CHAPTER

2

Assessment of Prescribed Fire as a Conservation Practice

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INTRODUCTION

Fire has played a key role in the formation of most rangeland ecosystems in North America (Axelrod 1985) and the world (Bond et al. 2003; Keeley and Rundel 2005). Alteration of fire regimes on US rangelands since European settlement has created cases of severely altered ecosystems that can eventually result in no-analog, novel, or emerging ecosystems (House et al. 2003; Hobbs et al. 2009). According to the Landscape Fire and Resource Management Planning Tools Project (LANDFIRE; an interagency vegetation, fire, and fuel characteristics mapping program sponsored by both the US Department of Interior and the US Department of Agriculture [USDA]–Forest Service), three-fourths of US lands dominated by native vegetation show moderate or high departure from reference conditions as a result of altered fire regimes (The Nature Conservancy 2009). Because most rangelands are considered fire-dependent ecosystems, restoring historical fire regimes is fundamentally important when the management goal is to restore or maintain the potential (or historical) natural communities. For most ecological sites, the historical plant community was maintained by fire, and removing fire will cause the community to cross a threshold, often to woody plant dominance with reduced livestock production and loss of other ecosystem services. Rapid and extensive woodland expansion on rangelands clearly reflects the essential role of fire in the maintenance of historical rangeland ecosystems. These recent changes in land cover patterns emphasize that restoration of historical fire regimes are necessary to maintain these historical communities as outlined in the Natural Resources Conservation Service (NRCS) Ecological Site Descriptions. Yet, the implementation of prescribed burning as a conservation practice has been overshadowed by the implementation of other practices, especially prescribed grazing. In Oklahoma for example, from 2004 to 2008, NRCS implemented prescribed burning on 84 700 ha compared to 919 800 ha for prescribed grazing during 2004–2008. This 10-fold difference in the application of these two conservation practices clearly identifies the higher priority placed on grazing compared to that of burning. Considering that NRCS grazing practices operate over multiple years and that the practice of prescribed burning is a one-time application, the effective difference is actually considerably larger than 10-fold. Disproportionate implementation of these two practices is influenced by the complexity of social interactions among agencies, the general public, and public policy. Social and policy concerns are extremely different across various rangeland regions, ranging from complete acceptance of fire cultures (e.g., Flint Hills of Kansas and Oklahoma) to attempts to completely remove fire from the landscape (e.g., Great Basin).

A prescribed fire in a mixed grass prairie that has been invaded by woody plants. (Photo: John Weir)

With a few exceptions, fire regimes have been altered through intentional fire suppression and by grazing that uniformly reduces fuel loads. Therefore, invasion of woody plants (both native and nonnative) has converted many shrublands and grasslands to forests or woodlands because of the absence of fire for abnormally long periods after European settlement. In contrast, other rangelands, notably those of the Great Basin, have been largely invaded by exotic herbaceous species that increase fine-scale fuel homogeneity, which greatly alters the fire regime by increasing fire frequency. State-and-transition models suggest conversions to woody plant dominance and exotic annuals can eventually become irreversible and result in alternative stable states. Although rangeland management

Suppression of fire allows invasion of woody plants into grassland habitats. Prior to European settlement, First Nations actively burned the landscape for many reasons and maintenance of those ecosystems requires periodic fires. (Photo: Sam Fuhlendorf)

professionals generally support using fire in rangeland ecosystems, a long history of exclusion, uncertainty about the effects of fire, increased wildland–urban interface, socioeconomics, and natural resource policy are formidable barriers to reintroducing fire except in those ecosystems in which the fire return interval has been shortened. However, as long as maintaining ecosystem structure within a historical context is emphasized, fire regimes must be restored across most rangelands.

The USDA-NRCS Practice Standard for Prescribed Burning (CODE 338) describes the following purposes:

1. to control undesirable vegetation;
2. prepare sites for harvesting, planting, and seeding;
3. to control plant diseases;
4. to reduce wildfire hazards;
5. to improve wildlife habitat;
6. to improve plant production quantity and/or quality;
7. to remove slash and debris;
8. to enhance seed production;
9. to facilitate distribution of grazing and browsing animals; and
10. to restore and maintain ecological sites.

The Conservation Effects Assessment Program (CEAP) was initiated to determine the extent to which experimental data present in peer-reviewed research literature support these purposes. The general and value-laden nature of these purposes makes them extremely difficult to assess against experimental data; therefore, we analyzed the research literature to establish the ecological effects of prescribed fire from a broader perspective. Specifically, we evaluated the research literature available on plants, soil, water, wildlife, arthropods, livestock, fire management, fire behavior, smoke management, socioeconomics, air quality, fire history, and human health. These topics were selected based on input from rangeland CEAP teams focused on other conservation practices and initial evaluation of the literature in terms of topics that were covered sufficiently to draw meaningful conclusions. We also addressed issues related to spatial scale, temporal scale, and other general descriptions of the body of research and we then related our findings to the specific NRCS purposes for the practice of prescribed burning.

DEFINING OUR LITERATURE DATABASE

Evaluation of the peer-reviewed literature on prescribed fire first required determining methods to query the entire body of scientific literature on the topic. We wanted to include all relevant papers, but we limited the scope of the search to minimize less-relevant papers. We searched for papers that focused on fire (preferably prescribed), but largely excluded fire research from forested systems, which dominates the fire research literature. Many papers that report fire research on rangelands do not include the term *prescribed*, and many relevant papers do not use the term *rangeland*. We used multiple approaches (Table 1) to identify the most acceptable body of literature to evaluate. The data set built from the search with the term *prescribed fire* omitted numerous important papers from the pool, and many of the papers included some discussion of fire but with minimal or no data related to fire. Therefore, our final search used the term *fire*, which also located articles with *prescribed fire* in the title, to broaden the search. Although this approach excluded papers that reported research from regionally important ecosystem types (e.g., shinnery oak or chaparral vs. shrubland) and papers in which the title contained other key fire-related words (e.g., burned, burning, and prescribed burning) but not fire, the search located more than 500 papers (Table 2). Assuming our search provided an adequate, unbiased sample of the literature, we evaluated the search database to determine the nature of information available through the peer-reviewed literature. We then supplemented this information with papers that addressed specific topics within our charge for this project. As with the comprehensive search, we used Web of Science to search for papers on a particular topic. We justified limiting our search to the indexed literature on the basis that it is widely accepted as scientifically valid and the primary science published in peer-reviewed literature.

TABLE 1. Number of papers identified for six topics in a Web of Science search of peer-reviewed journals. Each number represents the number of papers from the Web of Science for each topic listed.

Topic	Fire	Prescribed Fire
Rangeland	172	48
Shrubland	265	24
Grassland	931	138
Grazing	831	95
Wildland	494	83
Forest	6 648	671
Total with forest	9 341	1 059
Total without forest	2 245	318

TABLE 2. Numbers of papers identified in a Web of Science search using fire (not prescribed fire) and each of the words in the first column in the title of the paper. These papers formed the initial database that was analyzed.

Title search combining fire and one of the following words	Number of papers
Shrubland	24
Savanna	157
Grazing	86
Woodland	61
Wildland	150
Rangeland	18
Grassland	107
Total	563

EVALUATION OF THE DATA SET

Of the 563 papers (available in January 2008) from our query through Web of Science (Table 2), 474 papers were accessible and confirmed to be peer-reviewed research papers. Of these 474 papers, less than 10 papers were published annually from 1967 through 1989 followed by a marked increase with 20 or more papers

FIGURE 1. The number of papers published per year from a total of 563 papers published on rangeland fire. See text and Table 1 for explanation of papers selected.

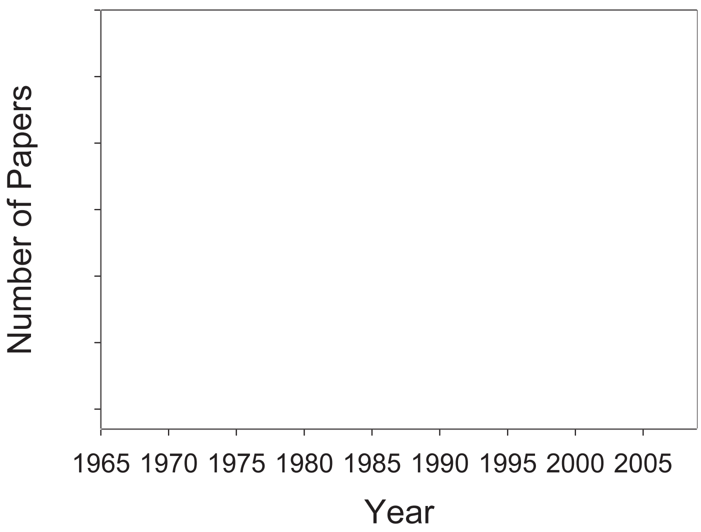


TABLE 3. Number of papers published by peer-reviewed scientific journals between1967 and 2007 based on a Web of Science search.

Journal	Number of papers
International Journal of Wildland Fire	25
JRM/Rangeland Ecology and Management	23
Ecology	15
Journal of Applied Ecology	15
Forest Ecology and Management	13
Vegetatio /Journal of Vegetation Science	15
Journal of Ecology	12
Journal of Tropical Ecology	12
African Journal of Ecology	11
Austral Ecology	10
Plant Ecology	10
Journal of Arid Environments	8
Remote Sensing of Environment	8
Australian Journal of Ecology	7
Biotropica	7
Ecological Modelling	7
Journal of Biogeography	7

published each year from 2000 to 2007 (Fig. 1). These data suggest that the research community may view fire with increasing importance but these conclusions could be limited by the words included in the search.

