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Fire and Restoration of Sagebrush Ecosystems

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Abstract

*Wildlife managers often resort to prescribed fire to restore sagebrush (*Artemisia *spp.) ecosystems thought to have been affected by fire exclusion. However, a fire mosaic of burned and unburned areas may be tolerated by certain wildlife but can be detrimental to sagebrush obligates. This article assesses evidence about the historical frequency and pattern of fire in sagebrush ecosystems and the need for prescribed fire. Fire-scar data from nearby forests require adjustment to estimate fire rotation, the time required to burn once through a sagebrush landscape. Estimates from forests require correction for unburned area and because sagebrush burns less often than forests. Recovery time also might indicate fire rotation. Mountain big sagebrush (*Artemisia tridentata *ssp.* vaseyana*) recovers within about 35–100 or more years after fire, and Wyoming big sagebrush (*A. t. *ssp.* wyomingensis*) requires 50–120 or more years. Fire rotation in other ecosystems is 2 or more times the recovery period. Together, the evidence suggests fire rotations may be a minimum of 325–450 years in low sagebrush (*A. arbuscula*), 100–240 years in Wyoming big sagebrush, 70–200 years or more in mountain big sagebrush, and 35–100 years in mountain grasslands with a little sagebrush. Given these long rotations, fire exclusion likely has had little effect in most sagebrush areas. If maintaining and restoring habitat for sagebrush-dependent species is the goal, fire should be suppressed where there is a threat of cheatgrass (*Bromus tectorum*). Elsewhere, fire does not need to be reintroduced until native understory plants can be restored, so that sagebrush ecosystems can fully recover from fire.*
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Key words

Artemisia *spp., fire history, fire rotation, prescribed fire, sagebrush.*

Sagebrush (*Artemisia* spp.) ecosystems and the species dependent upon them are under threat in western North America (Knick et al. 2003). Sagebrush has been viewed as a pest and eradicated using fire and other means but also has been converted to agriculture, overgrazed by domestic livestock, and invaded by non-native plants (Vale 1974, Knick and Rotenberry 1997, Knick et al. 2003). In this context, fire may be a double-edged sword in perpetuating and restoring sagebrush landscapes and their associated wildlife. Invasion by cheatgrass (*Bromus tectorum*) has led to a grass–fire cycle in which increasing cheatgrass promotes large fires that allow cheatgrass to increase further, eroding and fragmenting remaining stands of sagebrush (Whisenant 1990, Knick and Rotenberry 1997, Knick 1999). Fire also may have been reduced or excluded in some areas due to loss of fine fuels to overuse by livestock, landscape fragmentation, and intentional fire suppression (Wrobleski and Kauffman 2003). Are sagebrush landscapes suffering from too much fire or too little? Should fire be suppressed or restored? Answers to these questions depend on the situation but also on our understanding of the historical role of fire before EuroAmerican settlement.

How fire is managed may have significant implications for wildlife, as a mosaic of burned and unburned areas is characteristic of modern sagebrush fires, and the pattern and extent of patchiness influences wildlife. Small prescribed fires may directly decrease habitat for sagebrush obligates, such as Brewer's sparrows (*Spizella breweri*) and sage thrashers (*Oreoscoptes montanus*) (Castrale 1982, Kerley and Anderson 1995). At the landscape scale, the fire mosaic may have adverse impacts if unburned areas are too small, as these birds are favored by large, unfragmented sagebrush areas (Kerley and Anderson 1995, Knick and Rotenberry 1995). However, if unburned areas are large, these birds may be little affected (Petersen and Best 1987).

Earlier studies suggested that sage-grouse (*Centrocercus* spp.) might be favored by a burn mosaic (Klebenow 1973). However, sage-grouse may be adversely affected by a landscape mosaic of adjacent young burns, as these burns may all lack good nesting habitat (Nelle et al. 2000) and do not meet the habitat requirements of sage-grouse at other seasons (Wambolt et al. 2002). Brood-rearing habitat for sage-grouse may not be enhanced by fire in xeric sagebrush areas, even if a mosaic is created, as forbs and insects may not increase (Fischer et al. 1996). Overall, small infrequent fires may have a slight positive effect, but large, frequent fires (e.g., every 17 years) can cause extinction of grouse populations (Pedersen et al. 2003).

