Forum

Aboriginal Precedent for Active Management of Sagebrush-Perennial Grass Communities in the Great Basin

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Abstract

Until recently, most contemporary ecologists have ignored or diminished anecdotal historical accounts and anthropologists' reports about aboriginal fire in the Great Basin. Literature review shows that Indians practiced regular use of fire for many purposes, including the obvious reasons of increasing the availability of desired plants, maintaining habitats for animals used as food, and driving game during hunts. Historical accounts of prehistoric anthropogenic firing, inferences from fire-scar data, and data regarding annual production capability of representative sagebrush (*Artemisia* spp.)-perennial grass ecological sites indicate that prehistoric conditions were neither fuel- nor ignition-limited. According to many sources, this "active management" by Indians was widespread, significant, and more common than lightning-caused fires, resulting in mosaic vegetation patterns that subsequently moderated the behavior of "natural fires." This interaction between Indian-burning and lightning fires may have strongly influenced the pre-Euro-American settlement vegetation of the Great Basin. At the very least, the landscape was a patchwork of areas altered by aboriginal people and areas shaped primarily by bio-physical processes. Based on this prehistoric precedent, current historically unprecedented conditions (fuel load and exotic weed invasion threats), and predicted climate change, contemporary active management of sagebrush-perennial grass communities is paramount. Restoration measures should be scientifically based and tailored to achieve ecological resilience and functionality in specific sites. Prescribed fire is not always ecologically appropriate or judicious, especially in Wyoming big sagebrush (*A. tridentata* spp. *wyomingensis*) communities, so managers should consider using other alternatives where an intentional low severity distubance is deemed necessary. Properly planned active management would disrupt fuel continuity for lighthning fires, ensure ecological process and successional integrity, and benefit multiple uses on a landscape scale.

Key Words: aboriginal fire, *Artemisia*, disturbance, historic range of variation (HRV), rangeland restoration, resilience

INTRODUCTION

Aboriginal manipulation of North American vegetation, primarily by burning, has been widely reported in the anthropological literature (e.g., Lewis 1985; Boyd 1986; Turner 1991; Pyne 1993, 1995; Gottesfeld 1994; Stewart 2002), but these findings have been largely ignored by ecologists (Kay 1995; Anderson 2002). In today's "back to nature" mindset, it may be more politically convenient to assume that because humans are often the cause of environmental degradation, direct involvement/manipulation by humans is undesirable. However, removing human influence from a landscape, often advocated for conservation purposes, can actually erode the qualities that were intended to be preserved (Botkin 1990; McCann 1999b). By ignoring the active management by historic occupants of the Great Basin, we may be dismissing critical precedent that has implication for our current situation of frequent fire and dominance of exotic annual grass in lower elevations (Davies et al. 2011b), lack of periodic fire and subsequent conifer encroachment at higher elevations (Miller and Rose 1999), and loss of sagebrush-perennial grass community resilience after disturbance and resistance to exotic weed invasion (Davies et al. 2011b).

According to Williams (2000), marginalization of traditional knowledge arose partly out of ignorance and prejudice, but also because of the fragmentary nature of the evidence. Qualitative, anecdotal accounts of aboriginal burning found in notes, journals, and tribal oral tradition are not readily accepted by western scientists who, by training, focus on replicated, controlled experimentation and quantitative data. Furthermore, much traditional knowledge has been lost to time and forced assimilation (Kimmerer and Lake 2001; Stewart 2002). But there is little doubt that Native Americans fully understood the benefits they could receive by firing their environments (Anderson 2005).

If aboriginal burning was common before Euro-American settlement, there should be some historical and ecological evidence of such disturbance regimes. Contemporary ecological science suggests that fire disturbance within intact sagebrush-perennial grass communities results in herbaceous dominance for several years after the disturbance. "These communities evolved with periodic fires shifting dominance from shrubs to herbaceous species" (Davies et al. 2008, p. 1076). Seefeldt et al.

This paper was funded in part by the USDA-ARS Area-Wide Ecologically Based Invasive Plant Management program.

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Manuscript received 30 December 2011; manuscript accepted 15 February 2013.

(2007) reported that the herbaceous component of intact mountain big sagebrush (*A.t.* spp. *vaseyana*) communities can return to prefire conditions within three 3 yr after fall prescribed burning. According to Gruell and Swanson (2012), vegetation descriptions recorded by early explorers/travelers in the Great Basin were highly variable, largely a function of the ecological sites encountered and time since last disturbance. The landscapes also had much variability in topography, geomorphology, and soils across relatively short distances. For example, G. Stewart (1941), summarizing historical records based on technical reports from government surveys, historical documents/records, and diaries, indicated a predominance of perennial grass in northwest Utah; the area described consists primarily of elevated valleys, foothills, and benchlands. Similarly, government reports and accounts of explorers and early settlers indicated that pre-Euro-American settlement vegetation in the Cache Valley of Idaho and Utah had a major grass component (Hull and Hull 1974). In comparison, Vale's (1975) description of the early contact Intermountain West landscape as "visually dominated by shrubs" (p. 32) is based almost entirely on reports regarding explorer/settler travel routes through semiarid valleys, taken for relative ease of access. These areas were often dominated by basin big sagebrush (*A.t.* spp. *tridentata*), rabbitbrush (*Chrysothamnus* spp.), greasewood (*Sarcobatus* spp.), and saltbush (*Atriplex* spp.), which the early travelers referred to collectively as "sagebrush" (Young et al. 1979).

Gruell and Swanson (2012) cited many historical documents and newspaper articles documenting the abundance of grass that attracted ranchers to northern Nevada in the mid-1800s. One such account, in a March 16, 1870, editorial of the *Elko Daily Free Press*, stated: "In the summer season we have rich bunchgrass covering every hillside with a luxuriant growth..." Historic photographs in the shrubsteppe hills of this area show the dominance of native grasses (Gruell and Swanson 2012). The preponderance of perennial grass and forbs in at least some areas may be inferred by the relative abundance of pronghorn antelope (*Antilocapra americana*) and bighorn sheep (*Ovis canadensis*), grass- and open-habitat adapted wildlife species that were apparently more common than shrub-dependent species like mule deer (*Odocoileus hemionus*) in some areas of the Great Basin during both prehistoric and early historic times (Pippin 1979; Matheny et al. 1997; Sands et al. 2000; Gruell and Swanson 2012). Although pronghorns are considered a sagebrush habitat obligate, their affinity for relatively open habitat with short sagebrush and abundant herbaceous vegetation has been documented for the Great Basin (Yoakum 1974, 1978). Similarly, the formerly abundant white-tailed jackrabbits (*Lepus towensendii*) have an affinity for more grass-dominated habitats (Verts and Carraway 1998). Once the focus of repeated 110-km (one-way) migratory hunts by aboriginals in Grass Valley, central Nevada (Steward 1938), white-tailed jackrabbits are gone from much of their range in this area (Gruell and Swanson 2012). In comparison, the sagebrush obligate sage-grouse (*Centrocercus urophasianus*) was, based on anecdotal accounts, locally abundant in some areas but uncommon in others (Ridgway 1877; Klebenow 2001; Gruell and Swanson 2012) during the early Great Basin settlement period by Euro-Americans.

