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The Role of Prescribed Burning in Regenerating *Quercus macrocarpa* and Associated Woody Plants in Stringer Woodlands in the Black Hills, South Dakota

Carolyn Hull Sieg[1] and Henry A. Wright[2]

[1]Rocky ***Mountain Forest and Range Experiment Station, SDSM&T Campus***
501 E. St. Joseph Street, Rapid City, South Dakota USA 57701
Tel. 605 394 1960; Fax 605 394 6627

[2]***Texas Tech University, Lubbock, Texas***

Abstract. Throughout the range of *Quercus macrocarpa,* fire historically played an important role in maintaining ***Quercus stands.*** However, little is known about the role of fire in maintaining stringer *Quercus stands* on the western edge of its distribution. This research suggests that prescribed burning could be used to rejuvenate woody plants in *Quercus* woodlands. Relative to unburned areas, there were more ($p < 0.1$) *Quercus*, *Fraxinus pennsylvanica* and *Acer negundo* sprouts following spring burning. However, *Quercus* seedling density did not increase ($p = 0.22$) relative to unburned sites, and changes in the density of woody understory species in response to burning were erratic. Dormant season burning has some appeal from a fire control point of view and because carbohydrate reserves in woody plants are high during this time. However, if the objective is to regenerate woody plants and/or mimic historical fires, prescriptions should be set to achieve high intensities.

Keywords: ***Quercus macrocarpa; Acer negundo; Fraxinus pennsylvanica;*** **riparian; gallery forests; eastern deciduous forest.**

Introduction

Research throughout the range of *Quercus macrocarpa* Michx. (bur oak) has shown that in areas previously dominated by this species, it is being replaced by more shade-tolerant species (e.g., Lindsey and Schmelz 1965, Johnson et al. 1974, Schlesinger 1976, Parker et al. 1985, Abrams 1986). The presence and maintenance of many species of *Quercus* in central and eastern North America is often associated with recurring fire (Abrams 1992), and prescriptions for fire alone and in combination with cutting have been developed for a variety of *Quercus* woodlands ***(e.g.*** Johnson 1993). However, little is known about the role of fire in maintaining *Quercus* on the western edge of its distribution, and even less is known about fire effects on *Quercus* and associated woody species in stringer woodlands along both perennial and non-perennial water courses.

Quercus reaches the western limit of its distribution in the western Dakotas and eastern Wyoming (Johnson 1990). *Quercus* occurs as an understory species in *Pinus ponderosa* Laws. (ponderosa pine) stands in the Black Hills of western South Dakota, as short-statured, shrubby plants in the northern Black Hills, and as tall trees in ravines and along waterways of intermittent streams draining out of the Black Hills into the foothills. Poor tree reproduction in stands dominated by either *Quercus* (Sieg 1991) or other eastern deciduous species is a common problem in woody draws and other stringer woodlands in the Northern Great Plains (Severson and Boldt 1978). Further, shrubs, if present, are limited to *Symphoricarpos occidentalis* Hook. (western snowberry), and *Poa pratensis* L. (Kentucky bluegrass) is increasingly replacing native *Carex* spp. (sedges) (Hodorff et al. 1989).

Stands of *Quercus* along streams and in draws have an actively growing herb layer during the frost-free period, have higher relative humidities than adjacent grasslands, and have running water or moist soils which slow the spread of fire into these communities. In most years, prairie fires would tend to skip over or only burn lightly through these stringer woodlands (Severson and Boldt 1978). However, the narrow configuration and close proximity of these woodlands to flashy grassland fuels suggests that historically they were exposed to a high number of grassland fires that would inevitably enter the woodlands, especially in dry years and on hot and windy days. In northeastern Kansas, *Quercus* gallery woodlands burned, but less frequently than adjacent grasslands (Abram 1985).

*Deceased

Because deciduous trees and shrubs sprout from rhizomes, root collars, or stems, they survive or even expand when topkilled by fire. White (1983, 1986) suggested that prescribed burning could be used to "thin stands from below," whereby fires topkill smaller Quercus trees, leaving larger trees as acorn producers. Many other woody species occurring in Quercus stands, including *Prunus virginiana* L. (chokecherry) and *Symphoricarpos* sprout following burning (Wright and Bailey 1982). Burning with sufficient severity to reduce the canopy cover of the overstory will also enhance light levels. Survival of *Quercus* reproduction in the eastern and central United States is highly dependent on disturbances that increase light levels (Johnson 1993).