Similarly, generalist small mammals (e.g., deer mice [*Peromyscus maniculatus*]) are not adversely affected by either a patchy spring fire or an extensive stand-replacing autumn fire, but more specialized small mammals (e.g., jumping mice [*Zapus princeps*]) cannot survive extensive stand-replacing fires (McGee 1982). Regeneration of sagebrush after fire is probably enhanced by dispersal of seed from unburned plants (Wrobleski 1999, McDowell 2000, Longland and Bateman 2002). When all sagebrush plants are burned, recovery is very slow, as seed does not spread far from mature plants (Welch and Criddle 2003). Thus, large fires that lead to extensive loss of sagebrush cover may have negative effects on sagebrush obligate and more specialized species and may delay sagebrush recovery after fire (Longland and Bateman 2002).

Given these effects, have sagebrush ecosystems actually been affected by fire exclusion or an increase in fire? Winward (1991) suggested that most sagebrush stands were $\geq$60 years of age, which he thought implied that fire intervals have lengthened. Wrobleski and Kauffman (2003) suggested that fire suppression and overgrazing by livestock have lengthened fire intervals, leading to increased dominance of sagebrush. Junipers (*Juniperus* spp.), pinyons (e.g., *Pinus edulis*, *P. monophylla*), and Douglas-fir (*Pseudotsuga menziesii*) are thought to have invaded former

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sagebrush areas due to fire exclusion (Arno and Gruell 1983, Miller and Rose 1999).

Fire likely has increased in sagebrush areas where cheatgrass has become common. Wildfires in former sagebrush areas now dominated by cheatgrass are burning at short fire rotations. Fire rotation is the time required to burn once through an area, equal to the size of a particular study area (Baker and Ehle 2001). About 26% of cheatgrass-dominated lands in the Salt Lake District of the Bureau of Land Management burned in 11 years (Roberts 1990), a fire rotation of 42 years. Fires burned 45% of the Snake River Birds of Prey Area in southern Idaho over a 7-year period, where over 50% of this landscape is dominated by cheatgrass, leading to a fire rotation of about 15.5 years (Pellant 1990). Former sagebrush areas now dominated by cheatgrass may have a fire rotation too short to allow re-establishment of sagebrush (Whisenant 1990). Large, high-intensity cheatgrass fires leave fewer and smaller unburned patches of sagebrush, that are especially vulnerable to further cheatgrass invasion (Whisenant 1990, Knick and Rotenberry 1997).

Threats to the sagebrush ecosystem and the declining status of sage-grouse and other species have led to interest in ecosystem restoration. Some restoration proposals call for use of prescribed fire, others suggest it is better to suppress fires, especially where cheatgrass is a threat (Hemstrom et al. 2002, Bunting et al. 2003). Moreover, there are competing ideas about how often fire historically burned these ecosystems (Winward 1991, Welch and Criddle 2003), and there is little understanding of the pattern produced by natural fires in sagebrush landscapes. Also, standard measures of fire frequency do not provide estimates of the rate at which fire burned across landscapes, and a reassessment is warranted (Baker and Ehle 2001).

The purpose of this article is to review and reassess evidence about fire history, fire rotation, and the pattern of fire across sagebrush landscapes and from this evidence suggest the most promising directions for restoration. Sagebrush taxa that have been the subject of fire-history research include mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*), and low sagebrush (*A. arbuscula)*.

Fire Intensity and the Fire Mosaic

Fire intensity in sagebrush in the modern era has varied over a 7-fold range due to variation in fuel loads, shrub density, fuel moisture, wind speed, and other factors (Sapsis and Kauffmann 1991, Pyle and Crawford 1996). Low fire intensity, however, does not usually increase sagebrush survival; when flames reach sagebrush, mortality is nearly complete and the fire is "stand-replacing" (e.g., Blaisdell 1953, Britton and Clark 1985, Acker 1988, Sapsis and Kauffmann 1991). Britton and Clark (1985:23) report: "it is relatively unimportant how fast the fire moves, how hot the fire is, or what the fire intensity is . . . if a fire front passes through an area, the sagebrush will be killed." However, silver sagebrush (*A. cana)* and three-tip sagebrush (*A. tripartita*) may be killed, but often will re-sprout (White and Currie 1983, Shariff 1988).