Paige and Ritter (1999), summarizing ecological literature, historical accounts, and explorer reports, concluded that before Euro-American settlement, "spotty and occasional wildfire probably created a patchwork of young and old sagebrush (*Artemisia* spp.) stands across the landscape, interspersed with grassland openings, wet meadows, and other shrub communities" (p. 6). In drier regions of the Great Basin where the Wyoming subspecies of big sagebrush (*A.t.* spp. *wyomingensis*) dominates, the fire regime was different (as described below) than that in higher precipitation areas (typically upper elevations) where the mountain subspecies of big sagebrush is more common (Tisdale and Hironaka 1969; Miller and Eddleman 2001).

Miller and Eddleman (2001), summarizing ecological literature, concluded that Wyoming big sagebrush and low sagebrush (*A. arbuscula*) communities had less frequent disturbance events but slower recovery rates than the mountain big sagebrush communities, which had more frequent disturbance and faster recovery rates. This created a mosaic of several successional stages across the landscape. Miller and Eddleman (2001) also indicated that, because of the resulting limited and discontinuous fuels, fires often left unburned islands, especially in Wyoming big sagebrush communities. Plant composition therefore varied across a spectrum of seral stages from dominant stands of sagebrush to grasslands, with much of the sagebrush steppe ecosystem comprised of open shrub stands with a strong component of perennial grasses and forbs. Fires in the mountainous areas created mosaics, with differences in slope and aspect, broken topography, and variation in fuel loads resulting in unburned patches after a fire. Weather conditions also affected historic patterns of vegetation composition on sagebrush landscapes (Miller and Eddleman 2001). Wigand et al. (1995) posited that during the Little Ice Age (LIA), the wettest and coolest period of the Holocene, herbaceous production was higher than in contemporary times. This increased grass cover likely supported higher fire frequencies (Miller et al. 2005). Certainly fire and weather were not the only sagebrush reduction agents. Sagebrush-defoliating insects (e.g., aroga moth [*Aroga websteri*]) may have reduced shrub cover in some areas, presumably with a corresponding increase in herbaceous vegetation, more likely by thinning sagebrush than eliminating it (Evers et al. 2013). Impacts from drought, freezekill, disease, and small mammals could also have reduced sagebrush in some areas, resulting in a successional shift to an earlier seral stage (Evers et al. 2013).

Summarizing an extensive review of historical literature, Gruell and Swanson (2012) concluded that accounts of early explorers, immigrants, government exploration/survey parties, and ethnographer interviews with Native American elders collectively reflected differences in ecological site potential and fire frequency. According to these authors, sagebrush and salt-desert shrubs dominated in the lower semiarid valleys, while riparian zones in these valleys supported an abundance of grasses, sedges, and small willows. Reflecting the occurrence of Indian burning and naturally occurring lightning fires, the upland communities were in early to mid-succession, supporting an abundance of bunchgrasses and open to moderate canopies of sagebrush. The growth form and distribution of woody plants reflected relatively frequent fire disturbances. In the mountains, the presence of small willows (*Salix* spp.) and

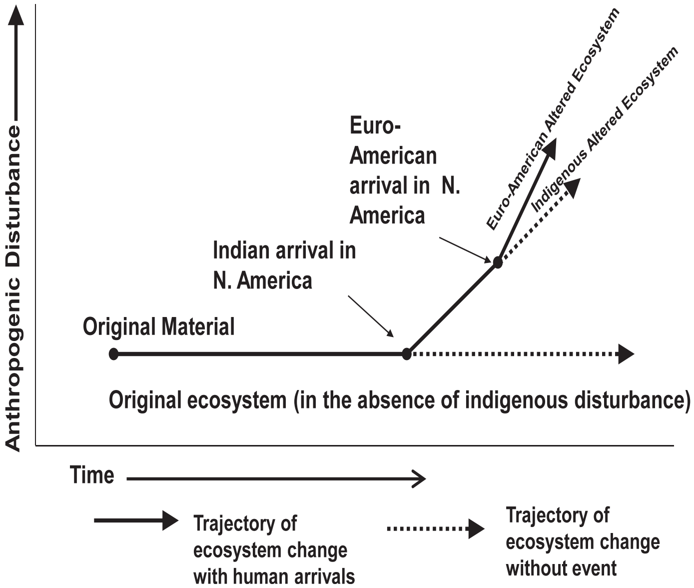

Figure 1. Ecosystems and anthropogenic influences (adapted from Anderson 2002).

aspens (*Populus tremuloides* spp.) suggests that these fire-adapted plants were in early succession. Fire-sensitive mountain mahogany (*Cercocarpus* spp.) was restricted to ridges and upper slopes where fuel discontinuity limited fire spread. An abundance of bunchgrass reflected frequent fire disturbance. Gruell and Swanson (2012) concluded that semiarid valleys (dominated by basin and/or Wyoming big sagebrush) apparently burned infrequently because of sparse grass and discontinuous shrub cover.

The historic differences among sagebrush-perennial grass communities across landscapes and through time, as impacted by disturbances before Euro-American settlement, may have important implications for contemporary vegetation management. The objectives of this article are to: 1) document, through literature review, practices of aboriginal vegetation management in the Great Basin, 2) vet these findings by comparing to inferences from fire-scar studies and information on the annual production capability of representative intact sagebrush-perennial grass ecological sites, and 3) discuss the implications of any such precedent for contemporary vegetation management.

EVIDENCE FOR INDIAN-MANAGED ECOSYSTEMS

North America in General

The most powerful tool that aboriginal people had for landscape manipulation was fire, which was used to modify the environment for survival (Kimmerer and Lake 2001; Keeley 2002). Not surprisingly, the use of fire by indigenous people has affected in some way every ecosystem in North America (Pyne 1982; Gruell 1985; McCann 1999a; Williams 2000; Kimmerer and Lake 2001). According to Anderson (2002), humans are an ecological force within an ecosystem, influencing its trajectory in ways that are often highly culture-specific (Fig. 1). Anderson (2002) also maintained that the purposeful use of fire enabled Native Americans to systematically alter their environment over long periods of time and at scales varying from individual shrubs to whole bioregions.