An important outcome of the search was that rangeland fire research literature is dispersed among numerous ecological journals. Furthermore, most continents are well represented in the research, and topics include those not explicitly addressed in the NRCS purposes for prescribed burning. More than 150 journals, mostly international ecological or applied ecological journals, published rangeland fire research (Table 3). Most of the research was located in North America, but substantial research was conducted in Africa, Australia, South America, and Europe. Research from the United States contributed 214 of the 474 papers in the data set. The majority of papers reported research on plants, fire management, soils, fire behavior, socioeconomics, and wildlife. Authors described their papers as addressing a variety of vegetation types, with over half of the papers classified as savannas and grasslands (Fig. 2). Most of the articles recognized by our search terms in the United States reported research from the Great Plains, followed by the West Coast, Intermountain West, Eastern Forests–Grasslands, and Desert Southwest (Table 4). Topics in the database focused on plants, socioeconomics, fire management, soils, fire behavior, and wildlife, in respective order from highest to lowest, with all other topics having 10 or fewer papers (Table 4).

Perhaps the most revealing outcome of our search was that it uncovered critical limitations to applying the research literature to management applications, which is a fundamental barrier to constructing research-informed purposes for prescribed burning. First, we found that most of the research was conducted at temporal and spatial scales inappropriate to management. Second, the fire research literature generally ignores fire as a dynamic disturbance process that varies in frequency, intensity, and time since fire (most studies are less than 5 yr postfire). Finally, most research failed to evaluate fire in the context of other disturbances, such as grazing and drought, on complex landscapes. More than half of the papers reported research conducted on experimental units of 1 ha or less and many studies were conducted on much smaller plots and on individual plants (Fig. 3). Fifteen percent of the studies were based on modeling and 6% on geographic information systems with minimal field evaluations or immediate application to management. Many studies (27%) simply compared a burn treatment to an unburned control, which obviously simplifies fire to the point of irrelevance to management.

Fire regime, the features that characterize fire as a disturbance within an ecosystem—fire frequency, severity, behavior (i.e., fire intensity), predictability, size, seasonality, and spatial pattern (Morgan et al. 2001)—was rarely evaluated. Only 12.5% of the papers focused on *fire frequency*, and only 4% focused on understanding changes that occur over variable times since fire. *Fire season* was evaluated in 7% of the studies and *fire intensity* was evaluated in 9% of the studies. Most studies failed to specifically discuss the interaction of fire with

FIGURE 2. Percentage of 474 rangeland fire studies within each of seven major vegetation types as described by the authors. Papers were published in peer-reviewed journals and located in a Web of Science search.

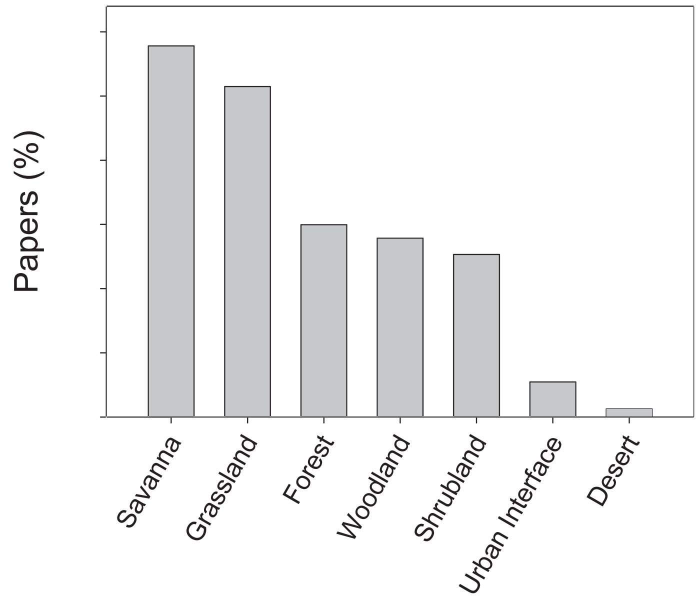
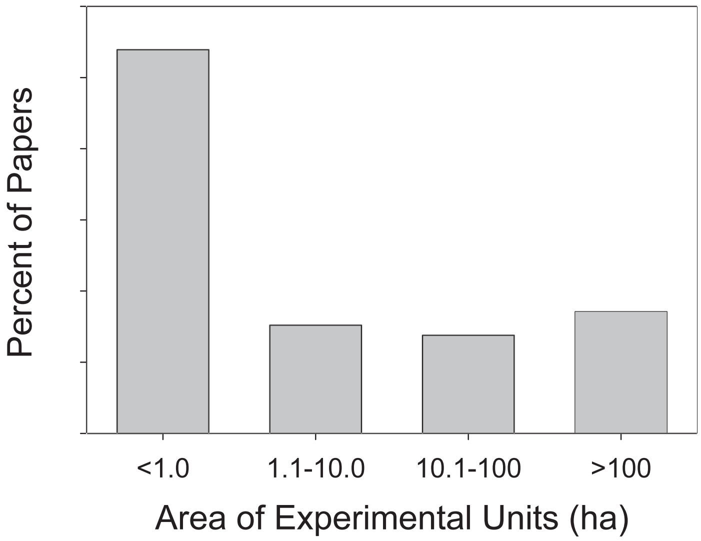


TABLE 4. Number of papers published reporting research on topic areas conducted within geographic regions of the United States based on a Web of Science search.

Topic area	Not specific	Eastern forests and grasslands	Great Plains	Intermountain West	Southwest Deserts	West Coast	Total
Plants	4	9	22	8	13	12	68
Soil	1	2	8	2	2	2	17
Water	1	0	0	0	0	0	1
Wildlife	2	1	3	3	1	2	12
Arthropods	0	0	8	0	1	0	9
Livestock	1	0	0	0	0	0	1
Fire Management	4	4	0	7	1	9	25
Fire Behavior	5	3	2	1	2	1	14
Smoke Management	1	0	0	1	0	1	3
Socio-economics	10	2	2	7	1	6	28
Air	0	1	2	2	2	3	10
History	1	2	0	3	0	1	7
Health	3	0	0	4	0	3	10
Other	3	0	2	0	1	3	9
Total	36	24	49	38	24	43	214

FIGURE 3. Number of rangeland fire papers published in each of four spatial scales. Papers were published in peer-reviewed journals and located in a Web of Science search.



grazing and only 26% and 19% of the studies specifically stated that they included ungrazed and grazed sites, respectively. Grazing was a part of the experimental design in only 13% of the studies. Because the vast majority of rangeland is grazed, the failure of research to address the interaction of fire and grazing severely limits applying the research to support NRCS purposes for prescribed burning.

EVALUATION OF FIRE EFFECTS ON ECOSYSTEM COMPONENTS

Prescribed fire is currently conducted on rangelands for many reasons, but a primary purpose is to reduce encroachment of invasive woody plants (see Fire and Plants section, Composition Changes subsection). Because fire can both positively and negatively influence ecosystem components, fire should be evaluated from the perspective of all ecosystem components. Therefore, we evaluate the literature available on plants, soil, water, wildlife, arthropods, livestock, fire management, fire behavior, smoke management, socio-economics, air quality, and fire history. Although we will evaluate the entire dataset when appropriate, on occasion we focus on data from specific rangeland regions of the United States to illustrate differences and similarities between regions.

Fire and Plants

The data set included 220 papers focused on plants and plant communities. Nearly 25% of the papers on plants evaluated community composition and structure following prescribed fire and wildfires. Ten percent of the papers evaluated biomass production, 6% discussed plant diversity, 5% considered mortality to individual plants, 5% focused on seed germination and establishment, and 2% considered plant (forage) quality. The remainder of the topics considered (plants as fuel, physiology, invasive species, harvesting, seed production) and were all below 2% of the papers evaluated and no conclusions could be drawn on these topics.

Biomass and Forage Quality. Plant productivity, plant nutrient content, plant diversity, and plant mortality responses to fire are highly variable (Blair 1997; Reich et al. 2001). Much of this variability depends on how productivity is defined. Forage or herbaceous production usually decreases for 1–2 yr after fire followed by a positive to neutral effect. An exception to this occurs in the tallgrass prairie where productivity can be enhanced from one spring fire following several years without fire (Blair 1997). Total aboveground biomass appears to be negatively associated with fire frequency although this depends on the ecosystem. Several studies indicate an increase in forage quality in mesic grasslands following fire (Hobbs et al. 1991; see wildlife and livestock sections), but these patterns are uncertain in more xeric regions. Grazing animals throughout all regions select recently burned areas for foraging sites over unburned sites, reflecting improved forage quality following fire. At a minimum, fire maintains openness of grassland landscapes, which sustains herbaceous biomass and forage quality/quantity. Because individual species and communities differ widely in response to fire, species diversity and plant mortality following fire cannot be generalized. Some evidence supports the NRCS purpose of using fire to enhance seed production, germination, and establishment, but these patterns are also species- and site-specific and cannot be generalized over all plants and ecosystems.

Compositional Changes. The majority of plant papers focused on community composition. There were 68 papers in the data set that evaluated vegetation dynamics and plant responses to fire within the United States. We evaluated 81 papers to identify regional differences and similarities among the Great Plains, Intermountain West, and the Desert Southwest. Of the papers reviewed, 65% reported results of prescribed burns, 21% reported results of wildfires (Fig. 4), and most (> 75%) fire treatments were applied in spring and summer. Several studies recognized that season of fire mostly had a minimal or temporary effect (Engle and Bidwell 2001). A major concern from the database is the limited number of long-term studies (Fig. 5). Twenty-two percent of the studies extended past 10 yr, of which a majority substituted space for time (comparing plant succession across fires of different ages), with the majority of studies (64%) not extending beyond 3 yr.