Fires, thus, do not thin sagebrush stands or lower their density by killing a certain fraction of sagebrush throughout a stand as was implied in the past (Winward 1991). Fire exclusion cannot be a cause of increased density in a particular patch of existing sagebrush (Wrobleski and Kauffman 2003), brought on by an absence of thinning fires, as thinning fires did not occur.

Table 1. *Percentage of area that is unburned within a fire perimeter in sagebrush. Studies reviewed include all studies conducted in North American over the last century.*

Sagebrush species Author(s)	Prescribed fires (%)	Wildfires (%)
Low and black sagebrush		
Boltz (1994)	—	57
Wyoming big sagebrush		
Boltz (1994)	—	
"Loamy 7–10"" ecological site		18[a]
"Loamy 8–10"" ecological site		12[a]
"Loamy 10–13"" ecological site		28[a]
Clifton (1981)	85–90	
Fischer et al. (1996)	43	
Petersen and Best (1987)	55	
Mountain big sagebrush		
Boltz (1994) ">12"" ecological site		21[a]
Raper et al. 1985		
West slope	40	
East slope	60	
Wrobleski (1999)	53 (36–62)	
Basin big sagebrush		
Boltz (1994) "Sand 8–12" ecological site		4[a]

[a] Estimates are derived by interpolating from a bar graph (Boltz 1994, fig. 2). Numerical ranges for Boltz's ecological sites are annual precipitation. Ecological sites that now contain significant cheatgrass and, thus, have less unburned area are omitted (e.g., "Loamy 10–12"").

Fire instead creates and controls the pattern and extent of a mosaic of burned and unburned areas. Unburned areas can result from 1) low sagebrush cover, 2) insufficient loading of fine fuels, 3) high fuel moisture, and 4) variable winds. A minimum of about 20% sagebrush cover and 300 kg/ha of herbaceous fuel might be required to carry fire in sagebrush (Britton and Clark 1985), but wind speed can significantly affect the fuel requirement (Brown 1982). Nonetheless, areas with low sagebrush density or little fine fuel can have mosaic burns (Ralphs and Busby 1979, Wright et al. 1979, Smith and Busby 1981). Lower fine-fuel production during droughts also may contribute to patchy burns (Hosten 1995, West and Yorks 2002). More unburned area also is common in cooler or moister parts of landscapes or during cooler or wetter conditions, as in early spring (Clifton 1981, Kuntz 1982, Boltz 1994, Colket 2003). Warmer, drier conditions, unless these reduce fine-fuel production, may lead to nearly complete sagebrush mortality and few or no islands of unburned sagebrush (Kuntz 1982, McGee 1982).

It is, thus, logical to suspect that pre-EuroAmerican fires in sagebrush landscapes left less unburned area in a mosaic, than is observed in modern prescribed fires (Wrobleski and Kauffman 2003), due to higher fine-fuel amounts, greater fuel continuity, and drier burning conditions. Modern fires often are burning through sagebrush that has reduced fine fuels due to overuse by domestic livestock. Today's summer wildfires seem to have less unburned area than do spring and autumn-prescribed fires, supporting the idea that hotter summer fires in the pre-EuroAmerican era would have left less unburned area (Table 1). Unfortunately, nothing is known directly about the extent and pattern of a fire mosaic in sagebrush in the pre-EuroAmerican era.

Table 2. Scar-based studies of fire history in forests and woodlands near sagebrush in the western United States.[a]

Author(s)	Location	Sample trees	Sagebrush	Crossdated fire scars?	Spread among sample stands?	Elevation (m)
Arno and Gruell (1983)	Southwest Mont.	Douglas-fir	Mt. big sagebrush	No	Not studied	Unknown
Burkhardt and Tisdale (1976)	Southwest Id.	Western juniper	Mt. big sagebrush Low sagebrush	Yes	Not studied	1,580–2,073
Houston (1973)	Northwest. Wyo.	Douglas-fir Lodgepole pine	Mt. big sagebrush	No	Yes	1,500–2,600
Miller and Rose (1999)	South Cent. Oreg.	Ponderosa pine	Mt. big sagebrush Low sagebrush	Yes	Yes	1,450–1,875
Young and Evans (1981)	Northeast. Calif.	Western juniper	Wyo. big sagebrush Low sagebrush	No	Not studied	1,350–1,430

[a] Gruell (1995) is not included because only 2 scarred trees were sampled and cross-dating was not used. This is an inadequate sample for determining fire history (Baker and Ehle 2001).