Further, in the southern Black Hills (Schripsema 1977) and in other regions (e.g., Curtis and Partch 1948) fire is useful in reducing the cover of *Poapratensis,* thus possibly providing microsites more favorable for the establishment of woody species that require mineral seedbeds for germination. Establishment of Q. *rubra* Du Roi-Little (red oak) in Mississippi was less successful where *Poa* ***was the*** predominant cover, compared to areas covered by shrubs and dense ferns (Scholz 1955). Removal of litter enhanced germination rates of acorns in Iowa uplands (Krajicek 1960). Mineral soils warm more quickly in the spring than soils covered by litter and this may also improve *Quercus* germination.

Although few quantitative data are available on the historical fire frequency in the Black Hills area, evidence suggests that fires were ecologically important in this region. Comparisons of photographs taken in 1874 during General Custer's expedition to the area with those taken 100 years later (Progulske 1974, Progulske and Shideler 1984) show that ***Pinus*** coverage has greatly increased, due at least in par tto fire suppression efforts since the arrival of Europeans. Opal phytolith analyses in the Devil's Tower region northwest of the Black Hills indicated that ***Pinus*** densities have increased in the last 100 years, and that grasslands and savannas have been invaded with ***Pinus*** (Fisher et al. 1987). Dendrochronology data in this same area revealed that between 1600 and 1770, the mean interval between fires was 27 years; from 1770 to 1900 the fire return interval was 14 years, and since 1900 fires burned on the average of every 42 years (Fisher et al. 1987).

The purpose of this study was to explore the role of fire in *Quercus* stringer forests on the eastern edge of the Black Hills. We hypothesized that where fuels were relatively continuous and dry, prescribed burning would increase tree sprouts and shrub densities and provide a microclimate for the establishment of *Quercus* seedlings. We also sought to identify plant and/or site characteristics that contributed to the response of woody plants following burning. McPherson et al (1990) is the authority for terminology used in this paper that pertains to fire management.

Study Area

The study area is located in Meade County, South Dakota, south of the town of Sturgis, in the Fort Meade Recreation Area. The 3000-ha Recreation Area was originally established as a Military Reservation in 1878 (Bureau of Land Management 1981). The Bureau of Land Management manages the Recreation Area for livestock grazing, forestry, wildlife, and a variety of recreational uses.

Vegetation on the Recreation Area consists of mixed-grass prairie dissected by intermittent streams an dpine-covered outcrops. Major grassland species include *Andropogon scoparius* Michx. (little bluestem) and ***A.*** *gerardii* Vitman (big bluestem), *Agropyron smithii* Rydb. (western wheatgrass), a nd *Stipa viridula* Trin. (green needlegrass). *Quercus, Fraxinus pennslyvanica* Marsh. (green ash), an d *Ulmus americana L.* (American elm) are major tree species along drainageway. *Pinus* dominates sandstone and shale outcrops. Elevation of the study area ranges between 1030 and 1130 m, and the area receives an annual average of 45 cm of precipitation (National Oceanic and Atmospheric Administration 1986). Annual precipitation totaled 74.6, 39.2, and 45.5 cm during the three years of this study. Average annual temperatures during the three years wer e 7.5, 9.6, and 9.8° C, respectively.

Methods

A total of 192 square 6- by 6-m plots were established and fenced to exclude livestock in 1986. The plots were randomly located in *Quercus* woodlands, and were distributed among four study sites (48 per site). Two of the four sites were on the floodplain and associated ravine of intermittent creeks, and two sites were in draws with ephemeral streams. On each site, 24 plots were burned in April 1987. Both burned and unburned plots were stratified to include similar ranges in slope, fuel load, soils, and aspect. Plots were located on relatively level floodplains, steep slopes either above the floodplains or along the sides of draws, draw bottoms, and some cut banks associated with channels. To maximize ease of burning, burned plots were clumped at one end of each site.

Pretreatment Data

Pretreatment data included overstory and understory woody plant densities, as well as soil and fuel characteristics. The overstory was characterized by measuring the diameter, height, number of juvenile crown sprouts, and condition of each tree $\geq$ 2.5 cm dbh, by species, in each plot. Ages of trees were approximated by counting annuli in increment cores taken at breast height from each tree. Density of seedlings and saplings < 2.5 cm dbh and woody understory species was measured by counting numbers of stems, by species, in five square 2- by 2-m quadrats in each plot. Great Plains Flora Association (1986) was the authority for plant nomenclature.