Plant response to fire was highly variable both across and within regions and ecological sites (Table 5). A large portion of this variability can be attributed to the interaction of multiple variables, which include site characteristics, fuel characteristics, climate, community composition, time since fire, fire season, fire intensity, and postfire management. However, several patterns are evident in fire related plant responses across regions and ecological sites. *Perennial grasses* declined in abundance in the first postfire growing season in 76% of the studies, but usually recovered within the second or third year. Abundance of perennial grasses increased in only 11% of the studies in the first postfire growing season and in 5% during the second or third year following fire, but no studies reported long-term declines in perennial grasses. *Annual grasses* were usually more abundant in the first, second, and third years following fires compared to unburned stands. *Annual and perennial forbs* were inconsistent in their response the first year following fire, but they were more abundant in four out of six studies by the second or third year. Abundance of both resprouting and nonsprouting *shrubs* (biomass, cover, or volume) was lower during the first 10 yr following fire. However, density of sprouting shrubs usually equaled or exceeded that of unburned communities within 3 yr following fire suggesting little or no mortality. Full recovery of sprouting shrubs occurred within 3–20 yr; recovery took 25–35 yr for nonsprouting shrubs on relatively wet sites (e.g., mountain big sagebrush [*Artemisia tridentata* subsp. *vaseyana*] in the 300–400-mm precipitation zone) and greater than 45 yr on dry sites (e.g., Wyoming big sagebrush [*A. t.* subsp. *wyomingensis*] in the 200–300-mm precipitation zone).

FIGURE 4. Number of rangeland fire studies addressing plant responses to prescribed fire and to wildfire in three rangeland regions of the United States.

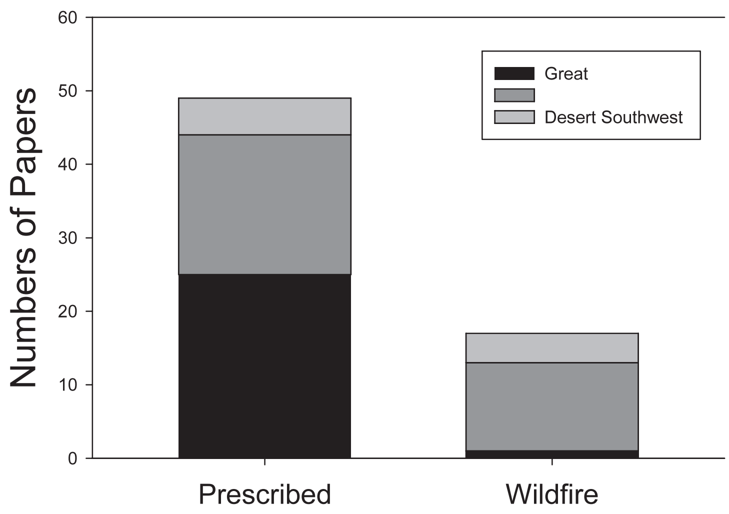
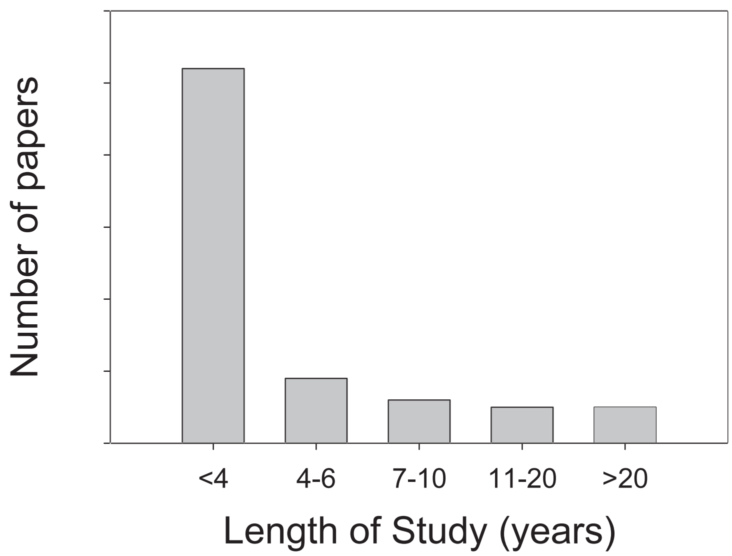


FIGURE 5. Time period over which individual research studies investigated plant response to fire on rangelands.



The use of fire to increase cover, density, and biomass of herbaceous vegetation, particularly perennial grasses, is only weakly supported in

TABLE 5. Numbers of studies indicating negative (–), positive (+), and no change (=) in response of plant groupings (total herbs, perennial grasses, etc.) to fire across specific regions (Great Plains, Intermountain West, and Desert Southwest).

	1 yr postfire			2–3 yr postfire			≥ 4 yr postfire		
Plant grouping	(–)	(+)	(=)	(–)	(+)	(=)	(–)	(+)	(=)
Total herbs	7	4	4	2	3	3	0	1	1
Great Plains	7	4	3	2	2	3	0	1	1
Intermountain West	0	0	1	0	1	0	0	0	0
Desert Southwest	0	0	0	0	0	0	0	0	0
Perennial grasses	20	3	3	3	1	17	0	1	1
Great Plains	5	2	1	1	0	5	0	1	0
Intermountain West	10	1	2	1	1	7	0	0	1
Desert Southwest	5	0	0	1	0	5	0	0	0
Annual grasses	1	4	0	0	3	1	0	0	0
Great Plains	1	2	0	0	1	0	0	0	0
Intermountain West	0	2	0	0	1	0	0	0	0
Desert Southwest	0	0	0	0	1	0	0	0	0
Perennial forbs	2	3	0	0	3	1	0	0	0
Great Plains	1	0	0	0	1	0	0	0	0
Intermountain West	0	3	1	0	2	0	0	0	0
Desert Southwest	1	0	0	0	0	1	0	0	0
Annual forbs	2	2	1	0	1	1	0	0	0
Great Plains	1	0	0	0	1	1	0	0	0
Intermountain West	1	2	0	0	0	0	0	0	0
Desert Southwest	0	0	0	0	0	0	0	0	0
Shrubs, sprouting	4	0	0	1	0	0	4	1	1
Great Plains	0	0	0	0	0	0	0	0	0
Intermountain West	1	0	0	0	0	0	4	1	1
Desert Southwest	3	0	0	1	0	0	0	0	0
Shrubs, nonsprouting	9	0	0	5	0	0	0	0	0
Great Plains	0	0	0	0	0	0	0	0	0
Intermountain West	9	0	0	5	0	0	0	0	0
Desert Southwest	0	0	0	0	0	0	0	0	0
Trees, nonsprouting	4	0	1	2	0	0	1	0	0
Great Plains	0	0	0	0	0	0	0	0	0
Intermountain West	3	0	0	2	0	0	1	1	0
SW Deserts	0	0	0	0	0	0	0	0	0
Woody plants	3	0	0	4	1	0	4	1	2
Great Plains	3	0	0	4	1	0	4	1	2
Intermountain West	0	0	0	0	0	0	0	0	0
Desert Southwest	0	0	0	0	0	0	0	0	0

the research literature. However, possibly the strongest argument for the use of prescribed fire is to maintain or restore a desired successional community or pattern of communities in different stages of recovery following fire. Although herbaceous vegetation rarely increases the year of the fire, herbaceous dominance over woody plants is favored by shorter fire-return intervals. A number of studies across US rangelands reported that shrubs and trees increase and herbaceous vegetation decreases with long-term fire removal, so maintaining or increasing relative abundance of herbaceous vegetation requires periodic fire. The length of the fire-return interval can also determine the proportion of area occupied by grassland, shrub-steppe, and conifer woodland communities.

Fire can be used to change plant composition (e.g., the proportion of C_3:C_4 plants, herbaceous:woody plants, and forbs:grasses) and reduce excessive litter buildup resulting in an increase of light to basal tillers (an issue restricted to highly productive sites). The literature is mixed on one of the greatest concerns over the use of prescribed fire—the potential for increasing invasive species. Fire can act as a trigger to force a desirable stable-state that may be at risk of resilience loss across a threshold to an undesirable invasive plant state. Cheatgrass provides an excellent example of this dynamic in the Intermountain West. On the other hand, fire can be used to control invasive species through direct control or by focusing herbivory on a relatively small burned area within a landscape (Cummings et al. 2007).

Great Plains. Of the 36 papers reviewed from the Great Plains, almost all were prescribed fires at the sublandscape level (plots and stands) evaluating burns during the spring and summer. Several studies also evaluated the timing of burning in the spring (early, middle, and late) and reported a significant effect on vegetation response. However, a literature review on the effect of season of burn on herbaceous species in tallgrass prairie suggested that the data were not conclusive (Engle and Bidwell 2001). Only a limited number of studies reported the method of burning or the prefire and postfire conditions. Nearly two-thirds of the studies were less than 3 yr in duration with only 14% exceeding 10 yr.

Production and composition of herbaceous communities following fire were highly variable across studies. In the first growing season following fire, total herbaceous vegetation was less abundant in seven studies, more abundant in four studies, and did not differ from unburned in three studies. In one study burning increased photosynthesis and nitrogen uptake in perennial grasses in the first year, but biomass was less on burned plots than on unburned plots. In the second and third postfire growing seasons (most often the third year), herbaceous plant abundance generally increased to equal or exceed that of unburned plots. Late spring fires (May) often increased biomass of tallgrasses whereas early spring fires reduced biomass. Spring fires favored late flowering and C_4 plants, whereas summer fires favored C_3 and early flowering plants. Timing of burning also influenced the proportion of grasses and forbs. Fire appeared to have an extended negative effect on herbaceous biomass if drought followed in the first season postfire. However, one study reported only a very weak relationship between fire, weather, and plant response. Perennial grass biomass usually increased following fire in productive tallgrass sites where excessive accumulation of mulch occurs. Forb production was often reported to be greater on unburned plots.

