5 were collected from live trees, 16 from stumps, 2 from snags, and 1 from a downed log. In addition, a master chronology was constructed using increment cores from seven living ponderosa pine trees on the study site. The master chronology provided dating control for the remnant (dead) wood samples.

Fire history methods followed those of Brown and Sieg (1996). The goal was to compile an inventory of fire events at this study site (Swetnam and Baisan 1996). Cross sections were prepared with progressively finer sandpaper from 60 grit to 400 grit using a belt sander and hand sander. Standard dendrochronological procedures were followed when cross-dating tree-ring series (Stokes and Smiley 1968). Tree-ring series were cross-dated using the master chronology as well as existing chronologies and pine ring-width index chronologies from the Black Hills (Drew 1974, Brown unpublished data). Dates were assigned to fire scars after all cross-sections were cross-dated and were then compiled into a fire chronology for the site. When possible, position of the fire scar within annual rings was assigned as early wood, late wood, or dormant season (Baisan and Swetnam 1990). Dormant season scars were dated to the earlier year.

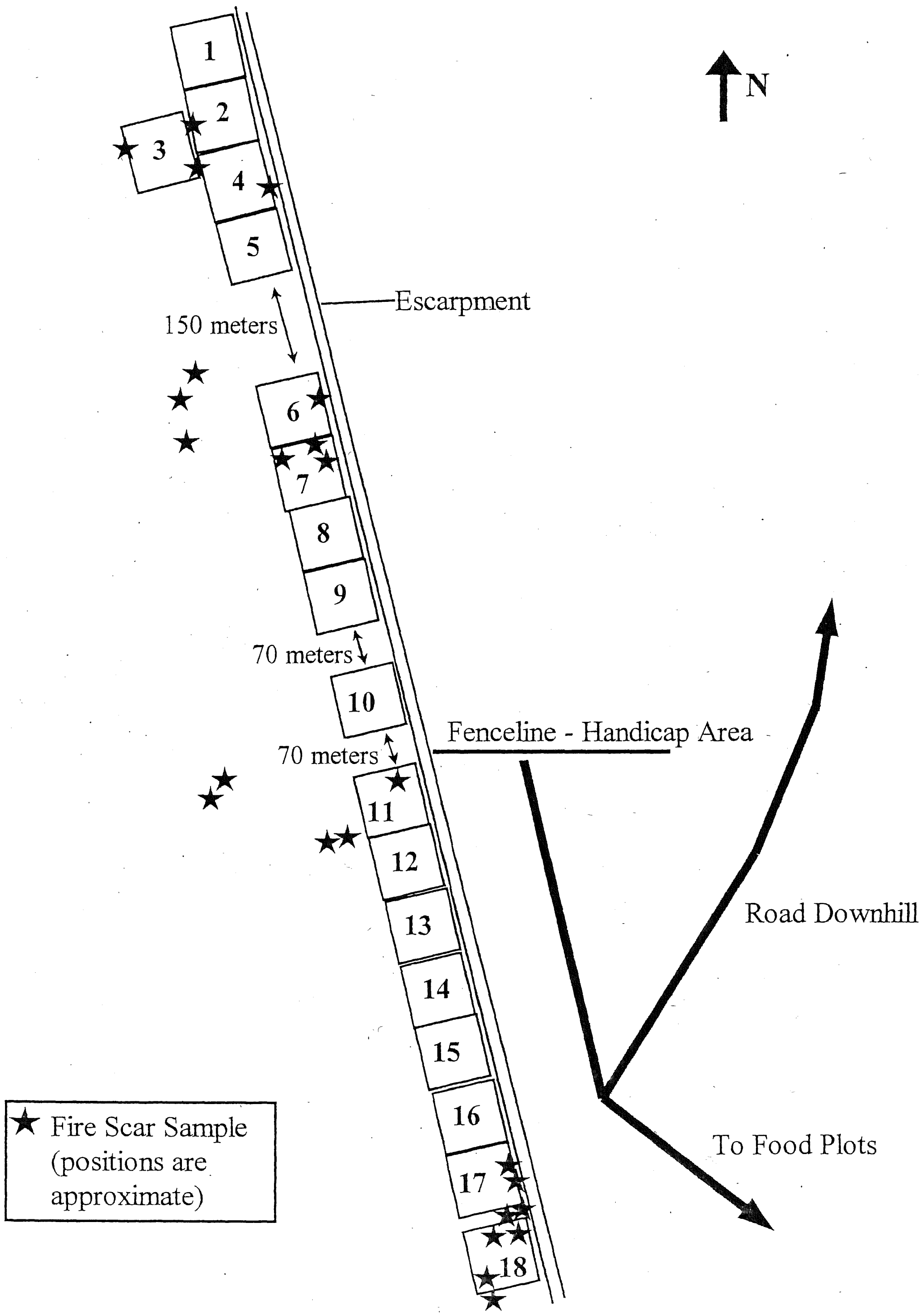

FIG. 4. Approximate locations of fire scar samples in relation to research plots on Badger GPA. Figure not drawn to scale. Samples were basically collected in four clusters.