Fine fuel loads were estimated in late summer 1986 by clipping herbaceous material at ground level in 10 20- by 50-cm quadrats randomly located in each 6- by 6-m plot. Materials were oven-dried at 60° C for 48 hours and weighed. Downed, woody fuels were recorded by diameter class (<0.6 cm, 0.6 - 2.5 cm, 2.6 - 7.5 cm, > 7.5 cm) along two 6-m transects in each plot; these data were summed for estimates of total woody fuel loads (Brown et al. 1982). Other measurements taken in each plot included: percent overstory frequency (determined with a box prism at four points in each plot), slope (&), and aspect (degrees). Surface soil moisture (O-2 cm) was determined gravimetrically (weighed, dried at 100° C for 48 hr, reweighed) in late July from four samples per plot; soil penetration was estimated from four randomly-located penetrometer readings in each 6- by 6-m plot. In addition, each plot was characterized with respect to landscape position (e.g. floodplain, slope, ravine bottom, cut bank).

Prescription

Given that these stringer forests are relatively green and moist during most of the growing season, and that woody species generally have the highest carbohydrate reserves during the dormant season (Kozlowski 1992), we set the prescription to burn the plots in the fall following a hard frost or in the spring before the trees had leafed out or cool season grasses had begun significant growth. The prescription called for temperatures between 16 and 27° C, relative humidity 25-40&, and wind speeds 13-24 kph; headfires were the preferred ignition technique to achieve maximum topkill of woody species (Wright and Bailey 1982). The preferred range of fuel moisture in fine (l-hour timelag) fuels was 7 - 20% (Mobley et al. 1973); in 10-hr. fuels (0.6 - 2.5 cm diameter), the preferred range was 6 - 15% (Beaufait 1966); and in 100+ hr. timelag fuels (> 2.6 cm diameter), the prescription called for moisture contents < 17% (Wright and Bailey 1982).

Prescribed Burns

Fuel and soil moisture were estimated and weather was monitored the day the plots were prescribed burned (17 April 1987). The percentage of the plant canopy cover in the understory that was green was estimated by 6 cover classes (Daubenmire 1959) in 2 randomly located 50- by 20-cm quadrats adjacent to each plot. Fine fuel moisture was then estimated by harvesting herbaceous plants at ground level in these 2 quadrats adjacent to each plot. Harvested material was weighed in the field, dried at 105° C for 48 hours, and reweighed. Moisture of larger fuels was estimated with fuel moisture sticks (lo-hour timelag fuels) and a fuel moisture probe (100-hour timelag fuels). Soil moisture at the time of the burn was determined gravimetrically (weighed, dried at 100° C for 48 hr, reweighed) from one random sample in each plot. Relative humidity, wind speed (20-30 cm above soil surface), and air temperatures were monitored every 15 minutes during the fires. Rate of spread of the flames was estimated with a stopwatch. Total time to travel across plots (6 m) was recorded.

Post-treatment Data

Following burning, woody overstory and understory species were sampled for two consecutive years in a similar manner to pretreatment measurements. In addition, tree scorch heights (height of scorch on tree boles) were recorded, and each plot was systematically searched for Quercus seedlings. Seedlings were counted and marked in July following the burns; seedling survival was estimated the following July as the number of marked seedlings alive in each plot.

Statistical Analyses

Number of tree sprouts and woody understory density were compared separately, by species, across four sites and treatments (burned and unburned) by analysis of covariance (Steel and Torrie 1980). Potential covariates included in analyses were slope, aspect, pretreatment value, soil moisture, soil penetration, landscape position, and overstory frequency. If a significant treatment by site interaction was detected, individual sites were analyzed by analysis of covariance, with Bonferroni corrections (e.g., $\alpha/4$) to maintain Type I error protection across individual analyses (Miller 1981). If a significant difference was detected between burned and unburned plant response, regression analysis was used to examine relationships between plant response and factors such as fine fuel loads, woody fuel loads, tree age and scorch height on trees. If a species did not occur on all sites, only those sites where it occurred were included in the analyses. Aspect data were recoded as four dummy variables for analyses, where 1 = "yes" and 0 = "no" for each of the four cardinal directions; landscape position was similarly recoded into six dummy variables. Normality was tested by plotting residuals. Homogeneity of variances was tested with Bartlett's Box F test; variances were homogeneous.

Results

Preburn Community

Overstory. Quercus was the dominant tree species, both in terms of density (1097 trees/ha) and basal area (39 m²/ha). *Crataegus rotundifolia* Moench (northern hawthorn), *Fraxinus* and *Ostrya virginiana* (P.Mill.) (ironwood) each had average densities between 200 and 245 trees/ha, but each had average basal areas of <1 m²/ha. Minor species included *Prunus virginiana, Shepherdia argentea* (Pursh) Nutt. (buffaloberry), *Prunus americana* Marsh. (wild plum), *Amelanchier alnifolia* Nutt. (Saskatoon serviceberry), *Acer negundo* L. (box elder), *Ulmus*, and *Pinus*. Saplings of any species were rare.

