Fire in the Black Hills Forest-Grass Ecotone[1]

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INTRODUCTION

SOUTH Dakota is located in the geographical center of the North American continent, equidistant from the Atlantic and Pacific Oceans, and midway between the North Pole and the equator (United States Dept. Interior 1967). The Black Hills are situated along the state's western border (Fig. 1) lying principally within parallels 43 and 45 degrees north latitude and meridians, 103 and 104 degrees, 30 minutes, west longitude, largely in South Dakota, partly in Wyoming (Johnson 1949). Total area is about 5,150 mi^2, including the Bear Lodge Mountains in northeastern Wyoming (Orr 1959).

After leading a scientific party through the Black Hills in the summer of 1875, Colonel R. I. Dodge (1876) concluded:

> The Black Hills country is a true oasis in a wide and dreary desert. The approaches from every direction are through long

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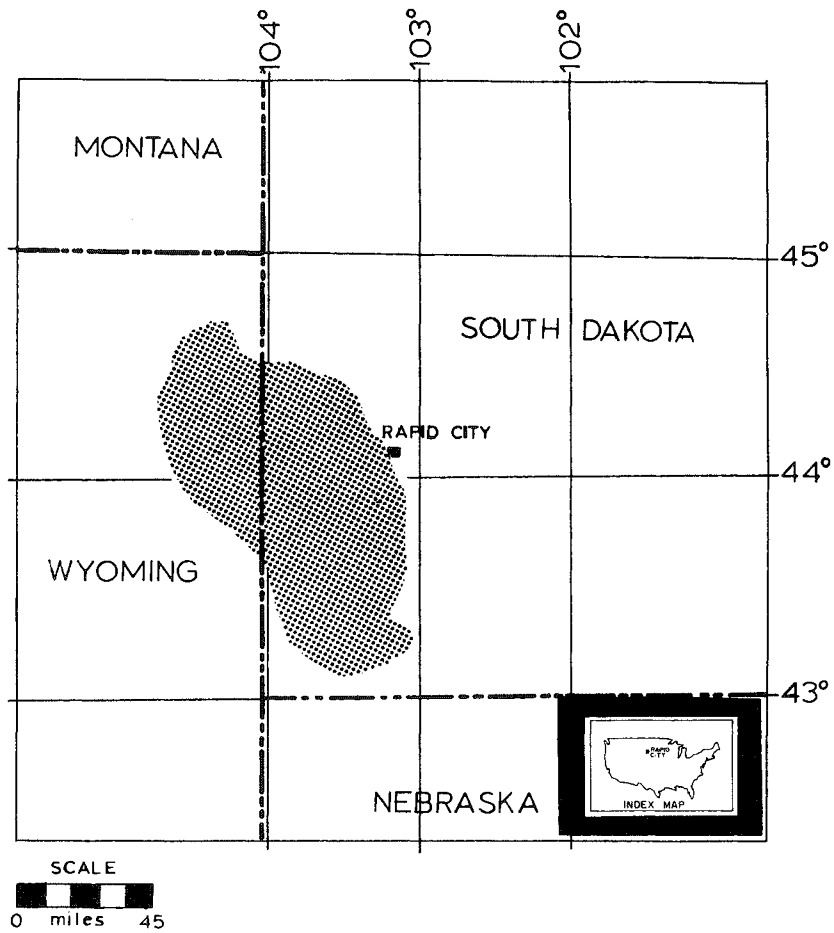

FIG. 1. Location and extent of the Black Hills.

stretches of inhospitable plains, treeless and broken, in which the supply of water is so saturated with bitter and nauseous alkalies as to be unfit for the continuous use of the white man.
Nature seems to have been at pains to set barriers around and about it. . . . but . . . I pronounce the Black Hills, in many respects, the finest country I have ever seen.
As a grazing country it cannot be surpassed; and small stock-farms of fine cattle and sheep cannot, I think, fail of success.

Dodge (1876) quite accurately predicted the future of the Black Hills stating:

> There appears no reason why the Black Hills should not be a most magnificent agricultural country. . . .
>
> However it may turn out as a farming country, there can be no doubt of its immense value as a grazing country. Splendid grass, pure water, excellent shelter from storms—nothing is wanting to fill all the requirements of a first-class stock-farm. It will, before many years, furnish beef and mutton, butter, cheese and wool for a nation. . . . In a few years, when this wilderness shall have been made to 'blossom as the rose,' with cozy farms and comfortable residences, when rocky crags shall have been crowned with palatial hotels, the tourist will find an ample reward in climbing the rugged heights, or exploring the dark defiles of this wonderful land.

Most of Dodge's predictions have become realities in slightly less than 100 years. Today many fine cattle and sheep ranches exist in the Black Hills, and the summer tourist industry is of absolute importance to most Hills communities.

Settlement and, in particular, mining in the Black Hills led to unique present-day land management problems. Throughout the Hills thousands of mining claims on which deeds were given created today's patchwork pattern of land ownership. This intermingling of private and public lands makes resource management difficult.

Fire suppression, following settlement of the Black Hills, has prevented the natural recurrent changes required by most plant communities. Interrupting these changes has led to stagnating ponderosa pine stands which are both hazardous and aesthetically unappealing. Along forest margins, fire suppression has permitted pines to extend their range into grassland at the expense of herbaceous vegetation.

In view of present and future land uses, there is an urgent need to examine fire as a possible management tool for reducing wildfire hazards and improving livestock and wild game ranges, timber productivity, and scenic vistas. The history of wildfires in the Black Hills must be reviewed in order to obtain a proper perspective of fire in various plant communities in the Hills area. In this manner the changes which have occurred with fire suppression may be delineated and, perhaps, underlying causes of change determined.

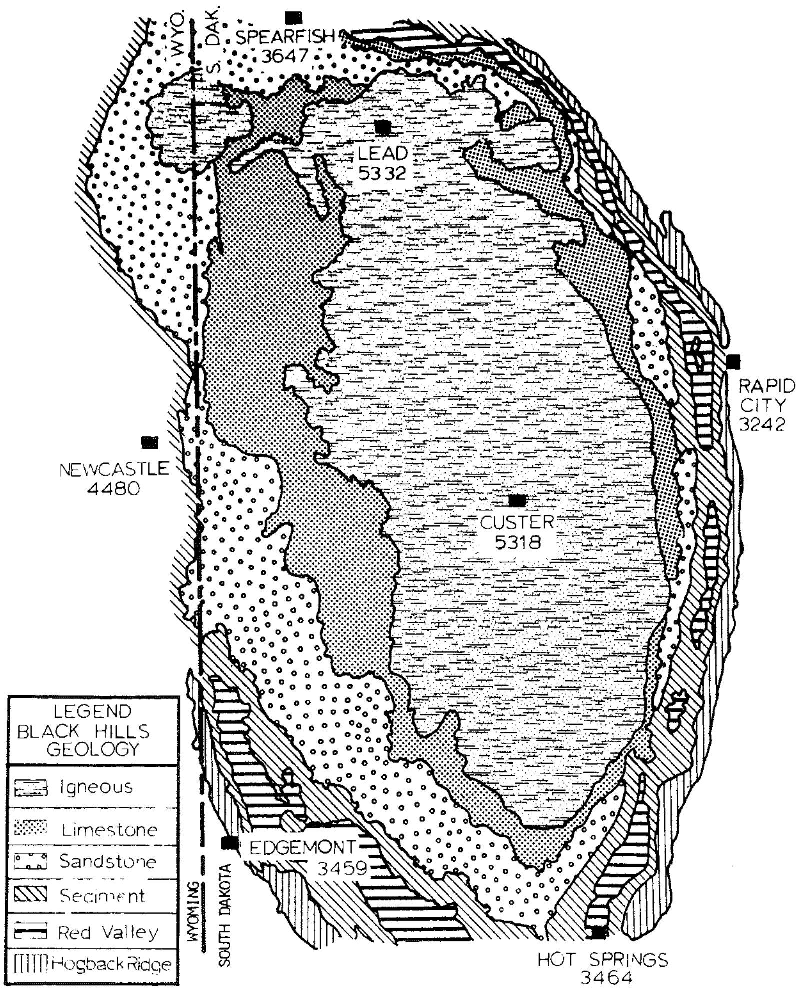

FIG. 2. Generalized geologic and topographic sketch of the Black Hills.