Shrub abundance (biomass, cover, volume) consistently declined the first year following fire and was generally less than the controls 3 yr after fire. Density of resprouting shrub species recovered or exceeded preburn levels within 3 yr following fire. Most shrubs in the Great Plains are resprouting and fire return intervals of 2–5 yr may be required to maintain herbaceous dominance. Nonsprouting encroaching trees, primarily Ashe juniper (*Juniperus ashei*) and eastern redcedar (*Juniperus virginiana*), increase without fire and gain dominance after about 30 yr. The effects of these fires depend on grazing intensity, which constrains fuel load and fire intensity.

Intermountain West. Of a total of 36 studies reviewed, 32% investigated individual plant species and 73% emphasized plant community responses. The majority of studies evaluated summer burns (57%, many of which were wildfires), but more than half considered fall or spring burns (35% fall, 21% spring) and only a single study evaluated winter burning. Spring and fall burns were prescribed fires. The majority of studies were short-term (72%) and only 8% exceeded 10 yr. Very few studies reported the method of burning or prefire and postfire conditions.

Thirteen studies reported total perennial grass response in the first postfire growing season, of which 10 reported a decline in cover, biomass, or density; one an increase in cover; and two no change in cover. The majority of these studies (7 of 9) showed that perennial grass recovered to that of unburned plots within 2–3 yr, whereas one study showed a decline in cover and one study an increase in cover. Perennial forbs generally increased as did annual grasses in the first postfire growing season. Bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg bluegrass (*Poa secunda*), and squirreltail (*Elymus elymoides*) were the most resistant to fire whereas Idaho fescue (*Festuca idahoensis* Elmer), Thurber's needlegrass (*Achnatherum thurberianum*), and rough fescue (*Festuca campestris*) consistently declined in the first year and either remained lower or recovered densities or cover equal to that of unburned plots. Broadleaved grasses and smaller bunches typically were more resistant to fire than fine-leaved grasses or large bunches.

Nonsprouting shrubs, primarily mountain big sagebrush and bitterbrush (*Purshia tridentate*, a weak resprouter), consistently decreased with fire and did not recover for 25–35 yr. However, recovery of Wyoming big sagebrush usually took longer with one study reporting only 5% sagebrush cover after 23 yr following fire. Cover of all shrubs (sprouting and nonsprouting) was reduced after fire. Few studies have evaluated sprouting shrubs (yellow and rubber rabbitbrush [*Chrysothamnus viscidiflorus* and *Ericameria nauseosa*], horsebrush [*Tetradymia* spp.]). However, limited work indicates biomass declines of these species in the first several years following fire with density typically recovering to preburn levels within 3 yr. In the Southwest, sprouting shrubs were the dominate vegetation 25 yr following fire.

Juniper (*Juniperus* spp.) and piñon pine (*Pinus* spp.) densities are reduced following fire, but large trees are more difficult to kill than small trees. Juniper cover of individual trees

> "A number of studies across US rangelands reported that shrubs and trees increase and herbaceous vegetation decreases with long-term fire removal…"

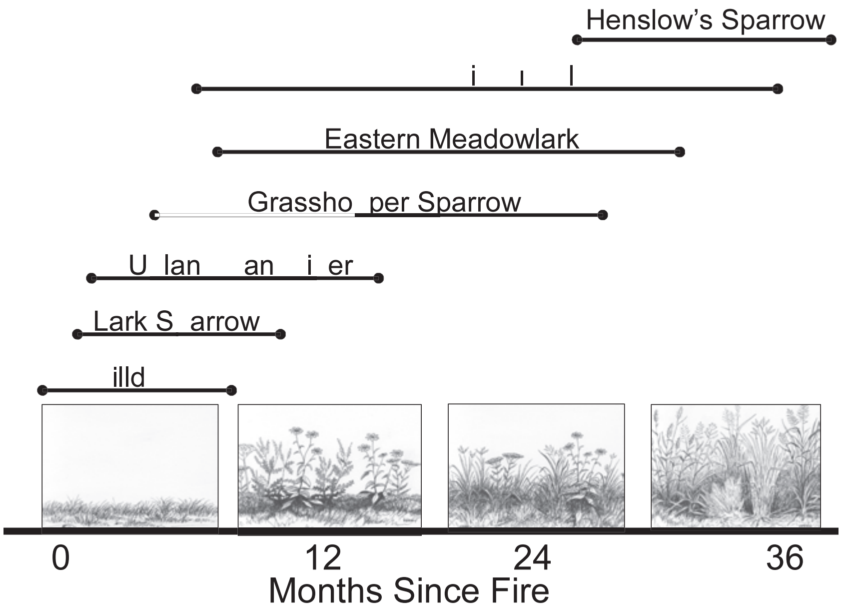


FIGURE 6. Response of grassland birds to time since focal disturbance by fire and grazing at the Tallgrass Prairie Preserve, Oklahoma, 2001–2003. Some birds native to the area require recently burned patches that are heavily grazed whereas others require habitats that are undisturbed for several years (Fuhlendorf et al. 2006). This research emphasizes that 1) the response of grassland birds to fire is highly dependent upon the interaction of fire and grazing and 2) fire management should not be considered in isolation from other environmental factors, including grazing. Figure courtesy of Jay Kerby and Gary Kerby.

increases slowly for the first 45 yr followed by rapid increase during the next 46–71 yr. Closed canopies can develop within 80–120 yr (Johnson and Miller 2006). Fire in woodlands is typically followed by an increase in perennial grasses and a reduction of woody plants. Sagebrush (*Artemesia* spp.) reached preburn levels in 36 yr and then often declined if piñon pine and/or juniper became established on the site. Understory cover declined to 5% of the adjacent grassland by 100 yr following fire as piñon and juniper woodlands developed (Barney and Frischknecht 1974; Wangler and Minnich 1996). However, understory composition following fire is highly dependent on the composition and abundance of the understory prior to the burn.

Fire and Wildlife

Of the 40 papers we evaluated concerning the effect of fire on rangeland wildlife, only 12 papers addressed US rangeland wildlife. These 12 papers focus on avifauna and small mammals, reflecting the large influence exerted by fire on habitat structure, to which these vertebrate assemblages are especially sensitive. It is interesting to note that measurements in most wildlife studies, including those we sampled, focus on wildlife population response and relatively few (only 2 of the 12 US studies) measured vegetation attributes (e.g., horizontal and vertical structure). Ten of the 12 studies were published since 2000, which indicates a recent upswing in research interest in wildlife response to fire. However, only 2 of the 12 studies included private land. The 12 studies were spread more or less evenly across geographic regions and vegetation types. As might be expected from a small number of studies, the studies addressed only a small number of questions related to the fire regime and the grazing environment. For example, only one of the studies (Fuhlendorf et al. 2006) addressed the ecological interaction of fire and grazing. From the Fuhlendorf et al. (2006) study and related research, we know that the ecological interaction of fire and grazing strongly influences habitat selection and habitat value for virtually all rangeland wildlife, including birds (Churchwell et al. 2008; Coppedge et al. 2008) and large ungulates (Hobbs and Spowart 1984; Coppedge and Shaw 1998; Biondini et al. 1999; Van Dyke and Darragh 2007). Large herbivores are attracted to nutritious regrowth of herbaceous vegetation, sometimes emerging outside the growing season (Coppedge et al. 1998; Biondini et al. 1999) on recently burned areas (Hobbs and Spowart 1984; Hobbs et al. 1991; Turner et al. 1994). In contrast, many, but not all, rangeland small mammal and bird species are more suited to areas not recently burned and grazed because these areas provide vegetative cover required for concealment or nesting. However, this influence can be mediated by drought (see Meek et al. 2008) and other factors.

The context in which prescribed burning is applied on rangeland marks the effect on wildlife species in question. Wildlife species in a given area have variable habitat requirements, so positive response by one species will likely cause other species to decline (Fig. 6). However, because rangeland and rangeland wildlife evolved with periodic fire and because periodic fire is required to maintain habitat suitable for wildlife species native to a particular rangeland region, fire is essential for maintaining rangeland wildlife populations.

Unnaturally long fire-return intervals often lead to tree encroachment and other changes that reduce habitat suitability for native wildlife species that are habitat specialists (Coppedge et al. 2001; Reinkensmeyer et al. 2007), some of which are species of conservation concern. In contrast, fire-return intervals greater than those with which an ecosystem evolved can have correspondingly deleterious effects on habitat and populations of habitat specialists (Robbins et al. 2002; Pedersen et al. 2003; Fuhlendorf et al. 2006; Rowland et al. 2006).

Fire and Water

We reviewed 25 papers that evaluated fire effects on various hydrologic processes in rangeland (Table 6). Hydrologic variables evaluated were water repellency (six papers), water quality (two papers), hydraulic conductivity or infiltration (six papers), and erosion/runoff (five papers). The majority of studies were conducted for 3 yr or less: 1 yr (52%), 2 yr (20%), and 3 yr (12%). Three studies (12%) were conducted for 5–6 yr, and one study was conducted for 9 yr. Variables that influenced the effects of fire on hydrology were aspect, fire severity, and microsites (coppice dunes formed beneath shrubs and trees vs. interspace). The largest decrease in infiltration rate and increase in erosion following fire occurred in coppice dunes beneath shrubs and trees. Fire had little effect on these two variables in shrub or tree interspaces. Water repellency usually occurred on both burned and unburned sites but usually increased, particularly beneath shrub and tree canopies, following fire. Hydrophobicity was reported to decline within several months to near preburn levels following wetting. Soil erosion on cooler, wetter sites in sagebrush-steppe communities (e.g., north aspects, or sites occupied by Idaho fescue compared to bluebunch wheatgrass) were less affected by fire than drier, warmer sites. One study reported rill erosion as the primary source of sediment and several studies reported rills readily formed in the coppice dunes. In general, these studies suggest that immediate effects of fire are largely negative on watersheds, but that the effects are short-lived.