Understory woody plants. Although total woody plant density averaged 25.3 stems/m², *Symphoricarpos* was by far the most common woody plant (15.9 stems/m²), followed by *Prunus virginiana* (3.6 stems/m²), *Toxicodendron rydbergii* (Small) (poison ivy) (2.1 stems/m²), and *Ribes missouriense* Nutt. (Missouri gooseberry) (1.1 stems/m²). *Acer, Celastrus scandens* L. (bittersweet), *Fraxinus, Ostrya, Quercus, Prunus americana, R. odoratum* Wendl. (buffalo currant), and *Ulmus* were uncommon in the understory.

Fuel loads and fire behavior

Fine fuel averaged 589.6 kg/ha on the four sites; downed woody fuel averaged 11.4 mt/ha (Table 1). Fuel moisture averaged 14.6% for fine fuels and 11.2% for heavy (100-hr) fuels; soil moisture the day of the burns averaged 37.8% over all sites. Percentage of green vegetation ranged from 6.1% to 13.8% on the four sites, averaging 8.7% overall. Average rate of spread ranged from 0.01 m/sec to 0.09 m/sec on the four sites. Temperatures during the prescribed burns ranged from 16 to 21° C, relative humidity ranged from 10 to 25%, and wind speed ranged from 9 to 16 kph. Due to low wind speeds, ring (circular) fires were used instead of head fires (Biswell 1989).

Postburn response

Overstory. Several overstory species sprouted following burning. *Acer, Fraxinus*, and *Quercus* had higher ($p \leq 0.1$) numbers of juvenile sprouts for two growing seasons on burned vs. unburned plots; the number of sprouts per tree on *Crataegus* trees was higher ($p = 0.01$) on burned plots only in the second growing season (Table 2). Numbers of sprouts on the remaining tree species did not differ ($p > 0.1$) between burned and unburned plots in either the first or second growing season following burning. Less than 5% of the trees of any species were topkilled. A few individual *Acer* and *Fraxinus* trees were scorched sufficiently to topkill them, and the interiors of two *Quercus* trees with previous fire scars and heart rot continued to burn for as long as two weeks. Fire also burned into the roots in a few cases where heart rot was present. Only one large-diameter *Quercus* with a large fire scar was totally consumed in the fire; it produced one sprout.

Characteristics of both the tree and the site influenced post-burn sprouting response. Number of juvenile crown sprouts before the burn was the most common significant covariate, indicating that the post-fire sprouting response was correlated with preburn sprout numbers. For most species, this relationship was positive, but numbers of post-burn sprouts on *Acer* trees decreased with increasing numbers of preburn sprouts (Table 3). Tree diameter also influenced the sprouting of *Acer* and *Crataegus*. For both species, sprouting increased with increasing tree diameter. *Quercus* and *Fraxinus* produced greater numbers of sprouts per tree with increasing scorch heights, but numbers of *Quercus* sprouts decreased with increasing age of the tree.

Site variables that influenced tree sprouting included slope, landscape position, and soil moisture (Table 3). Both *Acer* and *Fraxinus* had lower sprouting rates with increasing slope; sprouting response of *Quercus* was positively correlated with ravine bottom landscape positions. *Crataegus* sprouts increased with increasing soil moisture.

Table 1. Average (± SE) fuel loads, fuel and soil moisture, and percentage green vegetation immediately before burning, and rate of spread during spring prescribed burns in four *Quercus* woodlands in the Black Hills, South Dakota.

	Site				
Category	1	2	3	4	Average
Fine fuel load (kg/ha)	862.3 ± 95.0	485.9 ± 67.2	648.1 ± 72.3	332.2 ± 54.9	589.6 ± 119.7
Woody Fuel load (mt/ha)	20.6 ± 2.9	11.5 ± 2.4	6.3 ± 1.7	7.1 ± 1.4	11.4 ± 3.3
Fine fuel moisture (%)	29.5 ± 9.7	7.3 ± 2.7	1.8 ± 1.8	19.8 ± 2.0	14.6 ± 6.2
Woody fuel moisture (%)	13.3 ± 1.8	10.5 ± 0.8	9.2 ± 0.9	11.6 ± 1.5	11.2 ± 0.9
Soil moisture (%)	39.0 ± 1.2	40.0 ± 0.7	43.0 ± 1.1	29.3 ± 1.7	37.8 ± 3.0
Green vegetation (%)	13.8 ± 2.4	7.2 ± 3.7	7.8 ± 1.9	6.1 ± 1.9	8.7 ± 1.7
Rate of spread (m/sec)	0.05 ± 0.02	0.09 ± 0.03	0.01 ± 0.01	0.01 ± 0.01	0.04 ± 0.02

Table 2. Adjusted mean (± SE) number of new juvenile basal sprouts per tree on burned and unburned plots during the first and second growing seasons following spring prescribed burning in *Quercus* woodlands in the foothills of the Black Hills, South Dakota.