Stand Age

To determine the approximate age of living trees on the study site, cross-sections were collected from ten randomly selected stumps on each of the twelve research plots that received a cutting treatment. Pith dates were assigned to the cross-sections using the dendrochronological techniques described above. These dates are not exact germination dates, because they were collected 10 to 20 cm aboveground; rather, they represent approximate germination dates.

Land Use History

South Dakota Game, Fish & Parks records and historical documents were examined to determine past management activities on the research site.

Stand Characteristics

The overstory was characterized by measuring tree density, basal area, and overstory canopy cover. Basal area and density were calculated by tallying and measuring diameter at breast height (DBH) of all trees in the center 15 x 15 m of the plots. Percent overstory canopy cover was measured with a canopy cover tube at 2-m intervals along six permanent transects in each plot (Hetherington 1967).

Understory vegetation was sampled in August 1998 along the six permanent transects in each plot. Biomass of herbaceous species was estimated by clipping 30, 0.25-m^2 circular quadrats in each plot (5/transect). The material was sorted by species, placed in paper bags, oven-dried at 60 C for 48 hr, and weighed. Biomass sampling was destructive so quadrats were located in such a way that post-treatment sampling was not repeated in the same location. Shrub biomass was estimated by measuring shrub volume in 24, 1-m^2 quadrats in each plot (4/transect). Simple linear regression was used to estimate shrub biomass from shrub volume. Density of woody plants was measured in 24, 1-m^2 quadrats located at 2-m intervals along the six, 15-m permanent transects. Litter/duff depth was measured at 5-m intervals along the transects (3/transect).

Statistical Analysis

Mean fire interval (MFI) and standard deviation were calculated and reported three different ways: 1) all fires from all samples included in analysis, 2) only fires that were recorded by at least 4 samples included in analysis, and 3) all fires recorded when sample size >6 trees. MFI was interpreted as the interval between fires that occurred anywhere within the study area. Arithmetic mean and standard deviation were used to describe stand age.

Species richness and evenness were calculated for understory vegetation. Richness was calculated as the mean number of species encountered in the 30 quadrats used for sampling herbaceous biomass. Simpson's *1-c* and the Shannon-Weaver index H' were used as measures of evenness (Shannon and Weaver 1949, Simpson 1949); *1-c* and H' were highly correlated ($r = 0.97$) and only H' is presented. Arithmetic mean and standard deviation of diversity measures were calculated. ANOVA was conducted on richness, H', and production of dominant understory taxa.

RESULTS

Twenty-three of the twenty-four samples were cross-dated and dates were assigned to 161 fire scars (Fig. 5). Frequent fires were recorded on all trees between the mid-1500's and 1879. The fire in 1879 was the last recorded on any living or remnant sample. None of the fire-scarred trees that were alive in the 20^{th} century recorded fires after 1879 and none of the 120 cross-sections from the clearcut and partial cut plots had any fire scars. Several fire dates were synchronous among most samples, notably 1715, 1743, 1785, 1808, 1834, and 1854. Fires appeared to be less frequent but more synchronous in the 18^{th} and early 19^{th} centuries than during other periods. This period was followed by an increase in fire frequency in the mid- to late 19^{th} century. The majority of fire scars on samples from this site were either late-season or dormant-season scars. The mean fire interval (MFI), interpreted as the mean number of years between fires that burned some portion of the study area, was 11 to 15 years with a range of 1 to 43 years, depending on which fires were included in the analysis (Table 1).

The stand is notably even-aged and relatively young. Over 95% of the pith dates fall between 1883 and 1907 (Fig. 6), and the average age of tree in the stand is 101 years. The mean density of ponderosa pine is 2700 stems/ha with an average basal area of 60 m^2/ha and an overstory canopy cover of 96% (Table 2). Mean biomass in the understory was 26 kg/ha, of which 92% was contributed by shrubs. Richness and H' were 3.9 and 0.7, respectively, in each 15 X 15 m plot.