A mosaic pattern has been reported in some cases for several sagebrush taxa (Table 1). In low and black sagebrush (*A. nova*), fire is rare, due to sparse fuels, and often goes out (Beardall and Sylvester 1976, Britton and Ralphs 1979, Clifton 1981, Blaisdell et al. 1982, Bunting et al. 1987, Boltz 1994). Fuels also may be sparse or patchy in Wyoming big sagebrush, and unburned areas also are common after prescribed fires (e.g., Beardall and Sylvester 1976, Ralphs and Busby 1979, Petersen and Best 1987, Kerley and Anderson 1995, Fischer et al. 1996). Yet, unburned areas also are common after prescribed fires in mountain big sagebrush where fine fuels often are more abundant (Blaisdell 1953, McGee 1982, Raper et al. 1985, Nelle et al. 2000). Unburned islands are even found after hotter wildfires in both Wyoming (Hosten 1995) and mountain big sagebrush (Martin 1990). Unfortunately, few estimates of unburned area are available (Table 1), and it is unclear to what extent unburned area varies among sagebrush communities.

Evidence of Fire Rotation in Sagebrush

Fire Rotation and the Mean Composite Fire Interval

Fire rotation is the appropriate parameter for understanding and managing fire because fire rotation is a consistent measure of the rate of burning (Baker and Ehle 2001). If the fire rotation is 100 years, for example, on average a fire will burn across the whole landscape once per 100 years, and in so doing, fire also will reach each point in the landscape once every 100 years on average (Baker and Ehle 2001). The fire rotation is calculated by adding the areas of individual fires in a particular area over some period of time, and dividing this time period by the fraction of the area burned (Baker and Ehle 2001).

Because fire does not leave scars on sagebrush, evidence of fire in sagebrush comes from scarred trees within or near sagebrush. The most common parameter for comparing fire-scar data is the mean composite fire interval (mean CFI), which is the mean interval between fires in a composite list of all fires found on scarred trees within a small area of forest. Mean CFI, however, declines as more area or more scarred trees are sampled (Arno and Petersen 1983), an undesirable property. Mean CFI is simply the mean interval between fires anywhere within a sample area (Dieterich 1980), and many of these fires are small (Baker and Ehle 2001). Thus, mean CFI must be adjusted to estimate the fire rotation.

Correcting Mean Composite Fire Interval for Unburned Area and Adjacency

Since fire scars only record that a fire occurred but do not provide an estimate of the area burned in the fire, it is appropriate to correct scar-based estimates of mean CFI for several things to estimate fire rotation. The first needed correction is for unburned area, and the appropriate correction is as follows: fire rotation = mean CFI/(1.0 – mean fraction of unburned area). For example, if fires typically burned at a mean CFI of 50 years, but each fire on average leaves 40% of the area unburned, the fire rotation estimate is 83.3 years (50/1.0 – 0.4). The best available estimates of unburned area are from modern wildfires (Table 1).

Fire-scar evidence from forests also requires adjustment because a fire on a nearby tree may not always have burned the sagebrush (Wambolt et al. 2002). The most compelling evidence that fire burned through sagebrush is a specific fire documented in sample areas on both sides or scattered across a large sagebrush area. To show this, the fire must be cross-dated (the year verified by comparing tree rings with a known chronology), to document that the same fire year is found in locations that span the sagebrush. Only the Miller and Rose (1999) study, commonly cited as a study of sagebrush fire history, has cross-dated evidence of spread across a large area from a set of distinct sample stands (Table 2). This study likely was in a former grassland, not sagebrush, a point discussed later. In the only other study, commonly cited as evidence of fire spread through sagebrush, cross-dating was not completed (Houston 1973). All that is known is that some fires at distinct locations occurred within a few years of each other. If these fires cross-dated to different years, they were small spot fires that did not burn across much sagebrush. If they cross-dated to the same year, they likely were large, extensive fires that spread across the sagebrush. Neither possibility can be excluded. However, this study also is likely a study of a former grassland, not a former sagebrush area, as explained below.