PHYSICAL DESCRIPTION OF THE BLACK HILLS

General Geology and Topography

Early explorers noted the most conspicuous topographical features of the Black Hills: the encircling Hogback Ridge and Red Valley, the Limestone Plateau, and the central area (Hayden 1862; Dodge 1876; Newton and Jenney 1880). A generalized geologic sketch is shown in Figure 2. Elevations range from about 3,200 to 7,242 feet at Harney Peak, the highest point in the United States east of the Rocky Mountains.

Exposed granites and metamorphic rock formations in the interior Black Hills occupy about 20 percent of the total Black Hills area (Orr 1959). This central core is labelled "igneous" in Figure 2. Surrounding the central core is the Limestone Plateau where outcrops of both limestone and sandstones occur depending on elevation (Fig. 2). The plateau is wider on the west than on the east, and western elevations are higher than most of the central area.

Almost completely encircling the Limestone Plateau to the outside, and several hundred feet lower in elevation, is the Red Valley which lies between the "inner hills" and the Hogback Ridge or outer rim (Fig. 2). Conspicuous because of its red soil color, the valley has also been known as the "Devil's Race Track." The Red Valley ranges in width from more than 2 miles to much less where strata dip steeply, and along the eastern side varies in elevation from 3,300 to 3,500 feet (McIntosh 1949).

The Hogback Ridge forms an outer wall enclosing the Black Hills (Fig. 2) and is broken only by many stream gaps. Throughout most of its length it is a single crested ridge of hard sandstone, presenting a steep face to the inner Red Valley, and on the outside sloping less steeply to the surrounding plains (McIntosh 1949). Near Rapid City the elevation of the Hogback Ridge is about 3,800 feet, but at Elk Mountain on the west side of the Hills it is about 4,900 feet. The outer slope, Red Valley, and steep inner face of the Hogback are visible in a subsequent photo (Fig. 4).

Vegetation: Then and Now

McIntosh (1949) stated that from a botanical standpoint the most important climatological difference between the Hills and surrounding country is that the Black Hills receive much more precipitation. He calculated the average annual precipitation at five foothills recording stations to be more than 19 inches, and 24.5 inches at three northern Hills stations. To the east of the Hills on the plains to the Missouri River, average annual precipitation is about 16 inches. North of the Black Hills it is about 14 inches, and to the west about 15.5

inches. Striking differences in vegetation in and around the Black Hills reflect these varying precipitation amounts.

Mixed Prairie grasslands of the surrounding, drier plains provide a sharp contrast to the forest cover in the more humid, cooler climate of the Black Hills. Ponderosa pine (*Pinus ponderosa*) dominates the forest cover on all but the cool, moist sites where white spruce (*Picea glauca*) grows in nearly pure stands (Orr 1959). Highest quality pine sites are found in the central and northern regions. On the outer slope of the Limestone Plateau, where precipitation is less than 18 inches annually, the pines become smaller and more profusely limbed. Hayward (1928) stated that pine grows in an open savannah and fails to develop mature [commercial] stands in the drier habitats, especially in the southern Hills. Ludlow's (1875) description of the southern Hills is appropriate today: ". . . scattering of pine . . . bordering hills low, with a few stunted pines."

Pre-settlement description of pine size or quality is sketchy. Ludlow's (1875) report mentioned that most of the pine was small, ". . . not more than 12 inches in diameter." Dodge (1876) briefly alluded to pine quality in describing the last few miles of the Rapid Creek drainage before it leaves the Black Hills (the area presently between the Rapid City limits and Dark Canyon): "The timber is generally poor, a very small percentage being fit for sawing." Later he confounds the record when describing the wide valley into which Rapid Creek flows about 2 miles before it leaves the Hills (the present area of Rapid City west of the Hogback Ridge) by stating: "The sides and summits of the hills are covered with forests of pine timber better than average." Presumably he was describing timber on the outer slope of the Limestone Plateau (adjacent to the Red Valley) and not that on the Hogback Ridge.

A section on "timber" was included in the report of Newton and Jenney (1880), geologists with the Dodge expedition of 1875. Perhaps theirs is the earliest detailed account of pine quality. They noted exceptionally large trees (100 feet high, 35 to 40 inches through at the ground) in the lower valley of French Creek. They added that "trees of these large dimensions are, however, rare in the Hills." Further detail included:

> Timber of from 12 to 24 inches diameter is common, while extensive tracts are covered by a dense forest of small slender pines from 50 to 60 feet high, and rarely less than 8 or more than 12 inches through at the ground.
>
> The pine forest . . . will furnish good saw logs from 30 to 50 feet in length . . ., averaging . . . from 12 to 20 inches through at the ground.

Description of pine quality today would differ little from those cited. Most everywhere in the Black Hills pine density is greater than when first viewed by early explorers, although "dense thickets of pine" were noted in early accounts. One may reasonably conclude that trees of sawlog quality, described by Newton and Jenney (1880), are fewer in number today than in the late 1800's. Logging has removed larger trees and second-growth stands are overly dense because of nearly complete fire protection.

Isolated occurrences of limber pine (*Pinus flexilis*) were reported by Thelinius (1970). Common in the northern Hills, especially on north-facing slopes, are quaking aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*). McIntosh (1949) described the birch-aspen association as a secondary succession subclimax resulting where pines were cut or destroyed by fire. Bur oak (*Quercus macrocarpa*) occupies as much area as quaking aspen in the northern hills, occurring in nearly pure stands of scrub-like trees. Large oak trees are common in drainages in the northern and eastern Hills.

Occurring along streams within and extending from the Black Hills are willows (*Salix* spp.), redosier dogwood (*Cornus stolonifera*), and water birch (*Betula occidentalis*). Other deciduous trees found in the Hills include elm (*Ulmus americana*), wild plum (*Prunus americana*), pin cherry (*Prunus pennsylvanica*), boxelders (*Acer* spp.), cottonwoods (*Populus* spp.), and mountain ash (*Sorbus scopulina*).