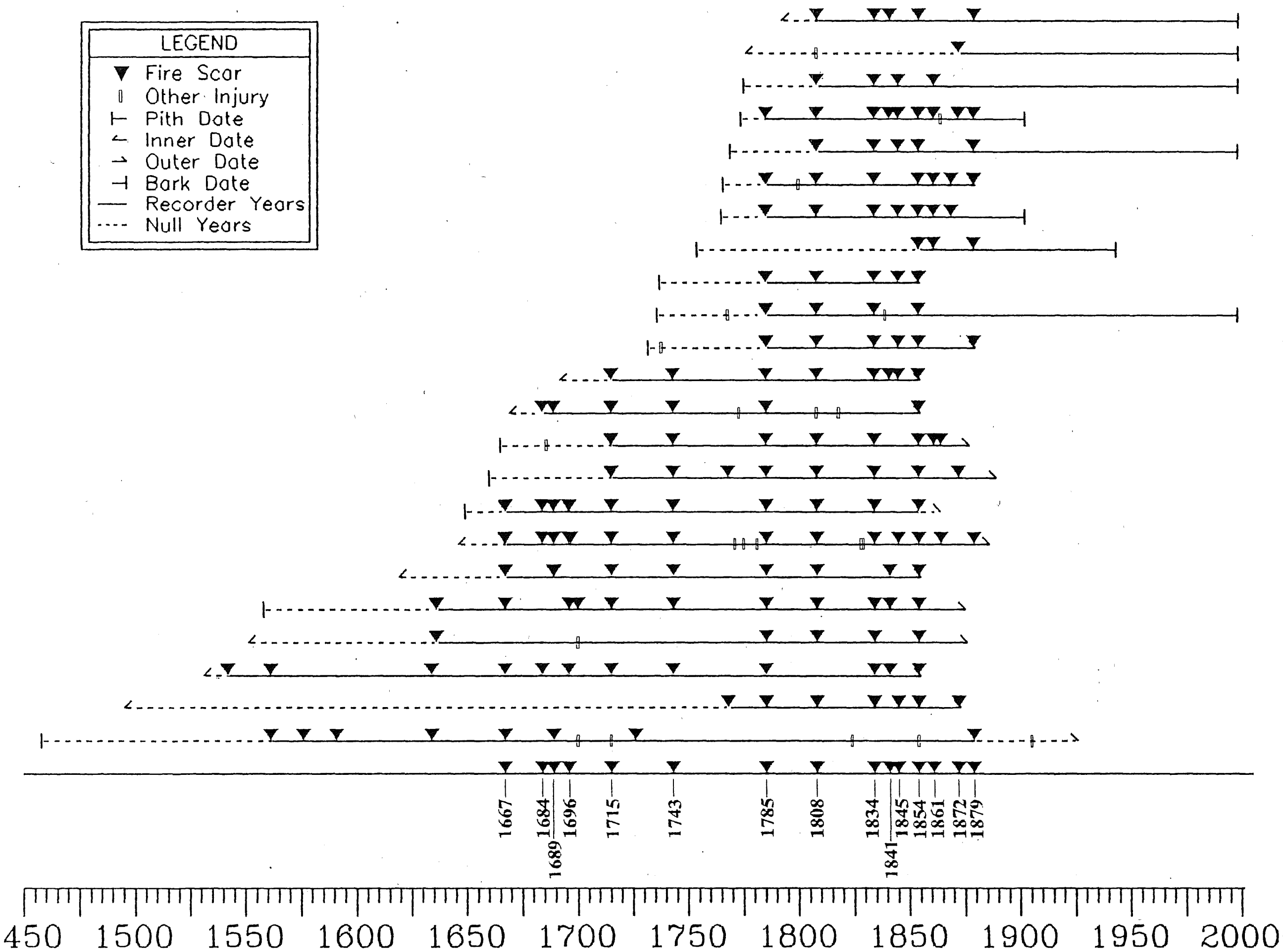

FIG. 5. Fire chronology for a ponderosa pine stand in the northern Black Hills, South Dakota. Time spans of individual trees are represented by horizontal lines, with fire scars noted by triangles at the dates they were recorded. Dates at the bottom of the fire chronology are those years when fire scars were recorded on at least 4 trees.

	Period of Analysis	No. of Intervals	MFI (± SD)	Range of Intervals	Years Since Last Fire
All Fires	1450-1998	26	13 ± 10	1 to 43	119
>3 Samples Scarred	1450-1998	14	15 ± 11	4 to 42	119
Sample Size >6	1667-1998	20	11 ± 8	1 to 26	119

TABLE 1. Fire history statistics calculated with three different restrictions placed on fires included in the analyses. Number of fire intervals, mean fire intervals (MFIs), ranges of fire intervals, and number of years since last fire for Badger GPA in the Black Hills, South Dakota.