Fire and Arthropods

Eighteen studies and one extensive literature review were evaluated for the effects of fire on arthropods. The majority of studies evaluated the response of grasshoppers (six studies) or arthropods in general ($n = 6$) to fire. Other species studied were ants (three studies), beetles (one study), and ticks (one study). In a literature review, Swengel (2001) reported few studies were conducted at the species level. The response of insects to fire was highly variable. Short-term and long-term response of insects to fire was influenced by intensity, complexity or patchiness of the burn, species requirements, and plant recovery. Thirteen of the 17 studies were conducted for 3 yr or less, three studies ranged from 4 yr to 9 yr, and one study extended for 25 yr. Insect abundance was usually lower (with the exception of grasshoppers) immediately following fire (up to 1–2 mo). In a 7-yr study across 21 different Great Plains sites, Panzer (2002) reported 93% of the species were consistent in their response to fire over the period of the study. Immediately following fire, 26% of arthropod species increased and 40% decreased. Of those that declined nearly two-thirds recovered within 2 yr. Insect orders *Homoptera* and *Hemioptera* appear to generally be more sensitive to fire whereas *Orthoptera* was little affected by fire. Fire effects on grasshopper populations generally showed limited response, but a shift in species composition frequently occurred.

Fire History

Obtaining a clear picture of the complex spatial and temporal patterns of historic fire regimes across the western United States before Euro-American settlement is unlikely. This can be attributed to limited sources of material (e.g., large charred wood or fire scars) available for reconstructing pre-historic fire regimes on most rangelands and the vast variation in fuel composition and structure,

TABLE 6. Effects of fire on several hydrologic variables compared to unburned plots and time periods required for recovery to near preburn levels.

Variable	Decreased	Increased	No change	Recovery
Soil repellency	1	5	0	2.5–3 mo
Infiltration	6	0	4	2 yr
Runoff	0	6	1	2 yr, 4–5 yr
Sediment loads	0	9	1	1 yr
Water quality	2	0	0	3–5 yr

In many cases, when woody plants reach a substantial size and/or density, fires will either be ineffective or require greater expertise to conduct them. Using extreme fires for restoration is an emerging topic in conservation of rangelands. An active prescribed burning program could help minimize the risk associated with extreme fires. (Photo: John Weir)

landscape heterogeneity, ignition from aboriginal and lightning sources, weather, and topography across this region. We reviewed 24 papers that attempted to describe pre-historic fire histories across the western United States. We tried to capture all of the papers that collected quantitative data to reconstruct pre-historic fire regimes related to rangelands. We also included several studies in ponderosa pine in addition to woodlands that evaluated the timing of reduced fire occurrence and livestock grazing. Twelve of the papers were based on fire scar data, two used charcoal or ash samples, and three used the presence of old-growth piñon or juniper trees. Of the 12 papers using fire scar data, samples were cross-dated in seven studies. Cross-dating is a procedure that verifies the exact year of the fire, important for calculating fire-return intervals and determining the extent of individual fires across larger areas.

Duration of the fire record based on fire scars ranged from 250 yr to 500 yr before present (BP). Charcoal studies ranged from 5 500 yr to 6 000 yr BP. Pre–Euro-American settlement fire regimes reconstructed from cross-dated fire scars or large charred wood across western rangelands are few and primarily restricted to the intermountain region. Fire histories based on fire-scarred trees are also spatially limited to the rangeland–forest ecotones in the Intermountain West, which often occur as mosaics of conifers and sagebrush-steppe grasslands. Fire-scar samples are usually collected from fire-resistant trees (e.g., ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) and occasionally less fire-resistant trees (e.g., Utah juniper [*Juniperus osteosperma*], piñon pine). Several of these studies also evaluated tree age structure in adjacent forest and shrub-steppe patches.

Pre-historic (pre-1900) mean fire-return intervals reported along ponderosa or Douglas-fir–mountain big sagebrush-steppe ecotones varied from less than 10 yr (three studies) to 10–30 yr (six studies). Studies reporting longer fire-return intervals were associated with low sagebrush (*Artemisia arbuscula*; 90 yr to 150 yr) and were based on tree age structure and charred logs and stumps of juniper. The relatively short fire-return intervals (< 30 yr) would have supported grass-dominated communities along the forest ecotones. Extrapolation of these fire-return intervals away from range–forest ecotones is probably speculative and likely becomes longer in more arid ecological sites, especially those occupied by Wyoming big sagebrush. Macroscopic charcoal data collected in central Nevada suggested that fire-return intervals in the drier Wyoming big sagebrush cover type over the past several thousand years were up to a century, with fire intervals varying with climatic fluctuations.

Several consistent patterns regarding fire-return intervals emerge from these papers. First of all, there is consistent evidence that most rangelands in the United States have experienced a dramatic increase in fire-return intervals over the past 100–200 yr. Six of the studies reported sharp declines in fire occurrences that coincide with the introduction of livestock. Piñon–juniper woodlands that have persisted for the past several or more centuries did not show evidence of high-frequency, low-intensity surface fires. Five of the studies reported probability of sites being occupied by old-growth trees to be associated with rocky surfaces and limited surface fuels but none as fire refugia. Three studies reported the probability of large fires increases in years preceded by wetter than average years. At a longer time scale, Mehringer (1987) and Mensing et al. (2006) reported a correlation of increased fires during periods of wetter than average conditions.

Quantitative measures of pre-historic fire return intervals in the tallgrass prairie are not available for the Great Plains. The assumption that prehistoric fire regimes in the tallgrass prairie were characterized by frequent low-intensity fires is primarily based on 1) observations from early explorers, trappers, and settlers, and 2) research showing that in the absence of fire these grasslands shift rapidly from prairie to woody species (Bragg and Hulbert 1976). Several authors have estimated mean fire-return intervals of 3–5 yr (Wright and Bailey 1982; Knapp and Seastedt 1996). However, little is known about the dynamics of native grass and woody species prior to Euro-American settlement. It is also likely that the influence of bison on fuel loads affected fire-return intervals across the Great Plains.

Fire and Soils

The vast majority (45 of 51; 88%) of the papers we evaluated on fire effects on rangeland soils were published in ecological or soil science journals rather than *Journal of Range Management*, *Rangeland Ecology and Management*, or applied ecology journals. Therefore, the overall emphasis within the research base leans toward ecological understanding rather than to explicitly answering management questions. Twenty-eight papers (55%) reported effects of fire on soil chemistry (pH, nutrients), and 17 (33%) reported on the effects of fire on one or more variables (infiltration, soil water content, water repellency, erosion) related directly or indirectly to the water cycle.

The literature on rangeland soils, including the effects of fire on rangeland soils, is quite voluminous. For example, one of the sampled papers is a recent analysis of the literature on water repellency. In it, Debano (2000) employed a bibliography of over 700 published papers reporting on either various aspects of water repellency (500 papers) or published papers (200) that contribute information directly related to understanding the basic processes that underlie soil water repellency. Water repellency, a global rangeland issue reported for numerous vegetation types following fire, also occurs in soils other than rangeland.

The scope of these studies further limits the inferential base for applying the results to

"…there is consistent evidence that most rangelands in the United States have experienced a dramatic increase in fire-return intervals over the past 100–200 yr."

Bison at the Tallgrass Prairie Preserve in Oklahoma grazing on a recently burned patch. (Photo: Steve Winter)

management of US rangelands. Although physical processes are not place-bound, only 16 of the 51 studies reported research from US rangelands. Fortunately, these were distributed more-or-less evenly across the United States (eight in the Great Plains or central prairies) and across vegetation types (grasslands, shrublands, etc.). However, small plots (0.0003–1 ha) were the general rule and studies often reported effects from a single fire (22 papers), and only 10 of the 51 studies encompassed time periods of 10 yr or more. An encouraging sign is a recent increase in published studies enhancing basic understanding of soil response to fire; the majority of papers published since 1998 (35; 69%) focus on this.

The influence of fire on soil depends largely on the prefire and postfire environment, interaction with other factors including grazing and invasive species, and the evolutionary history of the ecosystem with regard to fire frequency and grazing. However, it is notable that on US rangeland that are often characterized as lacking a long evolutionary history of frequent fire most fire research is based on observations following wildfires rather than controlled studies with prescribed fires. For example, portions of the Great Basin shrub-steppe have had substantial increases in fire-return interval and burn area over the past century (Miller et al. 2011). In contrast, prescribed burning and the ecological role of fire are the context of studies on rangelands characterized by a long evolutionary history of frequent fire, specifically the Great Plains.

Soil organic matter, resistant to change when rangeland fire is wind-driven and fueled by fine fuel, has long been a subject of interest to rangeland fire researchers (e.g., Reynolds and Bohning 1956; Owensby and Wyrill 1973). Recent research has increasingly reported the influence of fire on soil organic carbon (and CO_2 ecosystem flux) and carbon sequestration, which is tied to atmospheric properties related to global climate change. In the single study located in the United States that appeared in our sample (Ansley et al. 2006a), carbon storage in soil increased with fire, likely the result of a shift in species composition. Recent research in the Intermountain shrub-steppe suggests plant invasions (i.e., *Bromus tectorum*) can reduce soil carbon (Bradley et al. 2006; Prater and DeLucia 2006), but this did not occur in a similar shrub community when perennial native grasses dominated postfire (Davies et al. 2007). Burning changed soil carbon in a semiarid Great Plains rangeland, but the magnitude of change was inconsequential partly because of a relatively low CO_2 flux (MacNeil et al. 2008). In subhumid Great Plains rangeland where CO_2 flux is markedly greater, soil carbon flux increases with periodic burning over ungrazed rangeland because burning removes accumulated litter that creates temperature and light-limiting conditions for plant growth, but annual burning will reduce both soil organic matter and nitrogen mineralization (Ojima et al. 1994; Blair 1997). Annual burning over perhaps 20–100 yr may increase the fraction of passive soil organic matter at the expense of more active fractions, which might ultimately reduce total soil organic carbon (Ojima et al. 1994). Nevertheless, most ecosystem carbon loss in rangeland results from combustion of aboveground organic material (i.e., fuel), with the time to reach prefire levels dependent on primary productivity (MacNeil et al. 2008). Soil carbon response to the ecological fire–grazing interaction has not been investigated, but because nitrogen and carbon are coupled in the organic matter pool, soil carbon might show similar increases following fire–grazing disturbances to soil nitrogen (Anderson et al. 2006).