Along the outer slope of the Limestone Plateau are numerous rocky ridges which gradually or precipitously merge with the Red Valley. Predominantly warm season grasses occur on these ridges and adjacent uplands. McIntosh (1949) termed this grassland a "bunchgrass subclimax" forming an intermediate zone between Mixed

Prairie and pine forest. Little bluestem (*Andropogon scoparius*) is the dominant species. Other grasses of this essentially True Prairie association are big bluestem (*A. gerardi*), sideoats grama (*Bouteloua curtipendula*), Indiangrass (*Sorghastrum nutans*), prairie dropseed (*Sporobolus heterolepis*), prairie sandreed (*Calamovilfa longifolia*), stoneyhills muhly (*Muhlenbergia cuspidata*), hairy grama (*B. hirsuta*), and blue grama (*B. gracilis*).

Early explorers of the Black Hills briefly alluded to taller grasses on the outer slope, but no detailed vegetation description was made nor was pine encroachment mentioned. McIntosh (1949) conducted botanical field work in the Hills in summers of 1924 to 1930 and noted that pines were invading this grassland. Today, pine encroachment is most evident on areas of warm season grasses. Current research, to be discussed later, is focused on outer slope grasslands.

Ludlow (1875) merely noted that vegetation of the "red clay valley" was strikingly different from the Hills and "closely bordered by the open prairie." Dodge (1876) provided more detail of the Red Valley as follows:

> On the east side of the Hills the Red Valley is generally very narrow. . . . The climate is much warmer than that of the Hills . . . and the flora is very eastern. The soil . . . is very rich, and the whole country is covered with splendid grass.
> On the southeast, south, and southwest the Red Valley is generally narrow, dry, and sterile. The grass is poor, ...

Newton and Jenney (1880) stated that the inner edge of the Red Valley "marks with considerable accuracy the border of the timbered region of the Hills, though a few trees are in places scattered over its slope." The Valley was later labelled "undulating and treeless." Still later they noted that the Red Valley ". . . is generally well covered with the common short grass of the Plains, but is entirely destitute of trees, save that an occasional hill may sustain a few pines." The Red Valley is one of the most striking features of the region, according to Hayward (1928), "because of the red color of its soil and the absence of trees." Ponderosa pine encroachment into some areas of the Red Valley is quite evident today. Usually the trees germinate and survive on gravelly or rocky intrusions rather than on the finer-textured red soils of the Valley proper.

Vegetation of the Hogback Ridge was not described by early explorers. Hayward (1928) and McIntosh (1949) noted that open stands of ponderosa pine grow on the Hogback. Sandy soils derived from weathering sandstones support a "considerable growth of bunchgrass," according to McIntosh. A more detailed description of vegetation and soils of the Hogback north of the Hills is provided by Thompson and Gartner (1971). Western red cedar (*Juniperus scopulorum*) occurs on the Hogback in the southern and southwestern Hills.

Many living Black Hills pioneers have alluded to increased pine density and encroachment into grasslands adjacent to the Hogback Ridge. These changes have been documented by photographs taken 50 to 100 years ago and recently retaken (Phillips 1963; Thompson and Gartner 1971; Progulske 1972).

Forest Openings

Numerous large meadows or prairies dominated by grasses occur within the forested area of the Black Hills. Ludlow (1875) commented: "It is remarkable and characteristic of the hills that, in whatever direction we have wished to go, a creek-valley has always furnished a road." The upper Box Elder Creek area was described as ". . . prairie-like, undulating plains, . . . entirely treeless."

Dodge (1876) frequently mentioned " . . . many forest openings, larger or smaller, sometimes several miles in extent and very irregular in shape." He called these openings "parks," and attributed them almost wholly to fires. The process, according to Dodge, was as follows:

> A forest is destroyed [by fire]. In a few years another fire destroys the young growth . . . this happening several times at intervals of a few years, effectually destroys both roots and seeds, and converts pine forest into parks.

Various explanations for the occurrence of extensive grasslands within the forested area of the Black Hills were reviewed by White, et al. (1969). They concluded that soils in parks supported trees at one time and were not the sole environmental factor limiting pine establishment today. However, McIntosh (1949), postulated that some of the larger grassland parks in the Hills were "probably the direct result of soil conditions unfavorable for tree growth." He later cited the failure of replanted pine on one of the larger prairie areas (Bald Hills) as evidence to support his hypothesis. Admitting of insufficient data, McIntosh concluded that an accurate solution of the origin of Black Hills prairies could not be offered, although fire was suggested as a possible cause.

HISTORY OF FIRE IN THE BLACK HILLS AREA

Accounts written by the first white men to survey the Black Hills leave little doubt that fire was an important environmental and biological factor. Photographs taken at the time of the Custer expedition to the Black Hills (summer 1874), and recently retaken, verify the dramatic change in aspect, especially with regard to ponderosa pine (South Dakota Agr. Exp. Sta. 1971; Progulske 1972; Shideler 1972). These changes were coincident with nearly complete wildfire suppression following the establishment of the Black Hills Forest Reserve (in 1898) and rapid settlement of the region. Early settlers in the Hills area have related that exploitive timber cutting kept the pine forest open until restrictions limited timber harvest (Thompson and Gartner 1971).

The first explorers of the Black Hills frequently mentioned evidence of fires in the pine forests of the higher Hills. Ludlow's (1875) report of the Custer expedition included:

> There are few standing sound pines, but there seems to have been here, as in many other parts of the Black Hills region, very extensive fires, that have burned the former forest and left the charred trunks and limbs scattered on the surface . . . We have passed some pretty good . . . pine, but by far the greatest portion is small, . . . and lowbranched. A great many of the trunks are scarred by former fires.

Post-fire succession and recurrent fire in the same area was later alluded to by Ludlow:

> Fires have destroyed the trees, so that almost everywhere there is a growth of small aspens, with a few other shrubs. There are also a great many small pines and aspens, 10 to 20 feet long, lying dead on the ground, prostrated by wind from the northwest,

some are half burned; but most of them appear to have been dead when they fell.

Upon searching for an exit from the rugged Hills on the Limestone Plateau (in the present area near Blackhawk) Ludlow stated: "The open country mentioned is rolling, and has formerly been covered with pines, as shown by an occasional dead trunk."

Dodge (1876), in addition to frequent mention of parks (previously stated), also frequently used the terms "dense dark forests," "dense jungle," and "densely covered with thickets of pine." Timber and fire was described as follows by Colonel Dodge:

> Throughout the Hills the number of trees which bear the marks of the thunderbolt is very remarkable, and the strongest proof of the violence and frequent recurrence of these storms. . . . The woods are frequently set on fire and vast damage done. There are many broad belts of country covered with the tall straight trunks of what was only a short time before a splendid forest of trees . . . The largest of these fires occurred on the head waters of Box Elder Creek. What was evidently a beautiful body of timber fifteen miles long by at least five broad, is now only dead trunks, some standing, . . . the larger portion prostrate . . . making travel through them a trial. . . .

Newton and Jenney (1880) also emphasized the effect of fire on the forest:

> Severe thunderstorms prevail in the Black Hills during the summer months . . . lightning is . . . liable to strike the ground. . . . This causes some damage to the timber of the region. Often . . . trees showing unmistakable marks of lightning would be seen, . . .

The frequency of thunderstorms and lightning were alluded to as follows:

> It would seem that the pines growing in certain portions of the Hills were peculiarly liable . . . to be struck by lightning. On a hill near the headwaters of Spring Creek I counted twelve trees, growing on about two acres of ground, that were marked by lightning, and in a small park near by, among about one hundred trees, fourteen had been struck in previous years; some of them more than once.