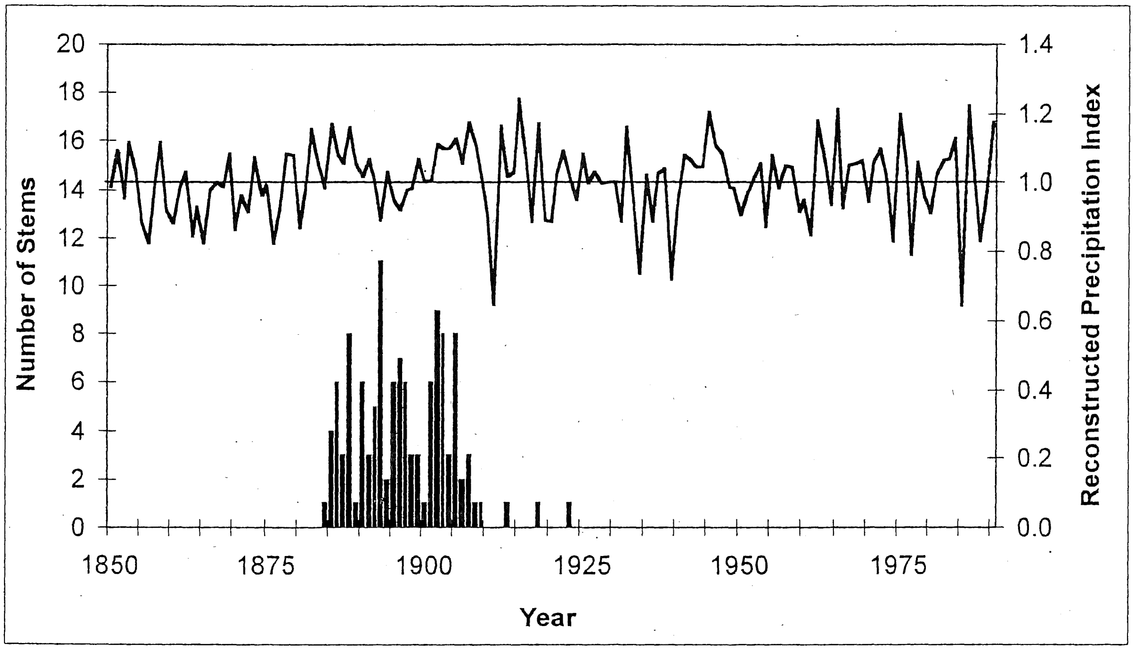

FIG. 6. Pith dates from 120 tree cross-sections collected from plots that received the overstory reduction treatment in the northern Black Hills, South Dakota. These pith dates give an approximate age of the living trees on the research site in 1998. The last fire burned on this site in 1879 and the stand was logged in 1903. Precipitation index, reconstructed using tree-ring data, is presented as a percentage of the 1919-1989 August to July annual mean precipitation from instrumental stations in the Black Hills and northern plains (Sieg et al. 1996).

	Overstory Canopy Cover (%)	Density (stems/ha)	Basal Area (m^2/ha)	Litter Depth (cm)	Graminoid Prod. (kg/ha)
1998	96 ± 0.8	2700 ± 200	60 ± 2	6.5 ± 0.1	0.9 ± 0.4

	Herb. Dicot Prod. (kg/ha)	Shrub Prod. (kg/ha)	Total Prod. (kg/ha)	*H'*	Richness
1998	1.2 ± 0.6	24 ± 8.7	26 ± 9.0	0.6 ± 0.1	3.9 ± 0.8

TABLE 2. Overstory and understory characteristics of the stand on the Badger GPA in the northern Black Hills, South Dakota measured in 1998. Means (± SE) are presented.

Discussion

The northern Black Hills was densely settled following the discovery of gold in 1874 (Progulske 1974). Timber harvest in the area was unregulated until the establishment of the Black Hills Forest Reserve in 1897 (Ball and Schaefer 2000). The specific area in which this study was conducted was under private ownership from 1903 until 1945 and was probably used primarily for ranching. The state of South Dakota purchased the land in 1945 as a game production area to be managed for deer winter range.

Fire history on this site is typical of ponderosa pine forests, particularly those in savannas of the Black Hills. Two fire history studies have been conducted in the southern Black Hills. The first reported fire history for interior ponderosa pine stands in Jewel Cave National Monument, which has elevations ranging from 1585 to 1768 m (Brown and Sieg 1996). The second was carried out in foothills ponderosa pine savannas of Wind Cave National Park, with elevations of 1100 to 1530 m (Brown and Sieg 1999). A similar study was conducted in ponderosa pine forests of Devils Tower National Monument in the northwestern Black Hills (Fisher et al. 1987).

The historic fire regime more closely resembles that found in foothills ponderosa pine stands (Brown and Sieg 1999) than those in interior ponderosa pine stands (Brown and Sieg 1996). This may not be surprising since this site is located on the perimeter of the Black Hills, although the site does not resemble a savanna in its current condition (Fig. 7). Some fire dates from this site coincide with fire dates found at sites in the southern Black Hills (e.g., 1684, 1785, and 1845 in foothills and interior stands, and 1879

FIG. 7. Photo taken in 1998 of a northern Black Hills ponderosa pine stand on the Badger GPA. This stand has high density, basal area, and canopy cover of ponderosa pine with very little vegetation in the understory and a thick layer of pine needles. Historic fire frequencies suggest that this stand was more savanna-like before Anglo settlement.

in interior stands; Brown and Sieg 1999, Brown and Sieg 1996). The fire of 1879 is also the last fire recorded on trees sampled at this site. The cessation of fires generally coincides with Anglo settlement of the area.