Nitrogen in aboveground biomass is volatilized in fire and varies with environmental conditions and fire characteristics in that drier fuels and soils and hotter fires result in more intense combustion and more nitrogen volatilization (DeBano et al. 1979). Because most prescribed burning objectives call for conditions that consume most aboveground herbaceous fuel, it is often assumed that fire depletes ecosystem nitrogen. Indeed, postburn soil inorganic nitrogen (NO_3 and NH_4) is often less, but greater herbaceous aboveground annual production and vegetation cover at some point after burning suggests plant-available nitrogen increases following burning.

Stocker calves grazing on areas recently burned in the summer and providing new growth forage in the fall at the Stillwater Research Range. Unburned patch is shown in the background. (Photo: Sam Fuhlendorf)

> “…documentation of fire behavior on rangelands does not provide suitable guidance to address the NRCS’s purposes of prescribed burning.”

Research in subhumid rangeland (Blair 1997) and semiarid rangeland (Davies et al. 2007) indicates that burning increases nitrogen mineralization and enhances other mechanisms that result in increased nitrogen. Therefore, burning indirectly enhances plant capability to utilize nitrogen. Annual burning of subhumid rangeland over a period of 20–100 yr has been predicted to reduce mineralizable nitrogen similar to the effect on soil organic carbon (Ojima et al. 1994). Because grazing reduces the amount of nitrogen available for volatilization by fire and because nitrogen loss is proportional to biomass available for combustion, grazing weakens the effects of fire on soil nitrogen (Hobbs et al. 1991). This likely explains why nitrogen fertility was not diminished with annual burning coupled with long-term moderate grazing (Owensby and Anderson 1967). Moreover, this mediating effect of grazing is subject to the effect of scale and preferential grazing of patches (McNaughton 1984; Hobbs et al. 1991). When fire and grazing interact spatially (i.e., the fire–grazing ecological interaction) in a subhumid rangeland, plant-available nitrogen increases in recently burned, focally grazed patches (Anderson et al. 2006), but unburned patches with minimal grazing pressure have low levels of available nitrogen. No published research on the effects of the fire–grazing interaction on soil nitrogen is available for other rangelands.

Some fire prescriptions, wildfire, and fuel situations in rangeland can result in extreme soil heating, which can markedly change soil chemical and physical properties. Brush piles and thinning slash, in particular, create intense heat that can change biological, chemical, and physical properties of soil and can induce undesirable vegetation change including plant invasions (Neary et al. 1999; Haskins and Gehring 2004). Although the mechanisms and impact of soil heating are known, other than postfire restoration (for example, see Korb et al. 2004), we found no studies that fashion rangeland fire prescriptions and vegetation management guidelines to reduce the impact of soil heating with burning brush piles and slash.

Fire and Livestock

Among the 476 papers evaluated pertaining to fire on rangelands, over 25% of the studies referred to grazing by either livestock or wildlife. However, only five papers evaluated the influence of fire on livestock performance, of which only one paper was from the United States. Recognizing the potential for bias within our initial literature review, we broadened our search criteria to include articles with “fire or burn” and “livestock, cattle, sheep, or horses” in the subject. Even with this less restrictive search, only three additional papers focused on fire and livestock and they revealed a span of 26 yr between studies. Due to the limited number and geographic scope of the studies, few detailed inferences can be made. Early research from the Great Plains region focused on livestock performance and indicated that midspring and late spring burning increased steer weight gains, particularly early in the growing season (Anderson et al. 1970; Smith and Owensby 1976). Burning portions of unimproved Florida rangeland annually improved calf production as much as 75% over unburned pastures (Kirk et al. 1976). The increased benefit from burning alone was comparable to supplemental feeding, especially when considering the increased cost of supplemental feed. Increased livestock performance is mostly attributed to increased forage quality from increased plant crude protein and decreased fiber content following fire (Grelen and Epps 1967; Allen et al. 1976; Kirk et al. 1976). Within the fire–grazing interaction, cattle are attracted to recently burned locations, which provide higher-quality forage than the surrounding matrix of unburned vegetation, and devote 75% of their grazing time within recently burned areas (Fuhlendorf and Engle 2004). The disturbance created by the interaction of cattle grazing and fire mimics historical grazing behavior of large ungulates and creates a structurally diverse landscape.

Prescribed Fire and Air Quality/Smoke Management

Rangeland fire generates a wide variety of by-products that fall into two broad categories, gasses and particulates. Smoke, the visible product of partially combusted fuel material, contains an array of organic and inorganic airborne particulates. Airborne particles can be a nuisance, reducing visibility hundreds of kilometers downwind from emission sources (Ferguson et al. 2003; McKenzie et al. 2006) and degrading air quality (Martin et al. 1977).

Prescribed fire produces 15–25% of airborne particulates and 7–8% of hydrocarbons emitted to the atmosphere annually (Martin et al. 1977). However, environmental conditions, fuel characteristics, and characteristics of the fire itself influence the amount of noncombusted material produced. Relatively low-intensity fires, where more complete combustion is expected, were modeled to produce about 50% less smoke than higher-intensity fires with higher rate of spread and less complete combustion (Glitzenstein et al. 2006). Fuel consumption and fire intensity clearly influence emissions from rangeland fire.

Particle size influences the period of suspension in the atmosphere. Relatively large particles, between 0.07 µm and 1.0 µm diameter, may take days to settle out, whereas small particles less than 0.07 µm do not settle under natural conditions (Martin et al. 1977). Larger particles do not remain suspended for long time periods, yet can be problematic for individuals with asthma or other chronic respiratory conditions (Dockery et al. 1993). Although smoke management is important as it relates to air quality, our review of the literature revealed that only six papers addressed smoke management on rangeland and thus conclusive evidence is limited. Further investigation is needed to provide a complete understanding of how prescribed fire influences air quality.

Fire Behavior and Fire Management

In addition to contributing to an understanding of the influence of fuels and environmental conditions on fire behavior, many of the fire behavior studies that we reviewed more directly addressed questions related to other sections of this report. Only a few studies addressed plant responses (e.g., tree mortality; Kupfer and Miller 2005) as a function of fire behavior, and fire behavior was reported in several studies as one of several aspects of environmental conditions under which the study was conducted (e.g., Engle and Weir 2000; Ansley et al. 2006a). Measuring a correlate (e.g., char height on trees; Fule and Lauglin 2007) of a primary fire behavior characteristic (e.g., fireline intensity) was common (8 of 11 US papers).

We examined our sample of published papers to determine the extent to which they addressed NRCS's relevant objectives of prescribed burning (i.e., prepare sites for harvesting, planting, or seeding; reduce wildfire hazards; remove slash and debris). Of the 41 studies sampled on fire behavior, only 11 were located in the United States (and three were in southeastern forests), so specific application to US rangelands is minimal for at least three-quarters of the studies. Of the 11 US studies, two studies (Sparks et al. 2002; Glizenstein et al. 2006) related to wildfire hazard reduction and slash removal in southeastern US forests, and no studies were related to fuels management on rangeland. One study (Gilless and Fried 1999) examined a computer model for its utility in planning fire suppression. Based on our literature search, it appears documentation of fire behavior on rangelands does not provide suitable guidance to address the NRCS's purposes of prescribed burning. For example, mortality or scorch height of invasive woody plants is highly dependent on fire intensity, which is rarely measured in rangeland studies.

The refereed literature on fire management is insufficient to adequately evaluate the NRCS's purposes of prescribed burning (e.g., what types of management will promote different purposes). However, a significant quantity of literature on fire behavior and fire management, addressing both prescribed burning and fire danger related to rangeland is found in federal government documents, especially those published from the US Forest Service Fire Sciences Laboratory in Missoula,

Backfire of a prescribed burn at the Tallgrass Prairie Preserve of Oklahoma. (Photo: Terry Bidwell)

TABLE 7. Assessment of the 10 purposes within the Natural Resources Conservation Service (NRCS) prescribed burning conservation practice standard relative to the supporting experimental evidence. Observations on the evidence provided by the peer-reviewed scientific literature supporting NRCS purposes for prescribed burning.