Less compelling evidence of fire in sagebrush comes from single sample sites adjacent to sagebrush (Burkhardt and Tisdale 1976, Young and Evans 1981, Arno and Gruell 1983, Gruell 1995). It is likely that not all fires documented at a single forest location spread into or across the sagebrush; a single sample site really provides no evidence these fires did spread across the sagebrush (Welch and Criddle 2003), although some probably did.

Fire is documented from modern fire records to actually be less likely to be ignited and burn in sagebrush than in forests. The ignition ratio, which is the number of lightning strikes per fire start, is 144 in sagebrush–grass but only 42 in Douglas-fir and 24 in ponderosa pine (*Pinus ponderosa*), based on data from Idaho (Meisner et al. 1994). This suggests fires are much more likely to start in forests than in sagebrush, given the same amount of lightning. The ignition rate, which is the number of fires per 400,000 ha per year, is only 3.6 in sagebrush–grass, but is 25.5 in Douglas-fir and 81.9 in ponderosa pine, based on historical fire records from Colorado (Fechner and Barrows 1976). This also suggests that fires are less common in sagebrush than in forests.

If ignition ratios and rates were proportional to fire rotation, sagebrush would burn at rotations that are 3.4–6 times as long (based on ignition ratio) or 7.1–22.8 times as long (based on ignition rate) as in nearby forests. Other factors also affect fire rotation, but these data and arguments are evidence that fire burns at rotations that are longer in sagebrush than in adjoining forests, and a correction is needed when using fire-scar records from adjacent forests. It is not possible to estimate the necessary correction at present. I arbitrarily use 2.0 times mean CFI. This is likely an overly conservative, low estimate given the much larger numbers presented above and the fact that mean CFI underestimates fire rotation in the forest itself (Baker and Ehle 2001). Nonetheless, if the mean CFI in the forest is 50 years, this adjacency correction results in an estimated 100-year fire rotation in adjacent sagebrush.

A third problem that requires correction is that all the fire-scar studies (Table 2) use targeted sampling, which means that areas containing concentrations of scarred trees were sought, and trees with multiple fire scars were selected in these areas (Baker and Ehle 2001). However, these sampling areas and multiple-scarred trees may be those that have the most fire, while areas and trees with little evidence of fire are not sampled (Baker and Ehle 2001). For example, pinyon–juniper woodlands adjoining sagebrush in southwestern Colorado contain no fire scars or other evidence of surface fire, and instead burn in stand-replacing fires at about 400-year rotations (Floyd et al. 2000, 2004). Corrected for adjacency, this implies that fire plays a very minor role (fire rotation = 800 years) in these sagebrush stands. Because stands like these, that lack fire scars, are commonly not sampled, available estimates of fire rotation in sagebrush are likely too short. The magnitude of the targeting correction cannot be estimated now, but available fire rotation estimates are likely for parts of these ecosystems where fire was more frequent. Thus, the estimates that are derived by correcting estimates of mean CFI are low estimates.

Corrected Estimates of Fire Rotation from Scar-Based Studies of Adjacent Forests

Some initial sorting of the fire-scar studies (Table 2) is required before corrections are made. Three of the 5 fire-scar study sites often cited as evidence of fire frequency in sagebrush were primarily grassland, not sagebrush, prior to EuroAmerican settlement, and grasslands commonly are thought to burn more frequently than sagebrush. Arno and Gruell (1983:336) indicated that "on the widely distributed loamy soils where most of the fire history work was done, ten early photographs suggest that prior to 1900, sagebrush was restricted to small patches or widely spaced plants." Houston (1973:1115) suggested that "the conspicuous increase of fire-sensitive *Artemisia tridentata* in the steppe . . . would certainly be reversed if fire were reintroduced . . ." He showed a picture of a grassland in A.D. 1885 that was dominated by sagebrush in A.D. 1970, although a single photograph does not provide much evidence of the original character of the vegetation. Miller and Rose (1999:558) reported that "mean fire intervals of less than 15 years were adequate to inhibit western juniper [*Juniperus occidentalis*] encroachment and probably limit sagebrush cover allowing the herbaceous layer to dominate the landscape."