Increased fire frequency during the period from the mid- to late 19th century parallels other sites in the Black Hills, and it has been speculated that this was a result of increases in American Indian activities and/or activities of early Anglo settlers (Fischer et al. 1987, Brown and Sieg 1996, Brown and Sieg 1999). There was no apparent evidence of stand-replacing disturbance on this site for at least the past 400 years, except for timber harvest in the early 20th century.

In this study, two cut stumps had outer dates (1902 +) that appear to be death dates and may have been cutting dates. Nearly 25% of the samples collected from stumps on cut plots exhibited rapid growth between 1903 and 1908. Such rapid growth may have resulted form removal of large trees, which subsequently released resources for remaining seedlings and saplings. This dating was substantiated by historical records. A bill of sale was filed at the Lawrence County, South Dakota Register of Deeds Office on January 23, 1903 for saw timber on the quarter section where this study was conducted. In this document, timber harvest was to commence no later than June 1, 1903[1].

This stand apparently established after the 1879 fire, probably in response to above-average precipitation in the 1880s (Fig. 6). Ponderosa pine reportedly has episodic germination and often establishes during wet periods (Savage et al. 1996). This cohort of ponderosa pine would have been too small to have been harvested in 1903. Thus, trees in

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1 Lawrence County, SD Register of Deeds, Book 167, Page 333

the current stand apparently established in the 1880s and were not harvested in 1903 because of their smaller size.

The current ponderosa pine stand at the research site probably looks considerably different than it did 125 years ago. What was presumably an open, savanna-like ponderosa pine stand is now a very dense stand of relatively small diameter trees with little understory vegetation. The average diameter at breast height (DBH) of trees in this stand was just over 15 cm in 1998. By comparison, the average DBH was approximately 26 cm in a open ponderosa pine stand in the central Black Hills (Wrage 1994). The understory currently consists of a thick layer of pine needles.

Understory production in this stand was similar to that reported in other dense ponderosa pine forests. In the Black Hills, total understory production was reported as 25 to 113 kg/ha under dense stands (37-46 m^2/ha) of ponderosa pine (Pase and Hurd 1957, Uresk and Severson 1998), which resembles dense ponderosa pine forests outside the Black Hills. Herbaceous understory production was reported to range from 6 to 30 kg/ha in dense stands (46-70m^2/ha) of ponderosa pine throughout the western United States (Jameson 1967, Ffolliott et al. 1977). In contrast, relatively open ponderosa pine stands (< 23 m^2/ha) in the central Black Hills are characterized by understory production between 203 and 1750 kg/ha (Wrage 1994, Uresk and Severson 1998).

Evenness (*H'*), at 0.7, was low in this stand and the majority of understory biomass was contributed by a few shrub species. Species richness (3.9) was considerably lower than that reported for other ponderosa pine stands in the Black Hills. Wrage (1994) sampled 30, 0.10-m^2 quadrats per 0.04-ha plot and reported species richness of 45 for dense stands (> 60% canopy cover) and 60 for open stands (< 30% canopy cover). Another study in the central Black Hills reported species richness of 12 under dense stands (37-40 m^2/ha) and 18 to 36 under thinned stands (5-28 m^2/ha) when up to 25, 0.125-m^2 quadrats were sampled per 0.2-ha plot (Uresk and Severson 1989).

A likely series of events that led to the current stand conditions encapsulates environmental, climatic, and anthropogenic factors. Frequent fires burned through this stand for at least 300 years before Anglo settlement of the area. Cessation of the natural fire regime coincided with Anglo settlement. Following a large fire in 1879, favorable climatic conditions resulted in germination of one or more cohorts of ponderosa pine in the 1880s. The area was intensely logged in 1903 and 1904 to support a burgeoning human population. The cohort(s) of ponderosa pine that germinated in the 1880s were too small to harvest, so they were left to regenerate the stand. In the absence of fires or timber harvest, the stand remained densely populated and even-aged. During the ensuing century, the overstory canopy closed and most of the understory vegetation was replaced by a layer of pine needles.

In conclusion, frequent fires burned in this stand for at least 300 years before settlement of the area. Cessation of fires and favorable ponderosa pine germination at the end of the 19th century, followed by logging in 1903 has resulted in the dense ponderosa pine on this site. The overstory was high density, basal area, and overstory canopy cover, and the understory was nearly devoid of vegetation.