Species	1st year		2nd year	
	burned	unburned	burned	unburned
Acer negundo L.	1.1 ± 0.5	0.1 ± 0.4[1]	1.3 ± 0.4	-0.1 ± 0.5[1,2]
Crataegus rotundifolia Moench	1.0 ± 0.2	0.7 ± 0.1	1.3 ± 0.3	0.1 ± 0.2[1]
Fraxinus pennsylvanica Marsh.	3.9 ± 1.0	0.5 ± 0.3[1]	4.1 ± 0.8	0.3 ± 0.4[1]
Ostrya virginiana (P.Mill)	0.3 ± 0.2	0.5 ± 0.4	0.1 ± 0.1	0.2 ± 0.2
Prunus virginiana L.	0.5 ± 0.3	0.4 ± 0.1	0.4 ± 0.1	0.6 ± 0.3
Quercus macrocarpa Michx.	2.2 ± 1.4	0.5 ± 0.2[1]	2.1 ± 0.2	0.5 ± 01[1]
Ulmus americana L.	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.3	0.5 ± 0.5

[1]Number of sprouts significantly ($p \leq 0.1$) different between burned and unburned plots within years.
[2]Negative adjusted means are valid results from analysis of covariance.

Understory woody plants. Density of woody understory species responded erratically to burning. *Crataegus* was the only species whose density increased in both growing seasons as the result of burning (Table 4). *Toxicodendron* density increased ($p = 0.05$) on burned plots the first growing season; *R. missouriense* density decreased ($p = 0.008$) on burned plots the first growing season. Several other species displayed significant treatment by site interactions, indicating that the response of these species differed by site. Density response of both *P. virginiana* and *R. odoratum* showed a significant treatment by site interaction in both growing seasons following burning. *P. virginiana* density increased ($p = 0.02$) on a floodplain site, but was similar on burned and unburned plots on the remaining sites. *R. odoratum* density decreased ($p \leq 0.04$) on a ravine site for two growing seasons following burning, but was unaffected by burning on the other sites. The response of *Acer* and *R. missouriense* differed among sites only during the second growing season following burning. *Acer* density decreased ($p \leq 0.008$) on floodplain sites, but was unaffected ($p = 0.38$) by burning on the ravine site. *R. missouriense* density decreased ($p = 0.01$) on one site; density was similar ($p \geq 0.38$) on burned and unburned plots on the remaining sites.

As observed with the overstory response, preburn abundance was the most common significant covariate for the response in density of understory woody species (Table 5), and the response of all species was positively correlated with their respective preburn densities. In addition, the response of several woody species was correlated with soil moisture and compaction. Density response of both *Acer* and *Crataegus* tended to increase with decreasing soil moisture, and in one growing season, *R. missouriense* density and *Toxicodendron* density were negatively correlated with soil compaction. Further, *Acer* density was positively correlated with slope on one site, *P. virginiana* response increased with increasing overstory frequency, and *Toxicodendron* displayed a negative association with north-facing aspects.

Quercus seedlings. Significant ($p \leq 0.01$) treatment by site interactions were detected for *Quercus* seedling density in both growing seasons (Table 6). In the first growing season, densities did not differ ($p = 0.22$) among sites, but there was a tendency on site 3 towards higher seedling densities on burned plots, and on the remaining sites to have higher densities on unburned plots. In the second growing season, *Quercus* seedling density was lower ($p = 0.02$) on burned plots on one site, but did not differ ($p \geq 0.5$) between burned and unburned plots on the remaining sites. The vast majority of seedlings,

Table 3. Significant ($p < 0.1$) covariates[1] for numbers of juvenile sprouts on overstory trees in the first and second growing seasons following spring prescribed burning in *Quercus* woodlands in the Black Hills, South Dakota.