Purpose	Aspects that agree with the purpose	Aspects that suggest limited or no support for purposes	Further needs and considerations
Control undesirable vegetation	Fire can be effective in reducing the stature of resprouting, fire-adapted shrubs and trees, some invasive herbaceous plants, and the encroachment of fire-sensitive shrubs and trees.	Most effects are too short-lived to support the purpose over meaningful management time spans. Most species are reduced only in stature and without mortality. Many species are not negatively affected by fire, and some species increase after fire.	Generalizations concerning season, frequency. and intensity of fire are mostly unsupported.
Prepare sites for harvesting, planting and seeding			No evidence in our database—additional searches[1] generated few additional papers with controlled comparisons.
Control plant diseases	One study from a comprehensive search[1] suggested that fire can reduce the density of host species (oak), but the authors recommended more study to validate their results.		No evidence in our database—additional searches[1] generated few additional papers with controlled comparisons.
Reduce wildfire hazards	Models and observational studies suggest that fire-induced vegetation changes can alter subsequent fire regimes and reduce fine fuel loads to decrease the likelihood of high-intensity, stand-replacing, destructive wildfire.	Prescribed fire that reduces woody plants and maintains grassland productivity can increase the likelihood of fire.	No evidence in our database—additional searches[1] generated few additional papers with controlled comparisons.
Improve wildlife habitat	Fire can maintain and restore habitat for native wildlife species in some situations.	Any action that improves habitat for one species likely degrades habitat for another.	Studies limited mostly to birds and small mammals. Time since fire, the key element, has been minimally studied.
Improve plant production quantity and/or quality	Several studies indicate increased plant production and forage quality but these are mostly restricted to the Great Plains—several additional studies indicate animal preference for burned sites. Most studies show an initial decrease in quantity and then recovery, with limited studies showing an actual increase over time. However, majority of studies do not evaluate response beyond 5 yr.		Minimal information on grazing animal response following fire. Therefore, if the purpose is intended to benefit livestock production through increased forage production or improved forage quality, support is limited. The use of terminology such as "plant quality" is overly broad and could suggest wildlife habitat is improved following fire, but this is not supported well in the research literature.
Remove slash and debris	Fire can be used in Southeastern pine forest to remove slash and maintain savanna and to remove brush piles and brush windrows.		No evidence in our database—additional searches[1] generated few additional papers with controlled comparisons. Because fire effectiveness varies, more study is needed on fire effects and fire management after brush treatments to restore rangeland.
Enhance seed production	Fire can increase seed production of both native species and exotic invasive plants.		Seed production is rarely measured in fire research. This purpose is irrelevant to those rangeland plants that reproduce vegetatively.
Facilitate distribution of grazing and browsing animals	Recently burned areas generally attract grazers because burning increases herbivore access to current year's forage growth.		The fire–grazing interaction is an appropriate tool that employs attraction of large herbivores to recently burned areas, but research is limited to experimental studies in Oklahoma and observational studies of wildlife.
Restore and maintain ecological sites	Fire regimes that mimic evolutionary conditions of the rangeland in question will maintain ecological sites and therefore maintain grassland, savanna, and shrubland ecosystem structure.	Reintroducing fire will not always restore ecological sites. Prescribed burning that creates fire regimes that do not mimic historic fire regimes can induce site degradation by altering biotic and abiotic characteristics (e.g., hydrophobic soil).	Most ecological sites lack a complete fire regime description (especially where fire intervals are long).

[1]Additional literature searches used a topic search in Web of Science for *fire* AND *rangeland* AND *Reduce wildfire hazards*.

Montana. The early science on fire behavior that culminated in Rothermel's (1983) seminal user-friendly fire behavior prediction model was applied to rangeland, and many rangeland fire managers have used this version of the model that does not require a computer. More recently, a suite of dynamic computer models have greatly expanded the management value of the Rothermel model to applications in variable terrain and varied fuels and fuel loads. Coupling these models with sophisticated fuel models informed by state-of-the-art fire–weather observing stations and near real-time remote sensing of fuels has greatly enhanced fire management on privately owned rangeland (Carlson et al. 2002; OK-Fire 2009).

Fire and Human Dimensions

From all of the papers evaluated, 36 addressed a wide variety of human aspects related to rangeland fire ranging from education and public perception of fire to health and policy issues. Although all regions of the United States were covered, over 80% of the studies focused on the West Coast or Intermountain regions. Human dimensions on rangelands have recently gained attention and are reflected in 75% of the studies pertaining to fire dated 2000 or later. Because of the recent interest in human dimensions, CEAP devoted an entire section to socioeconomics, so we restricted our summarizations to limit duplicate information.

DISCUSSION OF FINDINGS

Most research evaluated here was not developed with the intent of providing specific recommendation for management of rangeland landscapes. Moreover, constructing research based on NRCS purposes for prescribed burning is limited by spatio-temporal scale of the research; limited description of conditions prefire, postfire, and during the fire; failure to account for interaction with other disturbance processes occurring on rangelands (e.g., grazing, drought); simplifying a complex fire regime to a single treatment event; and the lack of a focus on fire effects that are highly dependent on time since fire. Even with this paucity of research evidence, our evaluation demonstrates that several of the NRCS purposes for prescribed burning can be justified but with many caveats (Table 7). Specifically, management of woody plant invasion is supported by a fairly consistent response in which prescribed fire limited invasion. It is less clear if fire can reverse woody plant invasions when thresholds have been crossed. The purpose of using prescribed burning for short-term control of undesirable plants is justifiable based on research that shows some herbaceous species respond negatively to fire in the first growing season following fire, especially when combined with focal grazing. However, most herbaceous species recover within 2–3 yr postfire regardless of season of the burn. Contrary to this purpose, some regionally important herbaceous species in each rangeland region of North America respond negatively to fire 1 yr, 2 yr, and 3 yr postfire. In general, few negative effects and more neutral and positive effects have been demonstrated on target herbaceous species in response to fire. With the exceptions of the expansion of invasive annual grasses in the Intermountain West following fire (Miller et al. 2011), these conclusions were surprisingly consistent across the Great Plains, Intermountain West, and Desert Southwest. A few studies report increased productivity and forage quality the year of the fire, but because these are mostly from mesic grasslands, this NRCS purpose for prescribed burning is not broadly supported by research evidence.

It is widely recognized that the importance of all processes on ecosystem structure and function are highly dependent on the scale of observation. In fact, it has been suggested that studies should be conducted at multiple scales and the interpretations of research should recognize the limited ability to translate conclusions across scales. Several rangeland studies have demonstrated that vegetation dynamics (Fuhlendorf and Smeins 1996, 1999; Briske et al. 2003) and wildlife populations (Fuhlendorf et al. 2002) are highly dependent on spatial and temporal scale and that important processes at one scale are not necessarily transferable to other scales. Our analysis suggests that the vast majority of the data available on fire is either conducted at scales too small to be relevant to management (< 1 ha) or, in some regions, based on wildfire. Most studies were limited to short-term responses (< 3 yr) and often a single application of a fire, so they have minimal application to the long-term goal of restoring fire to

"…most herbaceous species recover within 2–3 yr postfire regardless of season of the burn."

“Experimental fire research rarely treats fire as a *regime* in which fire recurs and response to fire is dynamic and variable with fire intensity, fire interval, and other fire variables.”

rangeland ecosystems and strategic ecosystem management.

Conducted largely as short-term studies on small plots, much of the research on prescribed burning is unable to describe complex patterns in space and time that may be associated with interactions with other disturbances, such as grazing and drought. Because these studies are but a step removed from highly controlled greenhouse studies with limited application in the real world, much of this research fits solidly within a “So what?” category when evaluated for specific management application. For example, a study conducted on vegetation response to burning that is conducted by mere coincidence in a drought and on small plots that were not grazed (e.g., Engle and Bultsma 1984) cannot be used to support prescribed burning relative to vegetation responses across spatially variable, grazed pastures in nondrought periods.

Long-term research at management-relevant scales that embrace interactive responses and complex patterns is insufficient to provide the NRCS with data necessary for constructing the relevant purposes for prescribed burning. The synergistic effects of fire and grazing on large landscapes have largely been uncoupled within rangeland research and conservation, even though most are aware that grazing by native and domestic herbivores is a dominant feature on all rangelands. An example of the uncoupling of fire and grazing is the tendency to recommend removal of grazing following fire, which does not seem to be supported by research. Grazing was part of the experimental design of fire studies in a mere13.3% of the studies and most of the studies inadequately presented the methods or results to provide effective conclusions regarding the presence or absence of grazing. Fire and grazing operated historically as an interactive disturbance process in which neither was independent of the other. When allowed to interact in space and time, fire and grazing create a shifting mosaic pattern that cannot be predicted from short-term, small-scale studies (Fuhlendorf and Engle 2001, 2004). Understanding the effects of a fire on grassland soils is highly dependent upon grazing (Hobbs et al. 1991). Moreover, nonequilibrial dynamics and resilience theory predict that episodic events, such as drought, can interact with other processes, such as fire and grazing, to promote changes that may not be predictable from understanding these events independently. Finally, most research on burning compares two treatments, *fire* and *no fire* (or burned and unburned), and the fire treatment is a single event rather than reoccurring fire couched within a complex fire regime.

Much of the research also lacks relevance to prescribed burning as a conservation practice because it fails to account for the potential for fire effects to be highly dynamic and variable with time since the previous fire. Only 4% of the papers included *time since fire* as an important variable when describing the magnitude and persistence of fire effects. This synthesis indicates that vegetation response 1–3 yr since the previous fire differs considerably from vegetation response in which the most recent fire was 4 yr ago or longer. Moreover, recovery rate varies greatly among response variables. Recovery of soil and water variables can be as little as several months to as much as decades depending on factors such as soil structure, vegetation condition at the time of the fire, and fire intensity. Fire frequency also compounds temporal response to fire, but it was a primary focus in only 12.5% of the studies. This further emphasizes that the research largely fails to assess dynamic fire regimes and the long-term dynamics of fire-dependent ecosystems.

Experimental fire research rarely treats fire as a *regime* in which fire recurs and response to fire is dynamic and variable with fire intensity, fire interval, and other fire variables. Research and management often approach fire as a single discrete event, so the impact of fire is highly dependent upon the conditions at the initiation of fire, conditions following fire, fire season, fire intensity, and time since fire. Research on fire regime rather than on discrete fire events would be more comparable to the study of grazing systems or constant stocking rates rather than the study of a single plant defoliation by a herbivore. Land grant institutions and federal agencies have been conducting research on grazing management for the past 50–100 yr and many of the methods have become standardized (which is not always positive). Fire research, on the other hand, has lagged

Prescribed fire on sand sagebrush rangelands in Oklahoma that was intended to create heterogeneity for wildlife, variable grazing distribution, and control the invasion of Eastern Redcedar. (Photo: John Weir)

greatly, and has increased meaningfully in only the past decade. The lag in research is largely due to limited recognition of the importance of fire in a grazing-centric discipline and the concomitant limitation in research funding (partially alleviated by the Joint Fire Science Program [JFSP]). Our synthesis suggests that relevance of fire regime research for management goals continues to lag behind grazing regime research.