Aboriginals repeatedly burned vegetation to modify plant and animal communities for human benefit and to increase productivity (Pyne 1995). Williams (2000) listed 11 general reasons for aboriginal use of fire (Table 1). Lewis (1973) identified 70 specific reasons why California native peoples burned the vegetation. According to Anderson (2002, p. 63), "Fire not only warmed hearths and kept predators at bay; it increased forage for wildlife, curtailed insects that plagued food crops, and promoted long, straight shoots for basketry." Based on 145 western US fire accounts from 1776 to 1900 as reported in 44 journals and other historical documents describing the activities of fur trappers, explorers, government surveyors, naturalists, emigrants, and military expeditions, ecologist George Gruell (1985) concluded that 41% of fires observed were ignited by Indians, located primarily in upper elevations, and often spread unchecked.

Great Basin

Anthropologist Julian H. Steward, based on his extensive investigations on cultural elements of Great Basin Indian tribes (Steward 1933, 1938, 1941, 1943), concluded that aboriginals in the area "changed the natural landscape by repeated firings, probably intentional as well as accidental . . ." (Steward 1949, p. 278). Steward described fire as being used frequently and widely by the Indians, maintaining that fire was often the primary factor determining the "natural vegetation" of the Great Basin and Plateau. A recently published book, Forgotten Fires—Native Americans and the Transient Wilderness, includes a thorough review of aboriginal fire across North America, including a 26-page chapter about the Great Basin and Plateau area (Stewart 2002). The manuscript was written in the 1950s by anthropologist Omer Stuart, but not published until half a century later after being discovered by Henry T. Lewis (University of Alberta) and M. Kat Anderson (University of California, Davis). According to Anderson (2002), Stewart was prescient, ahead of his time in recognizing that indigenous fire management practices had significant consequences on vegetation and wildlife. Through an extensive literature review, Stewart (2002, p. 233) concluded that, "The statements of burning by Indians . . . are sufficient to support the conclusion that fire was used by Indians of the Great Basin and Plateau regularly and for many purposes." This conclusion was based on the results of tribal interviews by anthropologists (Table 2) and corroborating visual observations from early explorations between 1776 and 1878 within the sagebrush region of Utah, Nevada, Idaho, Oregon, and interior Washington (Table 3). Native Americans also had reason to minimize fire or use it selectively in some areas/seasons to avoid damaging important resources, such as productive nut-producing pinyon pine (*Pinus edulis*) groves, fuel for cooking fires, hiding cover for stalking game, etc.

Rexford Daubenmire was among the earliest American ecologists to recognize the importance of fire's influence on plant life in this region. Under the subheading "The Fire Climax," he concluded based on a 3-yr ecological study of sagebrush vegetation in southeastern Washington and Idaho:

Table 1. Reasons for aboriginal burning (adapted from Williams 2000).

Activity	Description
Hunting	To divert big game species into small, unburned areas for easier hunting, provide feeding areas, and drive game.
Crop management	To improve seed harvest, increase berry production, clear ground for planting, etc.
Range management	To improve game grazing/browsing potential.
Fireproofing areas	To protect certain medicinal plants, clear areas around villages, and reduce shrub and tree encroachment.
Insect gathering	"Fire surrounds" to collect and roast crickets, grasshoppers, etc.
Pest management	To reduce flies, ticks, mosquitoes, rodents, etc.
Warfare and signaling	To deprive enemy of hiding places; for offensive reasons as well or to escape enemy; for signaling, large fires were used.
Economic extortion	To implement "scorched earth" policy, depriving enemies of food sources, etc.
Clearing areas for travel	To clear trails and/or improve visibility in overgrown areas.
Felling trees	To kill so that wood could be used later.
Clearing riparian areas	To clear brush for new grasses and shrub/tree sprouts.

"Locally, the practice of burning the vegetation, which was started by the aborigines and is continued today, appears to have played a great part in eliminating *Artemisia* from the Artemisietum, especially in the northern and western parts of the zone" (Daubenmire 1942, p. 62).

Griffin (2002), integrating successional fire ecology and anthropological studies of historic subsistence patterns, resource use, and environmental manipulation, echoed many of Stewart's and Steward's observations. He noted that "... frequent to intermediate disturbance rates in both shrub communities and pinyon pine woodlands would have supported the subsistence patterns that (Julian) Steward and other anthropologists have described" (Griffin 2002, p. 88). More specifically, he indicated that Ute, Paiute, Shoshone, and Washoe hunter-foragers of the region "... likely benefited from periodic fires in the primary habitats they utilized" (p. 78), and that "the only environmental manipulation capable of widespread ecological change that was available to the aboriginal inhabitants was intentional burning" (p. 84). Griffin (2002) concluded that because of subsistence patterns, intentional burning could have affected vast acreages of this region.

Obviously, aboriginals in the Great Basin set fires for the same reasons that hunter-gatherers worldwide do: to cultivate and/or increase the availability of desirable plants, maintain habitats for prey animals, and drive game species during hunts. Other authors have also noted the importance of prehistoric and historic anthropogenic fires in and near the Great Basin. Gruell (1985) identified early historical descriptions of 43 fires in the Great Basin (between 1776 and 1900), 26 of which were reported as having been set intentionally. Based on her knowledge of aboriginal subsistence practices and vegetation ecology, Fowler (1986) speculated that the anthropogenic fires witnessed by Dominguez and Escalante in 1776 in Utah Valley, Utah, may have been a result of the frequent practice of fall burning by Indians rather than a defensive tactic. Burning during the fall was done apparently for the purpose of increasing spring yields (Fowler 1986), maintaining forage for game, and preparing areas for sowing of wild seeds (Steward 1941). According to Shinn (1980), aboriginal desert economies benefitted from late summer/fall burns because this was the annual period for gathering, preparing, and storing food supplies for winter. For North America in general, the majority of intentional aboriginal fires were set in the spring or late in the fall when burning conditions were less severe (Kimmerer and Lake 2001). Modern ecologists have noted that many cool season grasses in the northern Great Basin are least detrimentally affected by autumn fires when these species are dormant (Bunting et al. 1987; Seefeldt et al. 2007; Davies et al. 2008).