The extent of fires in the Black Hills and their effect on maintaining grassland parks within the forest was also described by Newton and Jenney (1880):

> The Black Hills have been subjected in the past to extensive forest fires, which have destroyed the timber over considerable area. Around Custer Peak and along the limestone divide, in the central portion of the Hills, on the headwaters of the Box Elder and Rapid Creeks, scarcely a living tree is to be seen for miles. . . . Some portions of the parks and valleys, now destitute of trees, show by the presence of charred and decaying stumps that they were once covered by forest, but generally the pine springs up again as soon as it is burnt off, though sometimes it is succeeded for a time by thickets of small aspens.

Early residents of the plains outside the Black Hills have mentioned the glow of flames in the sky over the Hills almost every night of the summer. McIntosh (1927) suggested both the important role of fire and the emphasis placed on fire control in the early 1900's:

> Within the last 50 years man, fire and the Black Hills beetle have been the most potent agents in altering the Black Hills flora . . . Fire has always been one of the forest's worst enemies. Although the United States Forest Service maintains lookouts in the Black Hills forests during the summer and carries on an active educational program against forest fires, fires are still all too frequent.

The probable effect of fire in maintaining large or small grassland parks within the forested area of the Black Hills has previously been discussed. Occurrence of fire in the foothill region, the Red Valley or the Hogback Ridge area was not mentioned in accounts of early explorers. That wildfires occurred in these areas is highly probable.

Biswell (1967) and others have reported that Indians deliberately burned forests in the Sierra Nevada and other mountain regions. While plains Indians apparently burned the grasslands for various reasons, it appears doubtful that they burned the Black Hills forests. Smoke from grass fires set by Indians obscured the view to the south and west from the top of Inyan Kara Mountain (west of the Hills) according to Ludlow (1875). He also reported that Indians burned the prairie ahead of the expedition for 8 consecutive days (about 200 to 250 miles) on the return to Fort Lincoln (North Dakota).

Evidence suggesting that Indians tended to avoid the Black Hills was presented by Dodge (1876). One Indian, interviewed through an interpreter, stated that although he was 50 years old, and had been around the Hills nearly every day of his life, "He had never before ventured inside." He further stated that at times squaws cut lodge-poles and bucks sometimes ventured into the Hills to hunt, "but that these stops are very short." His reasons for Indians not entering the Black Hills were: "The Hills were 'bad medicine,' and the abode of spirits," (2) there was no reason to enter except for lodge-poles; game was scarce and "more difficult to kill than that on the plains," (3) the thickets were "so dense that their ponies were lost if turned loose," and flies so bad that they were "tormented and worried out if kept tied up" (4) frequent rains were not liked by Indians, and (5) "that it thunders and lightnings with terrible force, tearing trees to pieces and setting fire to the woods."

As mentioned earlier, the most active ponderosa pine encroachment is on the outer slope of the Limestone Plateau (at the transition into the Red Valley) and on the Hogback Ridge. One foothills area landowner, the late Francis Murphy (see acknowledgments), estimated that the pine margin had moved about 1½ miles from the outer slope to the outside of the Hogback in his lifetime (58 years).

Thus, there is pine encroachment in the forest-grass ecotone of both the higher Black Hills and in the foothill region. The research reported herein is specifically directed toward the problem of pine encroachment into adjacent grasslands in the foothills area.

CURRENT RESEARCH IN THE FOOTHILLS FOREST-GRASS ECOTONE

Nearly all the land in the foothill region (including the outer slope, Red Valley, and Hogback Ridge) is privately owned. Livestock grazing is the principal use (Fig. 3). While ponderosa pine has probably always occurred in this area, the stands were formerly open. Most trees are of low quality. Some are suitable for pulpwood, but most are unfit for saw logs. Many landowners consider these pines as "plants out of place" which restrict production of herbaceous vegetation. Increasing stand densities and further invasion of the

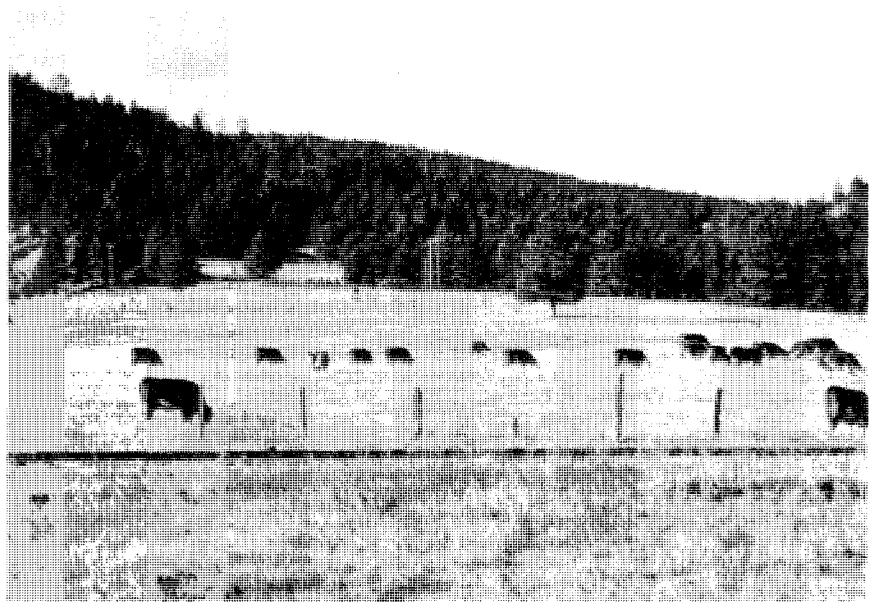

FIG. 3. Most foothill rangelands are privately-owned and used for winter livestock grazing. About 100 years ago pine in the foothills was described as open, with scattered trees. Now the stands are closed and dense with little understory vegetation.

grasslands occurred almost unnoticed by most landowners. If lower forage production or species composition changes were noticed, a solution to the problem was not devised because there was virtually no market for such low quality pine. A few landowners simply felled the invading pines in an attempt to improve forage for grazing livestock. One such attempt was recently reported by Thompson and Gartner (1971).

The demand for pulpwood in recent years has led to many thinning opreations on private lands. Landowners felt that harvesting the pulpwood would not only provide some economic return, but would also open the stand and permit increased forage production.

Both methods of removing invading pine trees accomplished the major objective, i.e. increasing forage production. However, succeeding management problems resulted. Thinning improved germination of many thousands of pine seeds, and survival of newly germinated seedlings was more successful apparently because herbaceous vegetation offered less competition for light, water, and nutrients than did the previous overstory of trees. The result in a few years following thinning was a dense stand of vigorous pine seedlings or saplings.

Slash dropped to the ground by thinning creates excessive fuels which increases the potential fire danger, inhibits grazing animals, and decomposing slash, especially pine needles, may inhibit grass growth. Aesthetic values are also diminished.

Much of the foothills pine range is used for wintering pregnant cows. Pine needle consumption by cows in late pregnancy has long been suspected of causing abortion. While thinning of pine stands has been suggested as a preventative measure, cows consuming fresh slash, or young pine seedlings, or both continue to abort calves. Other adverse effects of encroaching and ever-increasing pine stand densities were cited by Thompson and Gartner (1971).