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CHAPTER 4

Understory Vegetation Response to Fire and Overstory Reduction in Ponderosa Pine Stands in the Black Hills, South Dakota

ABSTRACT

Recurrent fires have been absent from many North American forests for a century or more, with consequential impacts on ecosystem structure and function. In dense stands of ponderosa pine (*Pinus ponderosa* Laws.) in the Black Hills of South Dakota, understory vegetation has been replaced by a thick layer of pine needles. I experimentally addressed the effects of prescribed burning and overstory reduction on understory vegetation. In addition, I examined the extent to which lack of a soil seed bank constrained understory recruitment in dense forests. Response of understory vegetation during the first growing season after application of treatments was sparse, with no significant treatment effect. There were, however, significant treatment effects during the second growing season. Total understory biomass ranged from 5.8 kg/ha on untreated plots to 1724 kg/ha on clearcut, unburned plots. Herbaceous dicots comprised over 90% of the total understory biomass. Both understory species richness and evenness responded to treatments, but understory woody plant density did not respond to either treatment. Only 57 individual plants, or 186 seeds/m^2, emerged from 1080 soil samples. Nonetheless, paucity of viable seeds in the soil seed bank does not appear to constrain recruitment of understory vegetation in dense ponderosa pine forests of South Dakota.

Key words: *Black Hills*; Pinus ponderosa *Laws.*; *prescribed fire*; *soil seed bank*; *understory*

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Laws.) and other western forests have undergone considerable change during the last century (Weaver 1943, Cooper 1960, Covington et al. 1994). Forests of western North America have experienced changes in structure and function that include increases in dense thickets of small, young trees, increased frequency and severity of insect and disease epidemics, increased severity of wildfires, and decreased number of large, old trees, tree vigor and herbaceous production (Weaver 1943, Wright 1978, Covington and Moore 1992, Arno 1996). These changes are most often attributed to the interactive effects of active fire suppression, logging, livestock grazing, and geographic fragmentation (Cooper 1960, Covington and Moore 1994, Swetnam and Baisan 1996, McPherson 1997).

Forests of the Black Hills are no exception to this general pattern. Ponderosa pine is the dominant overstory species in the Black Hills of South Dakota and Wyoming, covering nearly 95% of the area (Wright and Bailey 1982). Historically, recurrent fires were frequent in Black Hills forests (Brown and Sieg 1996), and were started by lightning and American Indians (Sieg and Severson 1996). Mean fire interval (MFI) was 20 to 23 years for interior ponderosa pine stands in the south-central Black Hills (Brown and Sieg 1996) and 10 to 12 years for pine savanna sites in the foothills of the Black Hills (Brown and Sieg 1999). Since Anglo settlement, fire frequency has decreased substantially. None of the trees sampled in the interior stands had fire scars that dated to the current century (Brown and Sieg 1996). Similar MFIs were reported for the Devil's Tower region on the northwestern edge of the Black Hills. The MFI was 14 years between 1770 and 1900, and 42 years since 1900 (Fisher et al. 1987).

Black Hills forests have been managed as intensely as any western timber type; nearly every hectare has been cut at least once during the past 125 years (Ball and Schaefer 2000). Large-scale timber harvesting began with the gold rush of 1876, while regulation of Black Hills forests began with the establishment of the Black Hills Forest Reserve in 1897 and the first timber sale from the national forest system in 1899. The combination of intensive silvicultural management and suppression of fires has resulted in increased density and extent of ponderosa pine stands (Progulske 1974, Progulske and Shideler 1983). This has led to decreases in understory productivity, extent of interior prairies and meadows, and species diversity (Parrish et al. 1996), all of which have likely caused a decrease in available forage for big game species such as white-tailed deer (*Odocoileus virginianus*) and Rocky Mountain elk (*Cervus elaphus*). In some areas covered with ponderosa pine in high densities, understory vegetation has been replaced by a thick mat of pine needles.

This study experimentally addressed the role of prescribed burning and overstory reduction in restoration of understory production on deer and elk winter ranges in the northern Black Hills. Treatments of overstory reduction, prescribed burning, and a combination of the two were randomly assigned to study plots. This study also examined the extent to which the soil seed bank constrains understory recruitment following disturbance in areas where fires have been rare in the last century and almost no understory vegetation is present.

METHODS

Study Area

See Chapter 2 for a detailed description of the study area and the research plots.

Application of Treatments

Treatments were randomly assigned to 0.2-ha plots. The cutting treatment (clearcut, BA thinned to about 12 m^2/ha, uncut) was applied during the autumn and winter of 1998-1999. Trees and slash were removed from plots to simulate whole-tree harvest. Skidding the trees off the cut plots disturbed the litter layer, so hand raking was used to redistribute the pine needles before the burn.

The objective of the prescribed burn was to reduce the litter layer and create a mineral soil seedbed while minimizing overstory mortality. I conducted the prescribed burn on 7-8 May 1999. Fire lines were constructed around all areas that were to be burned. The day before the research plots were burned, I burned areas between and around the plots to fine-tune our prescription and to reduce pressure from herbivores on the research plots. Weather conditions the day of burning were: light to 10 km/h winds out of the northwest, temperatures 14 to 18 C, and relative humidity 24 to 40%. Conditions were similar the day I burned the plots: light winds variable from west to north, temperatures 12 to 21 C, and relative humidity 30 to 60%. A strip-headfire technique was used to burn the buffer zones and the research plots. The strips varied from 5 to 15-m in width. Flame heights averaged 0.5 to 1.25 m.