Shinn (1980) and Harper (1986), integrating ecological literature, historical records, and anthropological studies, concluded that Indian burning of sagebrush-steppe communities of the inland Pacific Northwest and Great Basin was both widespread and significant. Similarly, Rhode (1999), reviewing anthropological and paleo-ecological studies, indicated that the prehistoric inhabitants of the Great Basin probably exerted significant environmental effects with fire at some times and in some areas.

DO MODERN MEASURES OF PAST FIRE OCCURRENCE REFLECT ABORIGINAL FIRE USE?

Scientific accounts in the literature for estimated fire recurrence in both the mountain and Wyoming big sagebrush communities

Table 2. Documentation of Indian use of fire from ethnographic histories across the Great Basin.

Ethnographic study	Geographic location	Statement
Steward (1938, 1941, 1943)	E. Nevada, W. Utah, S. Idaho, and W. Wyoming	Fire used to hunt deer and antelope and harvest seed.
Kelly (1932)	Surprise Valley, CA	Only means of taking deer wholesale was by firing ... late summer, usually mid-August.
Steward (1933)	Owens Valley, CA	Fire drives for hunting and burning for better wild-food crops.
Steward (1941)	Central Nevada	Indians continually burned over country.
Drucker (1941), Stewart (1942), and Steward (1941)	N. Arizona, S. Utah, and S. Nevada	Fire used to drive antelope and rabbits and increase seed yield.

Table 3. Observations by early explorers regarding Indian use of fire in the sagebrush region (compiled from Thomas 1983; Stewart 2002; Gruell and Swanson 2012).

Authority	Geographic location	Year	Statement
Escalante	Utah Lake, UT	1776	Meadows and pasture recently burned . . . [Indians] had put fires everywhere
Bryant	Morgan Valley, UT	25 July 1846	Smoke column rising from mountains to the West
Bryant	Salt Lake Valley, UT	30 July 1846	Fire raged on mountain all night
Egan	UT Territory	1846–1878	Rabbit hunting fire drives by Goshutes
Ogden	Independence Valley and Santa Rosa Mountains, northeast NV	1829	[Indian] fires in all directions
Leonard	Humboldt River, near Lovelock, NV	1833	Smoke rising from the grass in every direction
Fremont	Humboldt River, NV	1845	Indians in fall set fire to grass
Lienhard	Goshute Valley, northeast NV	26 August 1846	[Indian] fires on nearby hills and mountains
Bryant	Halleck, NV	8 August 1846	Fires ignited by Indians were visible in mountains and several places in valley a few miles distant
Kilgore	Goose Creek, northeast NV	1850	Saw Indian set fires (note: same area where Ogden suspected Indian fires had affected beaver habitat in 1826)
Egan	Ruby Valley, NV	1850s	Multiple fires set by Indians to drive jackrabbits
Burton	Toiyabe Mountains and Roberts Creek Mountains, central NV	1860	Sighted everywhere on the heights the fires of the natives; from the hills rose the smoke of Indian fires
Triplet	Lower Humboldt River, NV	1862	Indian signal fires on top of every mountain
Bonneville	Boise, ID	1833	Indians set fire to grassy plains
Furnham	Ft. Hall, ID	1839	Indians burned prairie, burning large sections of most productive part
Cox	Interior, WA	1831	Indians set fire to the long grass, the flames of which spread with great rapidity to drive game
Saint-Amant	Umatilla River, OR	1854	Indians set fires to entire prairies

are quite variable (Baker 2006). At the low end of the spectrum, mean fire return interval (MFRI) for mountain big sagebrush ranges from 6 to 60 yr, based on multiple sources in Table 4 as well as Heyerdahl et al. (2006) and Miller and Rose (1995). Most estimates of MFRI in Wyoming big sagebrush communities are not empirically based, but the product of opinion and circumstantial evidence, e.g., estimated time for sagebrush to re-establish (Miller et al. 2011). Based on macroscopic charcoal work in central Nevada, Mensing et al. (2006) recorded MFRI of up to a century for Wyoming big sagebrush communities in central Nevada, varying with climate and fuel-load. At the upper end of the spectrum, Baker (2006) determined that fire rotation for mountain big sagebrush is 70 to 200 yr, 100 to 240 yr for Wyoming big sagebrush, and 325 to 450 yr for low sagebrush. However, these calculations were based on 20th century data for ignition and fire spread within grazed landscapes with reduced fine fuels and altered species composition. Much of the difference between these extremes is explained by examining terminology definitions (from the Fire Effects Information Systems Glossary; US Forest Service 2011). MFRI (also called "mean fire free interval" or "mean fire interval") is the arithmetic average of all fire intervals determined in a designated area during a designated time period; the size of the area and the time period must be specified (units=years). On the other hand, fire rotation is the length of time necessary for an area, equal for the entire area of interest, to burn; area of interest must be clearly identified (units=years/area). Fire rotation is based on two adjustments: percent of the area unburned in a fire and adjacency to a forest.

The macroscopic charcoal analysis by Mensing et al. (2006) to reconstruct fire history in central Nevada showed that the fire regime was climate and fuel driven; sagebrush increased and fires were more abundant during periods of wetter climate, and vice-versa. By combining fire scar, fire rotation, charcoal, and vegetation recovery data, Baker (2011) estimated that sagebrush communities burned at multicentury levels. According to Romme et al. (2009, p. 217), "... the sagebrush community is very heterogeneous, and a single, broad characterization of historical fire rotations cannot adequately convey the complex historical role of fire in these ecosystems."

Estimating fire frequency is fraught with complications. Fule et al. (2006) maintained that the MFRI is more relevant than fire rotation. Fire rotation does not provide consideration of variability across space or time (Reed 2006). According to Miller et al. (2011), large fires dominate the fire rotation computation and are best calculated for an area that exceeds the largest fire expected in one rotation. Reed (2006) suggested that the fire rotation concept be abandoned because fire size is a totally random event and fire rotation does not reflect the burning potential at any point, whereas the true fire cycle is measured by the expected fire interval at a point. But even the more frequent fire occurrences estimated by using MFRI may not accurately reflect how often areas once burned (Kay 2007). In much of the Great Basin, and particularly among Wyoming big sagebrush, black sagebrush (*A. nova*), and low sagebrush communities, there are few if any old trees to record fire events (Gruell 1996). Therefore, MFRI estimates in the most arid or low-producing sagebrush sites are broad estimates based on little if any data from tree rings. Another problem is that not all fires scar all trees, and some trees are not susceptible to scarring (Young and Evans 1981).