Investigations in the Use of Fire for Managing Foothills Pine Grassland

Research was initiated in 1970 to study the ecology of ponderosa pine in the foothills region of the Black Hills. Included within the framework of the project was the potential use of fire in managing foothills vegetation resources. Goals included the study of controlled burning for the following purposes:

1) To reduce established pine seedlings in grasslands.
2) To reduce dense stands of seedlings and fine fuels (needles, twigs, and cones) as a pre-thinning practice.
3) To reduce post-thinning fuels.
4) To remove accumulations of dead grass residue in order to hasten nutrient recycling, green-up in spring, and improve grazing use.

Since techniques for burning in the Black Hills had not been established or even attempted, two small controlled burns were conducted in the late spring of 1970. One was in dense (dog-hair) pine, the other in an opening invaded by pine. It was soon discovered that techniques established by Biswell (1963) in California were applicable in foothills pine stands of the Black Hills. Pre-ignition climatological guidelines suggested by Biswell were also followed.

Burning for pine seedling reduction in June, 1970, was found to be impractical. Herbaceous fuels would not burn readily nor was enough heat created to kill pine seedlings because of the abundance of green forage.

Closer observation of the forest-grass ecotone along the eastern foothill region indicated that pine encroachment appeared to be restricted to a particular vegetation type or range soil group. Pine seedlings were numerous and invasion obvious in the bluestem type found on shallow, coarse textured soils. Conversely, there was no encroachment on adjacent finer-textured soils, occupied by western wheatgrass (*Agropyron smithii*) and its associates (Fig. 4). Pearson

FIG. 4. Pine encroachment on the outer slope of the Black Hills and in the Red Valley viewed from the Hogback Ridge. Bluestem sites (letter B) actively invaded by pine are darker shaded. Wheatgrass sites (letter A) are not invaded by pine and appear lighter in the photo.

(1923) reported yellow pine reproduction in the southwest was better on "coarser, sandy, gravelly, or stony soils than on finer soils regardless of origin."

Suspected differences in grass densities, season of growth, and soil textures between the two vegetation types were thought to prohibit pine seed germination in the western wheatgrass type. The point-centered quarter method for sampling grassland vegetation (Dix 1961) was used to compare vegetation attributes of a bluestem site with an adjacent western wheatgrass site. Both types were in the same pasture which had a recent history of light grazing.

Fifty points were systematically located at 2-foot intervals along 100-foot transects in each type. Each point was the locus of four quadrants (sample plots) in which distance from the locus to the

TABLE 1. AVERAGE RELATIVE FREQUENCY (%) AND ABSOLUTE DENSITY (SHOOTS/M^2) FOR SPECIES OCCURRING ON A BLUESTEM SITE AND ON A WHEATGRASS SITE ON THE OUTER SLOPE OF THE LIMESTONE PLATEAU, MURPHY RANCH, PENNINGTON COUNTY, SOUTH DAKOTA.

Species	Relative Frequency	Absolute Density
Bluestem Site		
Little bluestem	34.9	461.0
Hairy grama	15.6	135.9
Sideoats grama	15.6	131.0
Aster	7.3	82.5
Prairie junegrass	6.4	38.8
Big bluestem	4.6	29.1
Sedges	4.6	24.3
Blacksamson echinacea	3.7	19.4
Prairie dropseed	2.7	19.4
Stoneyhills muhly	1.8	14.6
Blue grama	1.8	9.7
Hoods phlox	0.9	4.8
Totals	99.9	970.5
Wheatgrass Site		
Blue grama	39.1	1525.7
Western wheatgrass	24.3	537.6
Japanese brome	23.5	595.7
Sedges	6.1	130.8
Needleandthread	4.3	72.6
Rose	0.9	14.5
Dotted gayfeather	0.9	14.5
Cudweed sagewort	0.9	14.5
Totals	100.0	2905.9

nearest rooted stem was recorded. Pine seedlings were counted in three, 10 × 100-foot belt transects in each type.

Relative frequency and absolute density were calculated for each species encountered (Table 1). Obvious vegetation differences include: (1) bluestems did not occur in the western wheatgrass type, and vice versa; (2) of the nine grasses and grass-like plants recorded in the bluestem type, all were warm season species except prairie Junegrass (*Koeleria cristata*) and sedges (*Carex* spp.); (3) blue grama was the only warm season species occurring in the western wheatgrass type, and the only grass which occurred in both types; (4) Japanese brome (*Bromus japonicus*) occurred only in the western wheatgrass type. Pine seedlings, not shown in the table, averaged 3,000 per acre in the bluestem type, but none were found in the western wheatgrass type. We concluded from this pilot study that:

1. The bluestem type consists primarily of warm season species which begin growth in May, after pine seedlings have initiated growth. Conversely, most species in the western wheatgrass type are cool season, directly competing with pine seedlings for moisture and nutrients at the same season.

2. The growth form of western wheatgrass, blue grama, and associated species makes establishment of pine seedlings difficult, if not impossible. Conversely, the bluestem type is "open" enabling successful germination and growth of pine seedlings. Differences in total absolute density between the two sites (2,906 shoots per m^2 in the wheatgrass type vs. 970 in the bluestem type) emphasize the "available space" concept favoring pine seedling establishment in the bluestem type.

3. Japanese brome, an invading winter annual, does not occur in the bluestem type. Rapid water infiltration in coarser soils presumably limits soil moisture for this shallow-rooted species which germinates in fall or very early spring. Pine seedlings, on the other hand, are able to rapidly extend a tap root downward to reach available soil moisture. Hence, the latter can successfully become established in most years of normal precipitation. Extremely high frequency and density values for blue grama can be attributed to the tillering habit

of that species. Prolific-seeding annuals, such as Japanese brome, may also be over-estimated by this sampling method.

Controlled Burning in Bluestems for Pine Seedling Reduction

Three controlled burns in bluestem grassland were conducted in late spring of 1971. The first was burned 24 April on the outer slope of the Limestone Plateau on the outskirts of Rapid City. Specifically planned to reduce flash fuels and potential fire danger in a low density, high valuation residential area, this fire was carefully set and controlled. Strip burning was used only where trees were not endangered.

Pre-burn data was collected along three 100-foot transects located across the slope at the upper, middle, and lower portions of the area to be burned. Transects 1 and 3 were located in rather open, bluestem grassland (Fig. 5), while transect 2 went through a rather dense group of pines.

Pine seedlings were counted in 38, one-m^2 sampling units systematically located along each transect. Herbaceous vegetation, mulch, and pine litter were collected in two, 30-cm^2 sampling units within each of five, one-m^2 frames.

Pine seedling mortality averaged 79 percent (Table 2). Note that seedlings were more abundant and mortality higher in transects 1 and 3 where herbaceous fuels were greatest. Fuels under the pines along transect 2 were moist. Lower pine seedling mortality (43 percent) and fuel reduction percentages reflect the incomplete burn occurring there.

Nearly all herbaceous vegetation and portions of a heavy mulch layer were consumed by the fire in the open grassland areas of the burn. Fuel reduction was considerably greater in the open grassland areas than under the pine canopy. However, fuel reduction percentages in Table 2 do not reflect complete consumption because seasonal forage production is included in the post-burn fuel weights.