Fire intervals in these former grasslands now dominated by mountain big sagebrush were summarized as <15 years (Miller and Rose 1999), 20–25 years (Houston 1973), and less than 35–40 years (Arno and Gruell 1983). Sagebrush could be found as scattered shrubs or small patches in these grasslands, given these reported mean fire intervals, but sagebrush did not dominate these sites. Corrections for adjacency and unburned area are not known for grasslands, but if the figures for mountain big sagebrush (2.0 correction for adjacency; 21% unburned area, Table 1) are used, the fire rotation estimates are <38 years (from Miller and Rose 1999 data), 51 years (from Houston 1973 data), and less than 89–101 years (from Arno and Gruell 1983 data) on these sites. A range of about 35–100 years is suggested by these estimates of pre-EuroAmerican fire rotation in grasslands with small amounts of mountain big sagebrush.

Given that only a few studies are of sites that predominantly supported sagebrush in the pre-EuroAmerican era (Burkhardt and Tisdale 1976, Young and Evans 1981, and the low-sagebrush part of Miller and Rose 1999), what do these remaining scar-based studies reveal about how often fires burned in ecosystems dominated by particular sagebrush taxa? Only one study separately analyzed low sagebrush areas, and in this case a single fire interval of 138 years was found (Miller and Rose 1999). This interval comes from cross-dated scars in more than one location spanning the sagebrush, so it does not need adjustment for forest adjacency but does require correction for unburned area. If the only estimate of unburned area (Boltz 1994) is used (57%, Table 1), the corrected fire rotation estimate is 321 years [138/(1.0 – 0.57)]. In the Young and Evans (1981) study, low sagebrush and Wyoming big sagebrush burned in 3 fires, leading to a mean fire interval of about 95 years, but these estimates are from adjacent forests, and a correction of 2.0 (see above) leads to a fire rotation estimate of 190 years in the sagebrush itself. After adjustment for unburned area, the fire rotation estimate is 442 years. Thus, corrected, rounded estimates of the fire rotation in low sagebrush may be approximately 325–450 years.

In Wyoming big sagebrush, there is one study (Young and Evans 1981). Their estimated interval of 95 years from 3 fires also requires correction for adjacency (a factor of 2.0, so 190 years) and unburned area. Using the mean of the estimates for unburned area in wildfires in Wyoming big sagebrush (Table 1, 19.33%), the estimated fire rotation is 236 years. Thus, this one estimate suggests the fire rotation in Wyoming big sagebrush may be about 235 years.

Burkhardt and Tisdale (1976) is the only study of a former mountain big sagebrush site, and fire intervals were not explicitly calculated. They reported (1976:478): "fires at intervals of 30–40 yr could maintain a sagebrush-bunchgrass community free of juniper. The data in Table 1 indicate that fires were probably more frequent than this." Given a 2.0 correction for forest adjacency and using Boltz's (1994) estimate of 21% unburned area, the fire rotation on mountain big sagebrush sites might have been somewhat less than 75–100 years. Waichler et al. (2001) has been cited (Crawford et al. 2004) as providing data suggesting mean CFI >200 years in xeric mountain big sagebrush on sandy soil in eastern Oregon. These data could not be located in Waichler et al. (2001), but these estimates, after correction for adjacency and unburned area, suggest the fire rotation in some mountain big sagebrush areas could be much longer than 75–100 years, perhaps several hundred years.

Past summaries of mean CFI in sagebrush did not recognize the limitations of these data and need for corrections to estimate fire rotation. Many summaries suggest that fires burned in some or even many mountain big sagebrush stands at intervals of 10 to somewhat less than 40 years (Winward 1985, 1991; Whisenant 1990, Miller 2002, United States Department of Interior 2002, Crawford et al. 2004), not recognizing that these short intervals are uncorrected mean CFI estimates for sites that were primarily grasslands, not sagebrush, in the pre-EuroAmerican era. Other summaries (Pellant 1990, Whisenant 1990) have used the "adjusted interval" of 32–70 years from table 1 in Houston's (1973) study, but this is also an uncorrected estimate from areas that were predominantly grasslands in the pre-EuroAmerican era. Summaries of mean fire interval for Wyoming big sagebrush have included 50 or 60 years on the low end (e.g., Miller 2002, United States Department of Interior 2002) or even 12–50 years for some stands (Miller 2002). However, there are no scar-based studies that support these short intervals. Moreover, all these intervals require correction for adjacency and unburned area and, once corrected, would still be low estimates, due to targeted sampling.