Species	1st growing season	2nd growing season
Acer negundo L.	+ diameter, - slope	-preburn no.[2], -slope, + diameter
Crataegus rotundifolia Moench	-[3]	+ soil moisture, + diameter
Fraxinus pennsylvanica Marsh.	+ preburn no., + scorch	+ preburn no., - slope, + scorch
Ostrya virginiana (P.Mill)	-	-
Prunus virginiana L.	-	-
Quercus macrocarpa Michx.	+ preburn no., + scorch, - age, + ravine bottom	+ preburn no., - age, + scorch
Ulmus americana L.	-	-

[1] A significant positive covariate is a variable positively correlated ($p \leq 0.1$) with the number of sprouts a species produces; a negative covariate is a variable negatively correlated with the number of sprouts a species produces.
[2] preburn sprout numbers
[3] Number of sprouts was similar ($p > 0.1$) on burned and unburned plots.

Table 4. Adjusted mean (± SE) woody plant density (no./m^2) on burned and unburned plots the first and second growing seasons following spring prescribed burning in *Quercus* woodlands in the Black Hills, South Dakota.

	1st growing season		2nd growing season	
Species	burned	unburned	burned	unburned
Acer negundo L.	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1[1]
Celastrus scandens L.	0.5 ± 0.1	0.3 ± 0.1	0.6 ± 0.1	0.6 ± 0.1
Crataegus rotundifolia Moench	0.3 ± 0.1	0.1 ± 0.1[2]	0.3 ± 0.1	0.2 ± 0.1[2]
Fraxinus pennsylvanica Marsh.	0.3 ± 0.2	0.7 ± 0.7	0.3 ± 0.2	1.5 ± 1.2
Ostrya virginiana (P.Mill)	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Prunus virginiana L.	4.2 ± 0.7	4.6 ± 0.3[1]	4.6 ± 0.7	4.6 ± 0.6[1]
Quercus macrocarpa Michx.	0.4 ± 0.3	0.4 ± 0.1	0.5 ± 0.1	0.4 ± 0.1
Ribes missouriense Nutt.	0.1 ± 0.1	0.2 ± 0.1[2]	0.1 ± 0.1	0.3 ± 0.1[1]
Ribes odoratum Wendl.	0.7 ± 0.2	0.6 ± 0.1[1]	0.8 ± 0.2	1.0 ± 0.1[1]
Symphoricarpos occidentalis Hook.	13.0 ± 2.3	11.8 ± 0.4	13.3 ± 1.7	12.7 ± 1.7
Toxicodendron rydbergii (Small)	3.1 ± 1.0	0.8 ± 1.8[2]	2.3 ± 0.5	2.3 ± 0.1
Ulmus americana L.	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1

[1]Significant ($p \leq 0.1$) treatment by site interaction.
[2]Stem density was significantly different ($p \leq 0.1$) within years between burned and unburned plots.

both on burned and unburned plots, throughout the study, were < 8 cm tall and had only one or two leaves. Survival of *Quercus* seedlings from the first growing season following burning to the second growing season was similar (p = 0.3) between burned (58.5%) and unburned (71.8%) plots.

Discussion

Prescribed Burn

Although fuel moisture and weather parameters during these burns were within prescriptions on most sites, fire spread was hampered by grasses matted by previous snow pack, lower wind speeds in the interior of the woodlands compared to uplands, and poorly distributed fuels. In several plots, it was necessary to relight areas that failed to burn. Wind speeds in excess of 13 km/hr are required to top-kill shrubs (Wright 1974). In the interior woodland plots, wind speeds occasionally dropped below this threshold, which likely explained the incomplete burning. Further, in some plots, sparse and poorly-distributed fine fuels decreased the rate of spread. At least 670 kg/ha fine fuels are required to carry fires on grasslands (Wright and Bailey 1982), so it is likely that fires did not burn well on plots with fine fuel loads lower than this threshold level. Finally, the distribution of woody fuels was uneven, so residual burning was limited to isolated locations.

Postburn Response

Overstory. In spite of the less than optimum conditions for regenerating woody plants, the number of basal sprouts for *Acer*, *Fraxinus*, and *Quercus* increased the first two growing seasons following spring burns; and the number of *Crataegus* sprouts increased the second year following burning. *Quercus* tolerates fires well in other regions and produces prolific sprouts following burning (Johnson 1990). However, little information is available on the response of other hardwood species to burning (Johnson 1984).

Although repeated fires would tend to decrease species such as *Fraxinus* and *Acer* (e.g. Johnson 1993), these species are tolerant of fire when burned in a dormant state (Wasser 1982). The association of sprouting rates between *Acer* and *Fraxinus* and slope indicated that the best

Table 5. Significant ($p \leq 0.1$) covariates[1] for density response of woody understory species the first and second growing seasons following spring prescribed burning in *Quercus* woodlands in the Black Hills, South Dakota.