Table 4. Fire history of areas in or adjacent to sagebrush communities as determined from tree ring analysis (studies 1 to 8) or inferences (study 9) based on vegetation parameters (described in footnotes).

Study No./Author(s)	Location	Sagebrush community	Mean fire return interval in yr (range)
1/Gruell (1999)	Hart Mountain, OR; Great Basin National Park, NV; Walker River, NV	Mountain	8–29 (3–32)
2/Miller and Rose (1999)	Paisley, OR	Mountain	12–15 (3–28)
3/Young and Evans (1981)	Lassen County, CA	Low	31 (10–95)
4/Miller et al. (2001)	Southeast OR	Mountain	6–18 (3–32)
5/Arno and Gruell (1983)	Southwest MT (Dillon area)	Mountain	21–60 (5–97)
6/Burkhardt and Tisdale (1976)	Owyhee County, ID	Mountain	14–29 (10–60)
7/Kitchen (2010)	White Pine County, NV; Millard and Beaver Counties, UT	Mountain	21–47 (12–156)
8/Houston (1973)	Yellowstone Park, North Range	Mountain	17–41 (6–60)
9/Miller and Heyerdahl 2008	Northeastern California	Mountain[1]	(< 25)
		Mountain[2]	(80–140)

[1]Sagebrush-Idaho fescue association: fire return interval inferred from presence of mollic soil horizon, deep loamy soil, absence of western juniper (*Juniperus occidentalis*), high perennial grass cover (> 30%), and high fuel load (~2 000 kg · ha^{-1}).

[2]Sagebrush-bluebunch wheatgrass association: fire return interval inferred from time since last known fire (60 yr), general absence to weak presence of mollic soil horizons (suggesting grasses did not persist as a dominant component), absence of live old western junipers but scattered snags > 140 yr old, and low fine fuel load (~255 kg · ha^{-1}).

EVIDENCE OF FIRE HISTORY IN THE GREAT BASIN

Fire is an ecological catalyst (Pyne 2004), a disturbance process that affects plant succession from small to large scales, depending on the specific event or spatial relationships among multiple events, across time. On sagebrush-bunchgrass rangelands without cheatgrass (*Bromus tectorum*) and other invasive nonnative weeds, vegetation composition can range from herbaceous- to shrub-dominated, depending on seral stage. The widespread absence of old trees to record fire events in the sagebrush-dominated portions of the Great Basin leaves the fire history across much of the region largely unknown. The few studies conducted have occurred primarily at the interface of mountain big sagebrush communities and conifer trees (Table 4). Their data show MFRIs (for scarring fires) of 6 to 60 yr, and a range between scarring fires of 3 to 156 yr. Except for the research by Miller and Heyerdahl (2008), none of the other studies in Table 4 or other reviews about fire ecology in the Great Basin (e.g., Wright and Bailey 1982; Bunting et al. 1987) provide quantitative data about fuel loads or fuel continuity in or across sagebrush ecological sites. At best, they speculate that low sagebrush communities, as compared to big sagebrush communities, have much longer return intervals because they produce less biomass. Further, the ignition of most historic fires is often apparently presumed to be lightning. For example, five of the nine references in Table 4 did not mention aboriginal fire. Native American influences prior to Euro-American settlement are largely ignored.

Was the Great Basin Fuel-limited?

Current and historic empirical data about fuel loads, fuel continuity, and ignition sources are scarce for sagebrush-bunchgrass communities. To determine whether sagebrush-bunchgrass communities in the Great Basin were fuel-limited before establishment of invasion by the highly flammable cheatgrass and other exotic annual weeds, we can examine information from the few available data sources on fuel loads. Stebleton and Bunting (2009) presented fuel load data from four Wyoming big sagebrush vegetation groups, with shrub and herbaceous cover above or below 25%. Two of these groups had minimal cheatgrass cover (≤ 5%) and average total fuel loads of 6 009 to 11 506 kg · ha^{-1}, with over 90% of the fuel load from shrubs (predominantly Wyoming sagebrush). Individual subplots (n=230) had herbaceous fuel loads that ranged from 10 to 743 kg · ha^{-1}. Focusing on annual (yearly) primary production, we summarized production data from sagebrush sites across four Major Land Resource Areas in Nevada (Table 5). We used 674 kg · ha^{-1} as a threshold because limited research summarized by Bunting et al. (1987) indicates that this is the amount of annual production necessary to carry a fire. Many low and big sagebrush sites have annual production values above the 674 kg · ha^{-1} threshold (Table 5). Shiflet (1994) reported mean annual production ranges of 330 to 750 kg · ha^{-1} for low sagebrush communities, and 440 to 775, 775 to 2 100, and 1 100 to 2 750 kg · ha^{-1} for Wyoming, basin, and mountain big sagebrush communities, respectively (all without cheatgrass).

For sake of comparison, the ponderosa pine (*Pinus ponderosa*) region of Arizona and New Mexico provides valuable insight. These forests have the best studied fire history in the United States, with a well-documented MFRI of 6 to 15 yr (Touchan et al. 1996; Fule et al. 2003). Empirical and modeling data indicate an understory herbaceous production of 454 to 1 452 kg · ha^{-1} annually (Covington and Moore 1994; Covington et al. 1997, 2001). Although the variables of monsoonal weather patterns and accumulated pine needles make comparison imperfect, we are still left with the obvious fact that many sagebrush-perennial grass communities have comparable herbaceous fuel loads, as demonstrated by sagebrush ecological sites in northern Nevada (Table 5). In a northern California study, Miller and Heyerdahl (2008) reported fine fuel loads ranging from 550 to 2 359 kg · ha^{-1} in mountain big sagebrush-Idaho fescue communities.

Potential fuel, however, is more than just the product of annual primary production; rather, it includes standing live vegetation, standing dead vegetation, and surface litter. Rickard

Table 5. Annual (yearly) vegetation production estimates for big sagebrush and low sagebrush sites in northern and central Nevada, based on data from NRCS (2001) and three undated NRCS ecological site description publications. Ecological site data are for mid-successional plant communities with approximately equal amounts of perennial grasses and shrubs.