The use of fire to improve wildlife habitat is a complex issue that is not easily evaluated because some species respond positively and others respond negatively to prescribed fire. Therefore, fire-improved habitat for one species likely translates into fire-degraded habitat for another. Groups of organisms that are negatively influenced often recover rapidly unless they occur in a highly fragmented landscape where dispersal from unburned areas is limited. These conclusions have led some authors to suggest that heterogeneity should be promoted to maintain a shifting mosaic landscape so that the entire landscape is not burned or unburned at any point in time, but research is lacking to support this across most rangeland types. Moreover, research on wildlife response to prescribed burning has preferentially focused on birds and small mammals. This likely reflects the fact that these species groups are more sensitive to fire-altered habitat than most other wildlife, and that these species are more easily studied. Consequently, specific species and not merely species groups must be identified when developing burning programs to support wildlife.

The responses of soils and hydrology to fire are highly variable, but water repellency (i.e., hydrophobic soil) is a negative effect of extreme soil heating that occurs mostly under intense wildfire where fire has been absent for many years or in ecosystems with less evolutionary importance of fire. In general, fire increased water repellency, runoff, and sediment loads and decreased infiltration and water quality. Most of these effects disappeared after 2–4

Landscape photo of northern British Columbia demonstrating a shifting mosaic of fire patterns. Vegetation patterns are all due to variable times since fire resulting in highly variable plant communities. (Photo: Sam Fuhlendorf)

yr. Variables that influenced the effects of fire on hydrology were aspect, fire severity, and microsite characteristics. Soil chemistry is also highly variable and dependent on the ecosystem studied, pre- and postfire conditions, invasive species, and grazing. Some fire prescriptions, wildfires, fire-return intervals, and fuel situations in rangeland can result in extreme soil heating, which can markedly change soil chemical and physical properties. Otherwise, fire events corresponding to the evolutionary fire regime have short-lived and slight influence on soil chemistry.

RECOMMENDATIONS

1. The need for historic fire regimes to maintain the structure and composition of historic plant communities is well supported by ample scientific evidence. Many of the purposes in this conservation standard would benefit from the incorporation of more-specific goals and outcomes that can be more effectively compared to and supported by evidence in the peer-reviewed literature. Refer to Table 7 for evidence provided by the peer reviewed scientific literature supporting the current NRCS purposes for prescribed burning.
2. Conservation outcomes of prescribed burning are most likely to be attained when the specific purposes for prescribed burning are tailored to the unique characteristics of the ecosystems being managed. Highly generalized purposes are necessary for the establishment of national guidelines, but they may often be misleading because ecological processes such as seed production, seed germination, plant mortality, etc. are likely to be highly variable among ecoregions and even within communities and soils within ecoregions. Even widely accepted generalizations, such as the NRCS purpose that fire can be used to control undesirable vegetation, carry caveats and exceptions when details are considered.

3. Fire effects on ecosystems are often considered to be static over time, even though the research literature indicates that fire effects vary with time since fire and time between successive fires. Therefore, conservation purposes need to incorporate temporal dynamics to the extent that this information is available. Rangeland ecosystems evolved under specific fire regimes rather than in response to individual fires, which requires that conservation programs incorporate comprehensive fire regimes that address both short- and long-term outcomes. Ecosystem responses to fire and the effects of fire are both strongly influenced by temporal scale and must be carefully considered in conservation planning. Ecological site descriptions and rangeland research suggest that the prescribed burning standard should elevate application (i.e., area, number of plans, etc.) of prescribed burning so that it receives as much or more emphasis as the application of the conservation standard for grazing. There is no single practice as important to the maintenance of rangeland ecosystems.
4. Given the foregoing cautions against nationally generalized purposes, the following purposes for the practice of prescribed burning are supported by the research literature. These purposes should consider the context of the fire regime, rather than a single fire in isolation:

    a. to alter plant composition, reduce undesirable herbaceous plants, and reduce accumulated litter for a short period of time (generally 1 yr);
    b. to improve forage quality for < 3 yr;
    c. to limit encroachment of fire-sensitive shrubs and trees;
    d. to manage stature of resprouting, fire-adapted shrubs and trees;
    e. to alter distribution of grazing and browsing to either promote uniform distribution (by spatially homogenizing attractiveness) or to promote heterogeneity for biodiversity;
    f. to reduce potential for high intensity, stand-replacing fire by reducing accumulated fine fuel;
    g. to maintain grassland, savanna, and shrubland ecosystem structure, i.e., to prevent transitioning to woodland; and
    h. to recognize that mosaics of plant communities that vary with time since fire are critical for wildlife diversity.

KNOWLEDGE GAPS

1. Fire is as critical as climate and soils to the maintenance of ecosystem structure and function in many systems, but only limited experimental evidence exists to support the specific NRCS purposes for prescribed burning, especially those that involving long fire-return intervals.
2. The experimental literature supporting prescribed burning is in need of greater managerial relevance that can be obtained by directly addressing spatial scale, temporal scale, and interaction with other disturbances, including drought and grazing. Reliance on information resulting from single fires applied on small plots tracked for a relatively short time interval greatly constrains inferences and application to ecosystem management and this information should be applied with caution.
3. Knowledge of smoke characteristics and smoke management, effects of fire on wildlife and insects, and fire behavior and fire management exist in some regions, but are limited in other regions. The lack of sufficiently meaningful data on these topics makes it difficult to inform prescribed burning practices at the national level.

CONCLUSION

The vast majority of scientific evidence addressing fire in rangeland ecosystems points to the value of and need to continue or restore fire regimes with conservation programs. This is especially relevant given the accelerating rate of woody plant encroachment in grasslands and savannas, but it is important to other conservation outcomes, including altering grazing behavior of ungulates and maintaining biodiversity. The incorporation of prescribed burning conservation programs must include an understanding of the dynamic role that fire plays in most rangeland ecosystems. Fire regimes are equivalent to soils and climate in terms of their influence on plant community

Fire in a mixed grass prairie. (Photo: Steve Winter)

composition and landscape patterns. Recognition of fire as a dynamic regime that has variable effects depending on the interaction with grazing and climate patterns is critical to optimizing conservation effectiveness in rangeland ecosystems.

The complex interaction of scientific knowledge, social concerns, and variable policies across regions are major limitations to the successful and critical restoration of fire regimes. Successful grassroots actions that have led to increased use of prescribed fire include the development of prescribed fire cooperatives through many of the Great Plains states. These cooperatives build on regional strengths to bring landowners together to conduct prescribed fires on landscapes that have variable ownerships. These cooperatives have enabled landowners to overcome issues associated with labor, liability, and training and to restore fire regimes in regions that have had fire removed for more than a century. Landowner cooperatives have the potential to transform the application of fire and indicate that successful conservation practices based on fire are possible even in areas that do not have a history of prescribed burning.

To address the shortfalls in research applicable to prescribed burning on rangelands and the limited application of prescribed burning on rangelands, we recommend that the NRCS position itself to drive rangeland research and fire research agendas. Research to support NRCS purposes for prescribed burning on rangeland, unlike forests, has been limited by insufficient funding. However, a NRCS-driven research agenda also is lacking because NRCS has been detached from federal fire programs, notably LANDFIRE and the JFSP. Involvement in these programs would afford NRCS a greater opportunity to engage the scientific community and interact with other federal agencies that are developing valuable fire management tools and promoting fire research. This would provide NRCS with a platform for developing a research agenda relevant to supporting fire management on private lands.

LANDFIRE is an interagency vegetation, fire, and fuel characteristics mapping project (www.landfire.gov). Developed through cooperation of natural resource agencies other than NRCS (Bureau of Land Management, US Forest Service, National Park Service, etc.) and The Nature Conservancy, LANDFIRE was initiated by a request from federal agencies to develop maps needed to help land managers prioritize areas for hazardous fuel reduction and conservation actions. LANDFIRE has spatial data layers that include all layers required to run fire modeling applications such as FARSITE and FlamMap, existing vegetation type, canopy height, biophysical setting, environmental site potential, and fire regime condition class, as well as fire effects layers. Since its initiation, LANDFIRE has been expanded to address the entire United States, including private as well as public land, but it also has some data needs. Vegetation dynamics models that operate with Vegetation Dynamics Development Tool software form a major component of LANDFIRE. These state-and-transition models are similar to those being developed by NRCS in that they describe pathways of vegetation succession and the frequency and effects of disturbances; however, these models are quantitative and based on extensive field analyses and modeling. Currently, rangelands are underrepresented and could be enhanced by involvement of NRCS in this national fire effort. We recommend that the NRCS engage the development and use of decision tools like LANDFIRE and OK-Fire (2009) that facilitate management and application of fire on rangelands.

The JFSP was created by Congress in 1998 as an interagency research, development, and applications partnership between the US Department of the Interior and the US Department of Agriculture–Forest Service (http://www.firescience.gov/index.cfm). Funding priorities and policies are set by the JFSP Governing Board, which includes representatives from the Bureau of Land Management, National Park Service, US Fish and Wildlife Service, Bureau of Indian Affairs, and US Geological Survey, as well as five representatives from the Forest Service. This program funds applied research focused on the management of fire for natural resource managers. NRCS should work to become a JFSP partner to support research applicable to privately owned rangelands. This would provide NRCS with a platform for developing a research agenda relevant to supporting fire management on private lands.

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