A small area (50 $\times$ 50 ft) was left unburned in the middle of the burn to compare forage production and composition changes in the growing season immediately after the burn. Total forage production did not differ in plots clipped after the growing season (1,858 and 1,863 lb per acre in the unburned and burned areas, respectively).

TABLE 2. PINE SEEDLING MORTALITY AND REDUCTIONS IN GROUND FUELS SAMPLED ALONG THREE TRANSECTS BEFORE (6 APRIL) AND AFTER (9 SEPTEMBER) CANYON LAKE HEIGHTS BURN OF 24 APRIL 1971. TRANSECTS 1 AND 3 WERE OPEN GRASSLAND; TRANSECT 2 IN PINE UNDERSTORY.

	Transect 1 (Grassland)	Transect 2 (Pine Understory)	Transect 3 (Grassland)	Average
Pine seedlings (no. per acre)				
Pre-burn	13,104	5,753	5,540	8,132
Post-burn	852	3,303	852	1,669
Mortality, %	93	43	85	79
Ground Fuels (lb. per acre)				
Herbaceous vegetation				
Pre-burn[1]	4,236	1,114	3,544	2,965
Post-burn	2,158[2]	999[3]	1,852[4]	1,670
Fuel reduction, %	49	10	48	44
Pine litter				
Pre-burn	457	9,236	115	3,269
Post-burn	113	6,535	18	2,222
Fuel reduction, %	75	29	84	32

[1] Includes standing dead vegetation and mulch.
[2] Includes 1971 forage production + 1047 lb. unburned residue.
[3] Includes 1971 forage production + 791 lb. unburned residue.
[4] Includes 1971 forage production + 572 lb. unburned residue.

Species composition was essentially the same in both the burned and unburned areas as shown in Table 3.

TABLE 3. SPECIES COMPOSITION (PERCENT BY WEIGHT) IN ADJACENT BURNED AND UNBURNED BLUESTEM GRASSLAND AREAS, CANYON LAKE HEIGHTS (BURNED 24 APRIL, 1971; SAMPLED 20 SEPTEMBER, 1971).

	Unburned	Burned
Little bluestem	85.3	51.4
Big bluestem	*	30.3
Sideoats grama	4.4	5.6
Hairy grama	1.6	0.3
Prairie junegrass	1.1	0.9
Needleandthread	0.7	1.2
Western wheatgrass	0.0	0.4
Sedges	4.3	2.8
Rose	0.7	0.0
Forbs	2.0	7.1
Totals	100.1	100.0

* Little and big bluestem not separated by species.

The second, spring 1971, fire was conducted on 29 April on a ranch 20 miles south of Rapid City. This area was also on the outer slope and site conditions were similar to the first area burned, but less fuel was available due to grazing. Pine seedling numbers averaged 1,000 and 3,000 per acre on level areas and slopes, respectively. On the former only 50 percent of the seedlings were destroyed with taller seedlings undamaged. Where an up-slope, head-fire was permitted, however, seedling mortality was 70 percent (Fig. 6).

Another bluestem burn was conducted on 1 May, 1971, on a ranch just north of the Black Hills on the Hogback Ridge. High range condition and no grazing the previous summer provided optimum fuel conditions. The fire was permitted to burn uphill in order to destroy the larger seedlings. The burn accomplished that objective. Productivity of little bluestem appeared to have been reduced for the 1971 growing season because warm season grasses had greened-up

FIG. 6. Post-burn view of 29 April 1971, burn on Murphy ranch taken shortly after smoke had cleared. Pine seedling mortality was highest where the fire burned up-slope (foreground). Though not readily apparent, all seedlings and two saplings in foreground were killed in the burn.

FIG. 7. Fully stocked stand of ponderosa pine on a high quality foothills pine site photographed 9 November 1970. Area was burned 14 April 1971, as a pre-thinning treatment to reduce ground fuels and kill pine seedlings.

and were actively growing. Forage production was not sampled because plots were disturbed.

BURNING FOR MANAGEMENT OF PINE AND GRASS

A controlled burn on a high quality foothills pine site was conducted in mid-April, 1971. In this fully-stocked stand on a north-facing slope controlled burning was designed as a pre-thinning treatment to remove fuel accumulations on the ground (Fig. 7).

Two treatments (burned and unburned) were randomly assigned to each of two replications (one up-slope, the other adjacent and down-slope). Plots were 100 $\times$ 100 feet in size. Within each treatment intensive pre-burn sampling was conducted along a permanent line transect to obtain information on pine seedling density, amount and kind of understory vegetation, and ground fuel loads.

The fire was ignited in pine needles along the upper side of each

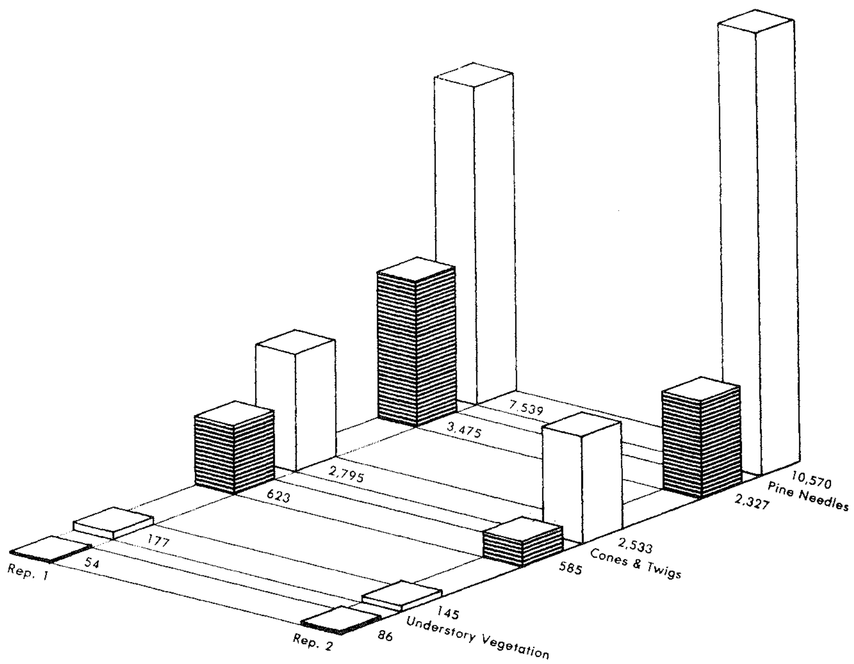

FIG. 8. Components of ground fuels in two replications before (clear bars) and after (striped bars) a control burn in a fully stocked stand of ponderosa pine 20 miles south of Rapid City, South Dakota.

burn plot and back-fired downhill. Once a blackened area about 20 feet wide existed up-slope from the line of fire, strip burning was used to hasten completion of the burn.

Pine seedlings averaged 23.5 per m^2 (95,150 per acre), but as many as 60 seedlings were counted in one square meter plot. Pine seedling mortality was nearly 100 percent. Pre-burn fuel loads averaged between 5 and 6 tons per acre and were reduced by 70 percent (Fig. 8). Pine needles comprised the largest portion of fuels, although woody fuels larger than 2 inches diameter were not weighed.