Overstory Sampling

The overstory was characterized both pre- and post-treatment by measuring tree density, basal area, and overstory canopy cover. Basal area and density were calculated by tallying and measuring diameter at breast height (DBH) of all trees on the center 15 m x 15 m of the 45 m X 45 m plots. Percent overstory canopy cover was measured with a canopy cover tube at 2-m intervals along six permanent transects in each plot (Hetherington 1967). Overstory measurements were collected before and after treatments were applied.

Post-burn char height, crown scorch, and ponderosa pine mortality were measured on every tree in the burned plots. Char height and crown scorch were measured in June 1999 on all trees within burned plots. Char height was an estimate of the charring on the tree boles measured with a telescoping measuring pole. Crown scorch was visually estimated as the percentage of foliage in the live crown that was killed. Ponderosa pine mortality was calculated as the difference in pine density between 1999 and 2000.

Understory Sampling

Understory vegetation was sampled in August 1998 (pre-treatment), July 1999 (first season post-treatment) and July 2000 (second season post-treatment). Biomass of herbaceous species was estimated by clipping 30, 0.25-m^2 circular quadrats in each plot (5/transect). The material was sorted by species, placed in paper bags, oven-dried at 60 C for 48 hr, and weighed. Biomass sampling was destructive so quadrats were located in such a way that post-treatment sampling was not repeated in the same location. Density of understory woody plants was measured in 24, 1-m^2 quadrats located at 2-m intervals along the six, 15-m permanent transects. Nomenclature follows that of the Great Plains Flora Association (1986). Litter/duff depth was measured with a meter stick at 5-m intervals along the transects (3/transect).

Species richness and evenness were calculated for all treatments using the species biomass data collected in 30, 0.25-m^2 circular quadrats in each 15 m X 15 m plot. Richness was the mean number of species per plot. Shannon-Weaver H' and Simpson's c were used as measures of evenness (Shannon and Weaver 1949, Simpson 1949).

Shrub biomass was estimated by measuring volume of shrubs in a total of 24, 1-m^2 quadrats located at 2-m intervals along the six, 15-m permanent transects. Methods used to measure shrub volume follow those used by McPherson and Wright (1987). Height and 2 diameters (D_1, largest diameter; D_2, diameter perpendicular to D_1) of each shrub were measured. Shrub volume was calculated with the equation: $V=\pi a^2b/6$, where V is shrub volume (cm^3); a is minor axis (cm; height or average diameter, whichever is smaller); and b is major axis (cm; height or average diameter, whichever is greater) (Phillips and MacMahon 1981). Relationship of shrub volume and biomass was determined separately for each species so that biomass could be estimated for shrubs sampled in the plots. Shrubs of each species were located in the buffer zones around the plots, measured for shrub volume, clipped, oven dried, and weighed. These measurements were used to develop regression equations between biomass and volume for each shrub species.

Soil moisture was measured in August and September of 1998, monthly from May to September of 1999, and monthly from May through July of 2000. A 1.9-cm diameter soil sampler was used to collect the upper 3 cm of soil from 6 randomly selected soil cores in each plot in 1998. Sample size was increased to 9 in 1999 and 10 in 2000 because variability in soil moisture was relatively high within each plot. Soil was collected and placed in plastic soil bags, weighed, dried at 100 C for 48 hours, and reweighed. Soil temperature was measured monthly August to September, 1998, and again May through July, 2000. Soil thermometers were used at 4 randomly selected locations in each plot during the peak temperature period of the day (1300 - 1600) to capture the maximum soil temperatures.

Soil Seed Bank

Soil seed bank was sampled in August 1998 and May 1999 to estimate the number of viable seeds in the soil seed bank before restoration treatments were applied. The May 1999 sample was collected shortly after the prescribed burn, and presumably before any seasonal seed input, to determine if the prescribed burn provided any environmental cues leading to increased seed germination. A seedling emergence method was used to estimate viable seed numbers in the soil (Ferrandis et al. 1996, Kitajima and Tilman 1996, and Ter Heerdt et al. 1996). Sixty soil cores (10/transect) were collected from each plot to a depth of 3 cm with a 1.9-cm-diameter soil sampler. The litter layer was included with the soil samples because this layer may contain a high number of seeds (Simpson et al. 1989). All cores from a transect were composited into a single subsample and placed in plastic bags for transportation to the lab. Litter and soil samples were stored in darkness for 8-10 weeks at 4-6 C.