Owyhee High Plateau MLRA[1]
32 sagebrush sites
14 with 674 to 1 123 $kg \cdot ha^{-1}$ production
7 with > 1 123 $kg \cdot ha^{-1}$ production
Malhuer High Plateau MLRA
60 sagebrush sites
25 with 674 to 1 123 $kg \cdot ha^{-1}$ production
22 with > 1 123 $kg \cdot ha^{-1}$ production
Humboldt MLRA
25 sagebrush sites
8 with 674 to 1 123 $kg \cdot ha^{-1}$ production
6 with > 1 123 $kg \cdot ha^{-1}$ production
Central Nevada Basin and Range MLRA
40 sagebrush sites
17 with 674 to 1 123 $kg \cdot ha^{-1}$ production
8 with > 1 123 $kg \cdot ha^{-1}$ production

[1]MLRA indicates Major Land Resource Area.

and Vaughan (1988) derived values from a 4-yr study in a Wyoming big sagebrush site in south-central Washington (Table 6). Their study site averaged about 21.6 cm of precipitation and had a mean high temperature in July of 37.6°C, similar to much of the Great Basin's sagebrush area, and had virtually no cheatgrass. Little other comparable information exists about above-ground biomass components for most sagebrush ecological sites. Data from Table 6 show that annual primary production is a small part of the total fuel on a sagebrush ecological site, but a value that is readily measured or available from ecological site descriptions. For utilitarian purposes, dividing 1 by the collective live : total fuel ratio (0.177) from Table 6 calculates a multiplier of 5.6 that could be used to estimate total fuel load for a given site if annual production is known. The specific multiplier undoubtedly varies, depending on the herbaceous : shrub ratio, but this example clearly demonstrates that total fuel load is from several to many times annual primary production. These data suggest that, even without a cheatgrass component, most sagebrush rangelands, including many low sagebrush sites, have adequate fuel loads to burn more frequently than 70 to 450 yr (the range estimated by Baker 2006). Even the drier Wyoming sagebrush ecological sites are subject to great fuel load variability.

Low sagebrush sites, in particular, have been reported to burn very infrequently because of fuel sparseness, especially soon after a fire. Virtually no data exists for low sagebrush sites regarding biomass accumulation across time. The authors have photographic documentation for three large, dispersed northern Nevada rangeland fires that, across years and locations, included numerous interspersed low sagebrush communities that were fire-impacted since 1999 (Figs. S1–S4; available online at http://dx.doi.org/10.2111/REM-D-11-00231.s1). All of these sites were on landforms with little (< 15%) or no slope, and none of the fires were cheatgrass-driven. Apparently,

Table 6. Weight of herbaceous and shrub fuel components, based on end of growing season data, on a Wyoming big sagebrush site in south-central Washington (adapted from Rickard and Vaughan 1988).

Plant part[1]	$g \cdot m^{-2}$	$kg \cdot ha^{-1}$
Herbaceous		
Live shoot	58	580
Standing dead	84	840
Grass crowns	99	830
Litter	153	1 530
Total	395	3 950
Shrub		
Leaves	8	80
Live wood	28	280
Dead wood	43	430
Woody litter	57	570
Total	136	1 360

[1]Live shoot : total ratio = 0.147. Live (leaves + wood) : total ratio = 0.265. Collective live : total ratio = 0.177.

fires in low sagebrush communities interspersed within big sagebrush-dominated landscapes are not rare when fuel loads have reached a minimum (largely unknown) threshold. Most likely, sustained winds, high temperatures, several consecutive wet years that allow accumulation of fine fuels, and low relative humidity interact with fuels and topography to drive many fires when fine fuels are not high (Riegel et al. 2006).

If fires can readily burn large areas with relatively low annual primary production, even without cheatgrass, the question becomes: how many years are required before there is enough biomass for a fire to potentially re-occur? The answer would provide some insight into the potential fire frequency prior to Euro-American settlement and the initiation of widespread, intensive livestock grazing. Very little published information exists about biomass production across time in the hundreds of sagebrush ecological sites found in the sagebrush biome. The authors have additional photographic documentation of substantial native perennial herbaceous fuel loads and connectivity 2 to 6 yr after fire in four locations, within predominantly Wyoming big sagebrush ecological sites, representing three northern Nevada wildfires that burned in two separate years (Figs. S5–S9; available online at http://dx.doi.org/10.2111/REM-D-11-00231.s1). The information summarized for sagebrush sites in Table 5, along with these photographs, suggests the potential to produce perennial herbaceous fuels with adequate biomass and continuity for relatively frequent reburns, assuming the presence of ignition sources. Snow-loads in most winters cause erect stems to become prostrate fuel, substantially increasing connectivity at multiple scales in and across ecological sites. Before the introduction of domestic livestock herds that had the potential to reduce fuel loads (Burkhardt and Tisdale 1976; Davies et al. 2010), there had not been large herds of native ungulates to perform an equivalent fuel reduction function since possibly the early Holocene 7 000 to 8 000 yr before present (Burkhardt 1996). Obviously, based on annual primary production, fuel load, and fuel continuity potential, Great Basin sagebrush-perennial grass communities, even before the accidental introduction of cheatgrass, were not fuel-limited. In fact, if herbaceous production during the LIA was indeed greater than today (Wigand et al. 1995), our calculations may be underestimations.

Was the Great Basin Ignition-limited?

The anecdotal accounts (summarized in Tables 2 and 3) from anthropologists and early explorers indicate widespread use of fire by aboriginals for multiple reasons. The language used in the descriptions suggests some fires were relatively large, multiple fires were often set, and grass was an abundant fuel, especially in higher elevations dominated by mountain big sagebrush. Although some native bunchgrasses, especially the broad-leaf species, may respond positively to cool season fire in the short-term through increased reproduction and high survival rates in mountain big sagebrush sites (Ellsworth and Kauffman 2010), it cannot be stated categorically that this characteristic overwhelmingly reinforces the concept of relatively frequent burns. However, many herbaceous species in sagebrush communities are adapted to fire (Miller and Eddleman 2001), with cover of several deep-rooted species recovering to preburn levels within 2 to 3 yr after fire (Miller et al. in press). These species include bluebunch wheatgrass (*Pseudoroegnaria spicata*; Blaisdell 1953; Conrad and Poulton 1966; Uresk et al. 1976, 1980; Hosten and West 1994), bottlebrush squirreltail (*Elymus elymoides*; Wright and Klemmedson 1965; Young and Miller 1985; Blank et al 1994; Bates et al. 2009), Columbia needlegrass (*Achnatherum lemmonii*; Baisdell 1953), and basin wildrye (*Leymus cinereus*; Everett and Ward 1984; Young 1987). Fine-leaf grasses such as Idaho fescue (*Festuca idahoensis*) and Thurber's needlegrass (*Achnatherum thurberianum*) are more sensitive to fire, suffering greater crown mortality and slower recovery rates than broad-leaf grasses (Blaisdell 1953; Wright 1971). However, both of these species can recover on more moist sites, with biomass and cover exceeding preburn levels within 3 to 5 yr after fall-applied prescribed fire (Davies et al. 2008; Bates et al. 2009).