Percentage composition and frequency of understory vegetation were determined 6 months before the burn (October, 1970) using the point quadrat method. In each treatment 1,000 points were recorded using a 10-pin frame. The frame was randomly located along 10 lines drawn perpendicular to the 100-foot permanent line transect bisecting each treated area.

Approximately 4 months after the burn (August, 1971), students in a range management summer class sampled the burned and unburned areas. Frequency determinations were made by randomly locating 100, 9.6 ft^2 circles. The same species were not encountered with this sampling unit as with the point method, and only species identifiable by all class members were recorded.

Composition of understory vegetation did not differ greatly be-

TABLE 4. AVERAGE PRE-BURN (OCTOBER, 1970) SPECIES COMPOSITION AND FREQUENCY AND POST-BURN (AUGUST, 1971) FREQUENCY PERCENTAGES OF PONDEROSA PINE UNDERSTORY USING TWO SAMPLING METHODS ON THE HART RANCH, PENNINGTON COUNTY, SO. DAK.

Date:	October 1970				August 1971	
Method:	Point Frame				9.6 ft^2 Circle	
Treatment:	Control	Burn	Control	Burn	Control	Burn
	(Composition, %)		(Frequency, %)		(Frequency, %)	
Grasses and Sedges:						
Sedges	48.5	56.0	43	44	89	90
Prairie dropseed	17.2	19.1	16	14	—	—
Needlegrasses	3.8	3.6	5	4	12	5
Littleseed ricegrass	1.3	1.8	2	2	14	1
Big bluestem	2.4	0.9	3	1	17	6
Wheatgrasses	1.6	0.0	3	1	3	14
Other grasses	6.7	1.9	8	2	0	0
Forbs:						
Missouri goldenrod	1.9	1.8	3	2	17	28
Anemone	—	—	—	—	5	14
Bluebell bellflower	—	—	—	—	0	7
Narrowleaf goosefoot	—	—	—	—	0	7
Vetch	—	—	—	—	3	15
Phlox	1.3	0.9	1	1	—	—
Spikemoss selaginella	0.4	1.9	1	1	—	—
Other forbs	2.0	3.6	3	4	—	—
Shrubs:						
Leadplant	10.0	5.0	13	6	45	44
Western snowberry	2.0	0.5	2	1	—	—
Skunkbush sumac	0.0	2.2	0	2	2	2
Currant	0.4	0.9	1	1	—	—
Common chokeberry	—	—	—	—	9	11
Rose	0.4	0.0	1	0	6	3
Totals	99.9	100.1				
Ponderosa pine seedlings:	—	—	27	36	75	3

tween treatments as noted in Table 4. While not shown in the table, composition was also virtually the same between replications. Grasses and sedges comprised the bulk of the understory (about 80 percent). Forbs and shrubs comprised the remaining 20 percent in nearly equal proportions.

Pre- and post-burn vegetation frequencies are not comparable due to the difference in size and shape of sampling units. On the same sampling date, using the same techniques, comparisons between treatments are valid. For example, the only apparent difference between treatments at the October, 1970, sampling date was in the percentage frequency of shrubs. Leadplant (*Amorpha canescens*) was more common in the unburned (control) treatments than in the plots to be burned. Following the burn, however, it appears evident that more forbs occurred in the burned areas than in the unburned areas. Field observations in 1971 tend to support this conclusion. Burning did not appear to affect the frequencies of grasses, sedges, or shrubs. Some grass species appear to have responded negatively to the burn, while wheatgrasses may have been favored.

Ponderosa pine seedling frequency between treatments at the August, 1971, sampling date was quite different. The nearly complete reduction of pine seedlings by the fire was previously mentioned.

Temperatures were monitored in one grassland fire and one fire in pine understory. Heat indicating crayons striped on 10×15 cm aluminum plates wrapped in foil were inserted vertically into the soil. At least 5 cm of each plate extended above the litter and 5 cm below the decomposition layer into mineral soil.

In the grassland burn (24 April, 1971), maximum temperatures above the soil surface were 400° F. Temperatures in the mulch layer ranged between 175 and 275° F, and did not exceed 200° F in mineral soil.

Higher temperatures were recorded at all locations in the pine litter burn. (14 April, 1971). Temperatures of 325 to 650° F were recorded immediately above the surface litter. In the layer of undecomposed pine needles, temperatures ranged from 225 to 450° F, and 200° to 350° F in the decomposition layer. Maximum temperatures in the mineral soil were 325° F at the surface, but no greater than 150° F at a depth of 5 cm. None of the fires thus far attempted, either in pine-grassland or in pine understory, have killed large pine trees (taller than 6 ft).

SUMMARY AND CONCLUSIONS

Historically, there has always been a zone of tension between forest and grassland. Woody and herbaceous vegetation have competed with each other on most every continent. Their struggle for light, water, and nutrients has at times and on certain sites favored one kind of vegetation over the other because of differences in climate, soil, and topography. In most cases where the actions of man have directly or indirectly caused herbaceous vegetation to regress by overgrazing or by near total exclusion of natural fires, woody plants have increased and, in many cases, become dominant. Explorers of the Black Hills alluded to the role of fire in maintaining open grassland (parks) within the ponderosa pine forest. Fire was also a contributing factor in restricting pine encroachment into foothill grasslands.

In the past, most forest managers have been reluctant to utilize fire as a management tool, but that attitude appears to be rapidly changing. Controlled burning in the foothill region of the Black Hills has been successfully demonstrated as a useful practice for maintaining high quality grasslands and reducing potentially dangerous ground fuel accumulations. Under a new approach to vegetation management, which should include the use of fire, benefits to society will accrue in the form of more productive grasslands with maximum diversity, more productive forests with botanically diverse understory, better wildlife habitat, increased water production, decreased cost of wildfire protection, and aesthetic enhancement of both grassland, forest, and overall scenery,

Research on the uses of fire as a management tool in the Black Hills area is relatively new. Limited controlled burning in 1970 and 1971 in the pine-grass ecotone of the eastern foothills area has indicated that:

1. Controlled burning is manageable in the spring and should also be usable in fall and winter depending on weather and moisture conditions of fuels and soils. In general, temperatures should be 70° F

or less, relative humidity 35 percent or greater, and winds 15 mph or less.

2. Controlled burning in bluestem grasslands for reducing invading pine seedlings is practical and will not reduce forage production (if burning is done before 1 May in most years), but will reduce ground fuels. Thus, fire appears useful to livestock managers, forest managers, and foothill residential landowners.

3. Light grazing or complete deferment prior to burning may be necessary on some bluestem ranges to assure an adequate fuel supply to kill pine seedlings.

4. Following a spring burn in bluestem grassland, the start of grazing may have to be delayed 1 to 4 weeks depending on post-burn weather, especially precipitation.

5. Head-fires or up-slope fires in bluestem grasslands are more successful for killing pine seedlings than back-fires or fires on level sites.

6. Small pine seedlings in pine understory are easily killed by either slow burning back-fires or by head-fires.

7. Controlled burning before thinning or logging is advisable to reduce pine seedling numbers and ground fuel accumulations.

8. Current and forecasted weather conditions must be carefully studied before igniting controlled burns.

Public support of controlled burning research and the application of fire as a management tool is vital. Public and private tours of the study areas have been frequent. Local newspaper coverage has been excellent and most helpful for obtaining public understanding of controlled burning even in the face of federal, state, and local efforts to strengthen air quality legislation.