Species	1st growing season	2nd growing season
Acer negundo L.	-[2]	+ preburn density, -soil moisture[3], + slope[3]
Crataegus rotundifolia Moench	+ preburn density, - soil moisture	+ preburn density
Prunus virginiana L.	+ preburn density	+ preburn density, +overstory frequency
Ribes missouriense Nutt.	+ preburn density	+preburn density, - soil compaction
R. odoratum Wendl.	+ preburn density	+ preburn density
Toxicodendron rydbergii (Small)	+ preburn density, - north, - soil compaction	-

[1] A significant positive covariate is a variable positively ($p \leq 0.1$) correlated with the density of a species; a negative covariate is a variable negatively correlated with the density of a species.
[2] Density was similar ($p > 0.1$) on burned and unburned plots.
[3] Significant covariate on one site only.

Table 6. Density (no./ha) of *Quercus* seedlings (± SE) during the first and second growing seasons following spring prescribed burning on four sites in *Quercus* woodlands in the foothills of the Black Hills, South Dakota.

	1st growing season		second growing season	
Site	burned	unburned	burned	unburned
1	660 ± 215	1759 ± 380	532 ± 175	1481 ± 330
2	104 ± 40	208 ± 65	23 ± 16	162 ± 55
3	1377 ± 370	590 ± 189	868 ± 267	440 ± 158
4	683 ± 187	1725 ± 223	475 ± 153	868 ± 155
Average	706 ± 206	1071 ± 396[1]	429 ± 142	692 ± 284[1]

[1] Significant ($p \leq 0.1$) treatment by site interaction.

response was on relatively level floodplains, and was attributed to higher soil moisture on those sites. Both of these species grow better on alluvial soils than on uplands in western North Dakota (Wali et al. 1980). Diameter also influenced the response of *Acer*, with larger diameter trees producing a greater number of sprouts than smaller diameter trees. Unlike some tree species, older *Acer* trees do not have thick bark that insulates the tree, and hence larger trees are more likely to sprout following burning than thick-barked species. However, the greater the number of pre-burn sprouts on *Acer* trees, the less likely they are to produce sprouts following burning that survive into the second growing season. Scorch height was a significant variable for *Fraxinus* response, indicating that trees require severe scorching to induce sprouting.

Quercus growing in ravine bottom sites produced more sprouts following burning than trees on slopes or floodplains. *Quercus* is less competitive on floodplains sites in this area than *Fraxinus* (Sieg 1991) and the relatively dry conditions following burning likely reduced water availability on slopes. Further, *Quercus* basal sprouting increased with increasing scorch height, indicating the need to damage the tree sufficiently to induce sprouting. Larger diameter *Quercus* trees have relatively thick bark that requires significant scorching to induce sprouting (Fowells 1965). The negative association of *Quercus* sprouting with increasing size may be related to the thicker bark of older trees and/or to the decline in sprouting ability and low carbohydrate reserves associated with senescence in trees (Johnson 1977). Further data are needed to quantify the inter-relationship between sprouting response, diameter and tree age.

Few comparative data on the response of *Crataegus* to burning are available. Fires may harm species such as *C. succulenta* Link (fleshy hawthorn) (Wright and Bailey 1982). Moisture is apparently an important component for predicting the response of *Crataegus*, as indicated by the positive correlation of number of sprouts with soil moisture.

Understory woody plants. Our hypothesis that prescribed burning would increase densities of woody understory plants was supported for some species. *Crataegus* was one of two species whose densities increased consistently the first season following burning, and was the sole species whose numbers increased on all burned sites the second growing season. A large portion of this increase in *Crataegus* density was contributed by seedlings. Fire apparently provided microsites for *Crataegus* germination. The density of *Toxicodendron* also increased on burned sites the first growing season following burning. Previous research on the response of *Toxicodendron* to burning has produced mixed results. In the southern Black Hills, *Toxicodendron* was one of the few shrub species that did not increase following a high intensity burn, and showed no change following a low intensity burn (Bock and Bock 1984). In our study, the initial density, along with aspect and soil compaction, influenced the response of *Toxicodendron*. *P. virginiana* density increased on some sites following burning. *P. virginiana* was among several woody species that sprouted vigorously following burning in other regions (e.g., Pelton 1953, Wright and Bailey 1982, Miller 1963).