Although forb species are variously impacted by fire, perennial forb production generally increases 2 to 3 yr after fire in more mesic sagebrush communities (Blaisdell 1953; Wrobleski and Kauffman 2003), but is less responsive in more xeric sagebrush communities (Blaisdell 1953; Bunting et al. 1987; Fischer et al. 1996; Riegel et al. 2006). Fire ignition timing affects perennial grass response (Wright and Bailey 1982; Bunting et al. 1987; Davies et al. 2007; Seefeldt et al. 2007; Davies et al. 2008). In the Great Basin, the cool season grasses that dominate this area are in general least detrimentally affected by fall burning (Bunting et al. 1987), but few studies have been done and variable results have likely been influenced by fire severity (Miller et al. in press). Cool season burns (especially fall) were commonly conducted by aboriginals, as mentioned earlier.

Much of the sagebrush region has fewer than 30 d of lightning per year, and many areas have less than 20 d (Houghton et al. 1975). The fire return interval, however, is very similar for southeast Oregon in the Great Basin (Miller and Rose 1999; Miller et al. 2001) and the ponderosa pine forests of Arizona and New Mexico where lightning occurs 60 or more days annually (USDOE 1979). This implies several possibilities with regard to pre-Euro-American settlement fires: 1) few days of lightning were needed to start most of the fires that burn a landscape when fires are not controlled; 2) additional ignition sources (i.e., anthropogenic) were present; 3) some fires were very large; or 4) a combination of the above.

Recent empirical information based on fire regime history reconstructed from tree rings (Kitchen 2010) has provided credible evidence of consequential anthropogenic fire ignitions in the eastern Great Basin. Results showed that early and late season fires, preferred times of intentional burning by Indians as mentioned previously, were more common between 1400 and 1900 CE than those during mid-season, the time during which lightning fires peak.

One aspect of fire largely overlooked by early explorers, ethnographers, and modern ecologists is escaped campfires. Native cultures apparently lacked the social pressure to extinguish fires, and many prehistoric campfires undoubtedly escaped (Stewart 1956), burning small to very large areas. In an article comparing aboriginal and lightning ignition rates in the United States, Kay (2007) estimated, based on a series of conservative assumptions, including the lowest population estimates for aboriginal populations in the Great Basin, that the aboriginal ignition rate in this region could easily have been 10 times the known lightning ignition rate. Adding in purposefully set aboriginal landscape fires, Kay (2007) maintained that the differential would actually have been much higher. Kay's calculations support the assertions made originally by Stewart (1956, 1963, 2002), and now echoed by many others that aboriginal ignitions probably overwhelmed lightning ignitions. Obviously, Great Basin sagebrush-perennial grass communities were not ignition-limited before Euro-American settlement.

Aboriginal- vs. Lightning-Caused Fires

According to Arno (1985), fires set by aboriginals augmented lightning ignitions, reducing the average intervals between fires in many grassland, shrubland, and dry forest vegetation types. He also indicated that aboriginal ignitions may date back 500 to 2 000 yr in parts of the West. "Fires set by hunter-gatherers differ from (lightning) fires in terms of seasonality, frequency, intensity, and ignition patterns" (Lewis 1985, p. 75). Reviewing literature for detail about the characteristics of purposefully set aboriginal fires, Kimmerer and Lake (2001) came to similar conclusions, also noting that the extent of purposely set fires was typically modest in size and the specific sites burned depended on food and material needs.

Regarding fire frequency, Kay (1998) concluded that frequent burning by Native Americans produced a higher frequency of low-intensity fires, as compared to lightning fires that typically are less frequent and of higher intensity. The vegetation mosaics created by aboriginals likely reduced the effects of high intensity, lightning-generated fires (Reid et al. 1989; Pyne 1993, 1995). Using a state-and-transition-based model to simulate successional trajectories in sagebrush ecosystems, Evers et al. (2013) found that increasing the probability of mosaic fire reduced the fire rotation interval in mountain big sagebrush communities. Kimmerer and Lake (2001, p. 38) concluded that "the most important outcome of fire use was the intentional creation of a mosaic of habitat patches that promoted food security by ensuring a diverse and productive landscape," with diverse habitats buffering the impact of natural fluctuation in a single food species and increasing overall productivity. Aboriginally set fires also had irregular burn margins, a phenomenon that accentuated the mosaic pattern. Modern fires often stop at roads or fire lines, which are unusually straight or smooth compared to natural fire margins that more often burn to a difference in fuel structure. Once Native Americans opened up the vegetation and produced fuel loading variability, subsequent lightning fires behaved more like those set by the aboriginals (Pyne 1993, 1995; Kay 1998). Taking a more moderate stance, Vale (2002, p. 298) concluded that "The pre-European landscape in the American West was a mosaic: some areas were altered by the activities of native peoples, including increased burning, and some areas were molded by natural processes." According to Christensen (1991), "In areas where fire exclusion strategies have altered fuel conditions, fire behavior may be considerably different than on pre-European contact landscapes."

EXTRAPOLATION FOR CONTEMPORARY ECOLOGICAL CONTEXT

In recent years, both anthropologists and ecologists have warned about the dangers of ignoring historic human impacts as a component of ecological variability (Swetnam et al. 1999; Griffin 2002). This review of literature demonstrably illustrates the active participation of aboriginal Native Americans in the vegetation management of at least major portions of the sagebrush ecosystem in the Great Basin. Integrating inferences from fire-scar history, a comparison of prehistoric human-ignited fires vs. lightning-caused fires, and annual production capability in sagebrush-perennial grass ecological sites, we suggest that prehistoric environmental conditions in the Great Basin were neither fuel- nor ignition-limited. Rather, a "big picture" emerges of relatively widespread and common burning that affected much of the landscape.

The authors acknowledge that contemporary application of prescribed burning to sagebrush-grass communities in a *carte blanche* manner to simulate aboriginal application would be disastrous. Nevertheless, we suggest that, based on aboriginal precedent, current historically unprecedented conditions (fuel load and exotic weed invasion threats), and predicted climate change, active management of sagebrush-grass communities is paramount. Such active management has also been strongly inferred (Young et al. 1979) or directly proposed by others (Wisdom et al. 2002; Kitchen 2010; Davies et al. 2011b). However, Davies et al. (2009) noted that returning ecosystems to historical or pre-Euro-American settlement conditions by reintroducing historical disturbance may be impractical. Rather, the authors maintained that objectives for ecosystem management should be focused on specific measurable goals that society has determined are valuable (e.g., soil stability, biodiversity, wildlife habitat, forage production, etc.). Balancing ecological principles with society's demands for resource production and sustainability is becoming the mandate (Keane et al. 2009). According to Griffin (2002, p. 95), "Better understanding of past human manipulations in the northern Intermountain West may allow us to understand better its regional ecology as it continues to organize itself in the context of biophysical conditions and constraints that have never before existed."