Samples were sieved through a # 5 soil sieve (4 mm) and then a # 8 sieve (180 μm) to remove larger material while preventing the loss of seeds. Remaining soil was spread to a depth of 0.5-cm in pots containing sterilized potting soil covered with a 0.5 to

1.0-cm layer of pure silica sand. Samples were placed in a climate-controlled growth chamber (12 hr light, 10-20 C, 75% RH), watered daily, and checked for new seedlings every three days. New seedlings were marked with color-coded toothpicks and removed when they were large enough to identify. Unidentifiable seedlings were transplanted and grown in individual pots until identification was possible. When no new seedlings emerged for more than 2 weeks, samples were allowed to dry. They were then disturbed by crumbling/mixing the soil and provided water for approximately six more weeks in the growth chamber, while they were again checked for seedlings every three days (Ter Heerdt et al. 1996).

Statistical Analyses

Data residuals were visually inspected to ensure that normality, linearity, and homogeneous variance assumptions of analysis of variance (ANOVA) were met before proceeding with analyses. Pre-treatment data were analyzed to assess the homogeneity of research plots. Statistical analyses were completed with JMP IN statistical software (SAS 1996). Individual ANOVAs were used to determine if pre-treatment differences were present in understory biomass (total and by guild), shrub density, litter depth, and stand characteristics (ponderosa pine density, basal area, canopy cover). Soil moisture and temperature were analyzed with repeated-measures ANOVA. Char height and crown scorch were analyzed with ANOVA, and correlation coefficients were calculated between these two measures and ponderosa pine mortality.

Repeated-measures ANOVA was used to analyze response of soil moisture and soil temperature two growing seasons after application of treatments. Response of litter depth the first growing season was analyzed with ANOVA. Since there was no response of understory vegetation the first growing season, ANOVA was used to analyze interactions and main effects of treatments on understory vegetation the second growing season (2000). Understory vegetation data were transformed with the common log transformation for analysis to satisfy the assumptions of ANOVA. When interactions were detected, LSD was used to determine differences between treatment combinations.

Shannon-Weaver H' and Simpson's c were highly correlated ($r = 0.97$) and only H' is presented. Differences among treatments in richness and evenness were analyzed with ANOVA. In addition, Ward's method cluster analysis (Ward 1963) was used to display relationships of vegetation production among treatments. Differences among treatments in number of viable seeds in the soil seed bank were analyzed with repeated-measures ANOVA.

RESULTS

Pre-treatment

Plots were relatively homogeneous before treatments were applied. Soil moisture ($p \geq 0.35$; MANOVAR Wilks' Lambda F-test), soil temperature ($p \geq 0.56$; MANOVAR Wilks' Lambda F-test), litter depth ($p \geq 0.44$; ANOVA F-test), total biomass ($p \geq 0.09$; ANOVA F-test), herbaceous dicot biomass ($p \geq 0.30$; ANOVA F-test), graminoid biomass ($p \geq 0.37$; ANOVA F-test; ANOVA F-test), and shrub density ($p \geq 0.34$; ANOVA F-test; ANOVA F-test) did not vary between treatments. Plots assigned to the clearcut treatment had greater shrub biomass than those assigned to the partial-cut treatment (54 ± 20 kg/ha vs. 2.8 ± 1.6 kg/ha; $p = 0.04$; ANOVA F-test), although all plots were characterized by little shrub biomass. Pre-treatment basal area on plots receiving the partial-cut treatment was higher than basal area on plots receiving the clearcut treatment or plots receiving the uncut treatment ($p = 0.03$; ANOVA F-test) (Table 3). However, overstory canopy cover and density did not reflect this pattern ($p = 0.06$; ANOVA F-test) (Table 3).

Post-treatment

Significant ponderosa pine mortality resulted from the prescribed burn. Ponderosa pine mortality on partial-cut plots was higher than that on uncut plots (81 ± 7% vs. 39 ± 5%; $p = 0.008$; ANOVA F-test). Reduction of basal area was also greater on partial-cut plots than on uncut plots (69 ± 10% vs. 17 ± 5%; $p = 0.01$; ANOVA F-test), but a reduction was not observed in overstory canopy cover. There was no difference in crown scorch between partial-cut and uncut plots (70 ± 10% vs. 74 ± 2%, $p = 0.78$;

	No Cut	Partial Cut	Clearcut
Canopy Cover (%)	95 (1.7) ^{ab}	99 (1.0) ^{b}	94 (0.7) ^{a}
Density (stems/ha)	2600 (220) ^{ab}	3400 (390) ^{b}	2300 (290) ^{a}
Basal Area (m^2/ha)	58 (1.8) ^{a}	67 (3.7) ^{b}	55 (2.3) ^{a}

TABLE 3. Pre-treatment overstory characteristics by cut treatment, collected in 1998 on the Badger GPA. Means (SE) are presented. Numbers within the same row followed by similar superscripts did not differ ($p > 0.05$).