Pretreatment densities of all species were consistently positive covariates in our study, indicating that the pre-fire composition is important in predicting the post-fire response. Armour et al. (1984) found pretreatment composition the most important variable in predicting post-fire response of the understory plants in ponderosa pine stands in Idaho. However, soil moisture, soil penetration, aspect, slope and overstory frequency also were significant factors determining the species response on our study area. Soil moisture is a critical variable controlling the response of plant communities to fire, especially in relatively dry regions (Wright and Bailey 1982). Aspect and slope influence soil moisture and temperature, and therefore indirectly influence plant response to burning.

Densities of some woody species decreased on burned plots on some sites in one or both growing season following burning. *Acer* was unaffected the first growing season, but decreased on floodplain sites in the second season; its response was related to slope and soil moisture. In addition to slope and aspect, overstory frequency also influenced the response of some woody species such as *Quercus*. *Quercus* is considered a relatively shade intolerant species; throughout most of its development it requires abundant sunlight (Abrams 1992).

Density of the remaining species showed no change as a result of burning or their response differed among sites. Ribes spp. responded erratically to burning. Soil compaction was an impediment to R. *missouriense* growth, as indicated by the decrease in density with increasing soil compaction. We attributed both the decline in ***R. missouriense*** and ***R. odoratwn*** on some sites and no change in species such as ***Ostrya, Celastrus*** and Ulmus to a combination of low fire intensity and relatively dry conditions following the burns. Light surface fires ignited in the fall in the southern Black Hills reduced densities of ***Ribes,*** but had no significant impact on densities of 10 other woody species; in contrast, a fall crown fire in the same area increased densities of all shrub species except P. ***virginiana and Toxicodendron*** (Bock and Bock 1984).

Quercus seedlings. Burning did not enhance germination rates of acorns nor survival of Quercus seedlings. Further, the relationship between seedling density and site factors was unclear. The only variable that was significantly correlated with ***Quercus*** seedling density was canopy cover of ***Carex*** spp. (sedges) (Sieg 1991). Further research, including information on long-term survival of various forms of woody plant reproduction, is needed.

Prescription recommendations. These initial results suggest that prescribed burning shows some promise for rejuvenating woody plants in ***Quercus stands;*** but modification of the prescription is necessary. From a fire control point of view, spring and fall burning have appeal. In addition, woody plants have higher carbohydrate reserves when they are dormant (Kozlowski 1992). However, prescriptions should be set to achieve high intensities if the goal is to regenerate trees and shrubs and/or to approximate historical fire effects. Some combination of cutting and burning may be helpful in reducing theoverstory and stimulating ***Quercus and woody*** plant reproduction, and multiple burns may be needed to greatly enhance ***Quercus*** regeneration (Johnson 1993).

If woody plant regeneration is the goal and dormant season burns are used, the following guidelines are suggested: 1) burn in the'fall so grasses are not matted down from snow; 2) wait until after a killing frost when the percentage of green grass canopy cover is <25&; 3) defer livestock grazing, if necessary, to ensure that fine fuel loads are consistently >700 kg/ha; 4) wait for wind speeds in excess of 13 km/hr; and 5) enhance woody fuels by either not allowing fuel wood cutting and scavenging, or by scattering and leaving slash following cutting to increase fire residence times.

The response of woody plants to prescribed burning in these stringer woodlands is influenced by soil moisture levels following burning, which are ameliorated by topographic features. On steep slopes, and with relatively low precipitation levels following burning, the sprouting response of woody plants in stringer woodlands will likely be lower relative to the response that could be expected on moist sites in wet years.

Summary

Prescribed burning shows some promise for regenerating woody plants in *Quercus* woodlands. Relative to unburned areas, there were more ***Quercus, Fraxinus*** and ***Acer sprouts*** following burning. However, ***Quercus*** ***seed***ling density did not increase relative to unburned sites, and changes in the density of woody understory species were erratic. ***Toxicodendron*** and ***Crataegus were the*** only woody species that increased consistently the first growing season following burning; P. ***virginiana*** density increased on some sites. Pretreatment sprout numbers and density of sampled species were the most common significant covariates for the response of plants to fire, indicating that pre-fire species composition is an important determinant in the response of deciduous woodland species. Other common covariates included aspect, soil moisture, and slope. Woody plant density was often higher following burning where soils were moist and topographic features ameliorated harsh site conditions. Dormant season burning has some appeal from a fire control point of view and because carbohydrate reserves in woody plants are high during dormancy. However, if the objective is to regenerate woody plants and/or mimic historic fires, the prescription should be set to achieve high intensities. Additional research is needed to fine-tune the prescription to achieve this objective.

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