Obviously, in light of contemporary cheatgrass invasion and conifer encroachment of sagebrush communities, current management is not producing desirable results over much of our sagebrush-dominated landscapes. Sustained active management of sagebrush-perennial grass communities is necessary, along with passive management to maintain treated areas. Such active management typically involves sagebrush reduction to set back succession to an earlier seral stage, removal of encroaching conifers, and/or seeding/planting desirable vegetation. Obviously, treatment size must also be carefully considered when working within critical wildlife habitat (Connelly et al. 2000; Beck et al. 2012). Because prescribed fire is not always ecologically appropriate or judicious, especially in Wyoming big sagebrush communities (Beck et al. 2012), managers should be prepared to use other alternatives. Though certainly not fire surrogates in the strictest sense, mechanical, herbicidal, and/or biological substitutes (Roundy 2005; Davies et al. 2011; Beck et al. 2012; Miller et al. in press) might be appropriate measures site-specifically where low severity disturbance is deemed appropriate.

Detailed comparison of these treatments is beyond the scope of this paper, but it is important to note that each has site/situation-specific advantages and disadvantages. For example, the mechanical removal of conifers during early to mid-succession stages of encroachment may be preferred in order to reduce the chance of exotic annual grass invasion that fire could bring (Davies et al. 2011b; Beck et al. 2012). Mechanical reduction of sagebrush by mowing has the advantages of leaving small sagebrush plants (Davies et al 2009), residual debris used for cover by wildlife (Dahlgren et al. 2006), and is easily controlled for application to smaller areas (Hess and Beck 2012). However, mechanical treatment of sagebrush is often a high-risk strategy in Wyoming big sagebrush communities, enhancing the potential for invasion of exotic annual grasses (Davies et al. 2011a). The comparative benefits and detriments of chemical treatments are a function of ecological site and specific herbicide used (Miller et al. 1980; Dahlgren et al. 2006; Beck et al. 2012). Strategic grazing may be used to reduce fuel loads and continuity (Davies et al. 2010, 2011b), and targeted grazing can be an effective tool to reduce exotic grass cover (Diamond et al. 2009), but timing and animal control are essential to reduce damage to desirable plant species. According to Crawford et al. (2004, p. 14), "Active management will likely be required to address the problem of annual grass invasion . . . a dilemma for which there is not currently a definitive solution over large scales." Although the current trend is to treat areas already dominated by cheatgrass, we submit that active management that addresses the *prevention* of cheatgrass invasion into sagebrush-perennial grass rangelands is the most practical and economical.

MANAGEMENT IMPLICATIONS

Regarding the contemporary use of prescribed fire, extreme caution is always mandatory. "A century or more of fire suppression in many ecosystems, in addition to an abundance of nonnative species in some landscapes, now makes it difficult to predict successional trajectories of communities after fires" (Pyke et al. 2010, p. 274). Because of our contemporary situation with the threat of exotic weed invasions, severe disturbances should be minimized (Sheley et al. 1999). However, intentionally applied low severity disturbances can serve to increase the capacity for intact sagebrush-perennial grass communities to be more resistant to exotic weed invasion in the long term and resilient after severe (e.g., wildfire) disturbances (Davies et al. 2008, 2009). Such active management is more appropriate in cool soil/higher soil moisture regimes, typically in higher elevations dominated by mountain big sagebrush communities (Seefeldt et al. 2007; Evers et al. 2013; Miller et al. in press) where postfire recovery rates are more rapid (Miller et al. 2001; Miller et al. in press) and the herbaceous component of a healthy intact community can return to prefire conditions within 3 yr postfire (Seefeldt 2007). Although some Wyoming big sagebrush communities fall within this cool soil/higher soil moisture regime, most Wyoming big sagebrush communities are at lower elevations within the warm soil/lower soil moisture regime and are more severely affected by disturbance (Miller et al. in press), requiring 25 to 100 yr for complete recovery (Baker 2011). Accordingly, associated wildlife species in these drier Wyoming big sagebrush sites can be negatively impacted by well-intended treatments (Beck et al. 2012).

In terms of contemporary active management, we think that emphasis should be placed on actions that are required to achieve ecological resilience and functionality. Bestelmeyer and Briske (2012, p. 654) concluded that future management of rangelands should be resilience-based to ensure sustainability of ecosystem services in an era of rapid change; such management would include directing trajectories of ecosystem change. In sagebrush-bunchgrass communities, invasion resistance and successional resilience are functions of a healthy bunchgrass component. More specifically, resistance of sagebrush communities to invasion by exotic weeds is directly correlated to perennial grass density (Roundy 2005; Chambers et al. 2007; Davies et al. 2008; Davies et al. 2011b), although the other functional groups are also important competitors that decrease invasibility (James et al. 2008). Active management may be necessary to: 1) improve site resiliency by restoring the perennial herbaceous understory that will lead to recovery after fire and/or 2) reduce fuel load and continuity to decrease size and intensity of wildfire events. Successional management of rangeland plant communities has been validated as a means to address exotic plant invasions and plant community restoration (Sheley et al. 2010). Widespread physical disturbance was an ecological driver in sagebrush-grass ecosystems prior to Euro-American settlement, and sagebrush communities remain disturbance-driven (Crawford et al. 2004; Seefeldt et al. 2007; Evers et al. 2013). Complete or near-complete removal of physical disturbance from these systems in and of itself constitutes a major disturbance. Alternately, if thoughtful active management is not applied, the *status quo* of predominantly passive management will result in successional changes that lead to permanent undesired vegetation (e.g., exotic weed monocultures or conifer encroachment) over vast acreages. Since pre-Columbian times, mankind has played a role in shaping landscapes in North America (McCann 1999b). Contemporary challenges require that we learn from the past and judiciously adapt best management practices to address ecosystem health and functionality into the future.

ACKNOWLEDGMENT

The senior author thanks Dr James A. Young (retired range scientist, USDA-ARS) for teaching by example the importance of historical information in interpreting ecological interrelationships.

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