Federal and state land management agencies in the Black Hills only recently considered using controlled burning as a management tool. Some are now planning or actively using fire to reduce pine encroachment, consume logging slash, improve big game range, and thin unproductive dog-hair pine stands. Landowners have frequently requested assistance in order to begin a controlled burning program. To be successful on private lands in the Black Hills area, controlled burning must be a cooperative effort of researchers, landowners, and state and federal agency personnel and fire-fighting equipment. Also imperative is a joint liability agreement in the event a controlled fire burns adjacent land owned or managed by another party. Just as the private landowner has recognized Nature's wrath when wildfires have burned from federal lands onto private lands, landowners using controlled burning should be protected by agreement or legislation if a fire accidentally gets out of control and burns adjoining federal or state land.

ACKNOWLEDGMENTS

Research reported in this paper was supported in part by the McIntire-Stennis Cooperative Forestry Research Program through the South Dakota State University Agricultural Experiment Station. The authors wish to acknowledge the following landowners for making the studies possible: Mr. & Mrs. R. D. LaCroix, Mr. & Mrs. Francis Murphy, Mr. & Mrs. Bill Thompson, and Western Cattle Company (Dan Lindblom, Area Supervisor). We also thank the Cleghorn, Hayward, and Hermosa volunteer fire departments for the use of fire-fighting equipment. The senior author is especially grateful for suggestions, support, and publicity offered by Dr. Harold H. Biswell and Dr. E. V. Komarek, Sr.

APPENDIX

Alphabetical list of plant species listed in Tables 1, 3, and 4. Common and scientific names follow the nomenclature recommended by Alan A. Beetle (*Recommended Plant Names*. Univ. Wyoming Agr. Exp. Sta. Res. J. 31. 1970).

Grasses and Grass-like Plants:
- Big bluestem (*Andropogon gerardi*)
- Blue grama (*Bouteloua gracilis*)
- Hairy grama (*Bouteloua hirsuta*)
- Japanese brome (*Bromus japonicus*)
- Little bluestem (*Andropogon scoparius*)
- Littleseed ricegrass (*Oryzopsis micrantha*)
- Needleandthread (*Stipa comata*)
- Needlegrasses (*Stipa* spp.)
- Prairie dropseed (*Sporobolus heterolepis*)
- Prairie junegrass (*Koeleria cristata*)
- Sedges (*Carex* spp.)
- Sideoats grama (*Bouteloua curtipendula*)

Stoneyhills muhly (*Muhlenbergia cuspidata*)
Western wheatgrass (*Agropyron smithii*)
Wheatgrasses (*Agropyron* spp.)

Forbs:
Anemone (*Anemone* spp.)
Aster (*Aster* spp.)
Blacksamson echinacea (*Echinacea angustifolia*)
Bluebell bellflower (*Campanula rotundifolia*)
Cudweed sagewort (*Artemisia gnaphalodes*)
Dotted gayfeather (*Liatris punctata*)
Hoods phlox (*Phlox hoodii*)
Missouri goldenrod (*Solidago missouriensis*)
Narrowleaf goosefoot (*Chenopodium leptophyllum*)
Phlox (*Phlox* spp.)
Spikemoss selaginella (*Selaginella densa*)
Vetch (*Vicia* spp.)

Woody Plants:
Common chokecherry (*Prunus virginiana*)
Currant (*Ribes* spp.)
Leadplant (*Amorpha canescens*)
Rose (*Rosa* spp.)
Skunkbush sumac (*Rhus trilobata*)
Western snowberry (*Symphoricarpos occidentalis*)

LITERATURE CITED

Biswell, H. H. 1963. Research in wildland fire ecology in California. Proc. Tall Timbers Fire Ecology Conf. no. 2, pp. 62–97.

Biswell, H. H. 1967. The use of fire in wildland management in California. *In* S. V. Ciriacy-Wantrup and J. J. Parsons [ed.] Natural Resources: Quality and Quantity. Univ. California Press, Berkeley and Los Angeles. pp. 71–86.

Dix, R. L. 1961. An application of the point-centered quarter method to the sampling of grassland vegetation. J. Range Manage. 14(2):63–69.

Dodge, R. I. 1876. The Black Hills. (Reprint, 1965). Ross and Haines, Inc., Minneapolis, Minn. 155 p.

Hayden, F. V. 1862. On the geology and natural history of the upper Missouri. Trans. American Philos. Soc. 12, Part 1. Philadelphia, Pa.

Hayward, H. E. 1928. Studies of plants in the Black Hills of South Dakota. Bot. Gaz. 85(4):353–412.

Johnson, H. N. 1949. A climatological review of the Black Hills. South Dakota School of Mines and Technology, Black Hills Eng. 29(1):3–25.

Ludlow, W. 1875. Report of a reconnaissance of the Black Hills of Dakota. United States Gov't Printing Off., Washington, D.C. 121 p.

McIntosh, A. C. 1927. Some sources of the Black Hills flora. South Dakota School of Mines and Technology, Black Hills Eng. 15:38–44.

McIntosh, A. C. 1949. A botanical survey of the Black Hills of South Dakota. South Dakota School of Mines and Technology, Black Hills Eng. 28(4):3–74.

Newton, H. and W. P. Jenney. 1880. Report of the geology and resources of the Black Hills of Dakota. United States Geog. and Geol. Survey, Rocky Mountain Region. U.S. Gov't Printing Off., Washington, D.C. 566 p.

Orr, H. K. 1959. Precipitation and streamflow in the Black Hills. United States Forest Serv. Rocky Mountain Forest and Range Expt. Sta., Sta. Paper no. 44. 25 p.

Pearson, G. A. 1923. Natural reproduction of western yellow pine in the southwest. United States Dep. Agric. Bull. 1105.

Phillips, W. S. 1963. Vegetational changes in the Northern Great Plains. Agric. Exp. Sta., Univ. of Arizona. Rep. 214. 185 p.

Progulske, D. R. 1972. Passport to 1874. South Dakota State Univ. Agr. Exp. Sta., Brookings. South Dakota Farm & Home Res. 23(2):17–35.

Shideler, F. J. 1972. One hundred year old photos and present research combine to show Black Hills forests then and now. Dakota Farmer 92(6):18–20. (Published in Aberdeen, S.D.).

South Dakota Agric. Exp. Sta. 1971. General Custer and forest management. 84th annual report South Dakota State Univ. Agr. Exp. Sta., Brookings. South Dakota Farm & Home Res. 22(4):49–51 + cover photos.

Thelinius, J. F. 1970. An isolated occurrence of limber pine (*Pinus flexilis* James) in the Black Hills of South Dakota. American Midl. Naturalist 84(2):411–417.

Thompson, W. W. and F. R. Gartner. 1971. Native forage response to clearing low quality ponderosa pine. J. Range Manage. 24(4):272–277.

United States Dept. of the Interior. 1967. Natural resources of South Dakota. Supt. of Documents, United States Gov't. Printing Office, Washington, D.C. 72 p.

White, E. M., J. R. Johnson, and J. T. Nichols. 1969. Prairie-forest transition soils of the South Dakota Black Hills. Proc. Soil Sci. Soc. America 33(6):932–936.