Evidence of Fire Rotation from Sagebrush Recovery Rate

The rate that sagebrush returns following fire is thought to be an indicator of fire frequency (Wright and Bailey 1982) and might also be used to estimate the fire rotation. Estimates of recovery time come from analysis of chronosequences of stands varying in time since fire (Fig. 1). Sagebrush density data are shown (Fig. 1), where cover data were not reported, but density is an insufficient measure of recovery, as it only indicates that shrubs are present, not that they are mature and have cover comparable to that in unburned control areas. Livestock grazing may hasten sagebrush recovery after fire (Pechanec and Stewart 1944), and more intense wildfires may decrease recovery, sometimes leading to fewer post-fire seedlings (Blaisdell 1953, Champlin 1983, Martin 1990). Unfortunately, there are insufficient data to allow analysis of the effects of these factors on sagebrush recovery rates.

In 2 studies, mountain big sagebrush recovered within about 35 years after fire to the same cover as sagebrush in unburned control areas (Fig. 1*a*). Welch and Criddle (2003) projected it would require 70 years or more just to get mountain big sagebrush back into the interior of a burn in Idaho, which is not recovery to full density, much less full cover. Perhaps a reasonable low estimate, then, is 35–100 years or more for recovery of mountain big sagebrush.

For Wyoming big sagebrush, the required recovery period is less certain, as available data are meager after about 20 years of recovery (Fig. 1*b*). Very little recovery within the first 20 years is generally consistent among studies (Fig. 1*b*). The Wisdom sites in southwestern Montana (Walhof 1997, Wambolt et al. 2001) are exceptional, as they averaged about 96% recovery of cover 9 years after fire. Walhof (1997:60) reported: "These 2 sites may be atypical, and their responses are clearly not similar to other published data . . ." Watts and Wambolt (1996) documented recovery to 76% of control area cover within 30 years, consistent with 72% recovery after 32 years at their Exclosure site in southwestern Montana (Walhof 1997, Wambolt et al. 2001). However, Colket (2003) found that, in southeastern Idaho, only 3 of 17 plots had recovered fully in density within 53 years, while full density recovery had been reached by 92 years on 16 of 17 plots. Colket (2003:58) reported that ". . . well over 53 years are required for big sagebrush to return to its pre-fire abundance." Another few decades beyond density recovery may be required for plants to mature and cover values to recover. Together these limited data suggest that full recovery of Wyoming big sagebrush may be quite variable but generally requires 50–120 or more years. In exceptional cases, recovery may occur within a decade (e.g., Wisdom sites).

The relationship between recovery period and fire rotation in other vegetation types suggests that fire rotation may be a multiple of the recovery period. In pinyon–juniper woodlands, for example, where documented fire rotations are 400–480 years (Baker and Shinneman 2004), the time to recover to a mature, closed-canopy condition is about 200 years (Tress and Klopatek 1987, Mehl 1992, Goodrich and Barber 1999), about half the fire rotation. Similarly, in lodgepole pine (*Pinus contorta*) and spruce–fir (*Picea–Abies*) forests, where fire rotations are about 300 years (Buechling and Baker 2004), a closed-canopy mature condition is reached in about 150 years, also about half the fire rotation (Despain and Romme 1991). Interior chaparral in southern California recovers within 20–30 years after fire, but fire rotations prior to about 1950, when fire regimes were less influenced by people, averaged about 80 years among nine counties (Keeley et al. 1999). These comparisons suggest the fire rotation may be twice or more the recovery period. Thus, fire rotations would be 70–200 years or more in mountain big sagebrush and 100–240 years or more in Wyoming big sagebrush. These estimates, which are imprecise, are at least similar in magnitude to scar-based estimates.

Conclusions

Combining the fire-scar and recovery evidence, the best available estimates of fire rotation are 325–450 years in low sagebrush, 100–240 years in Wyoming big sagebrush, 70–200 years or more in mountain big sagebrush, and 35–100 years in mountain grasslands where sagebrush is a minor component. These estimates are likely low estimates because they could not be corrected for targeted sampling and they use a conservative estimate of adjacency correction, but fire rotation in sagebrush cannot be estimated more precisely at this time using available data.

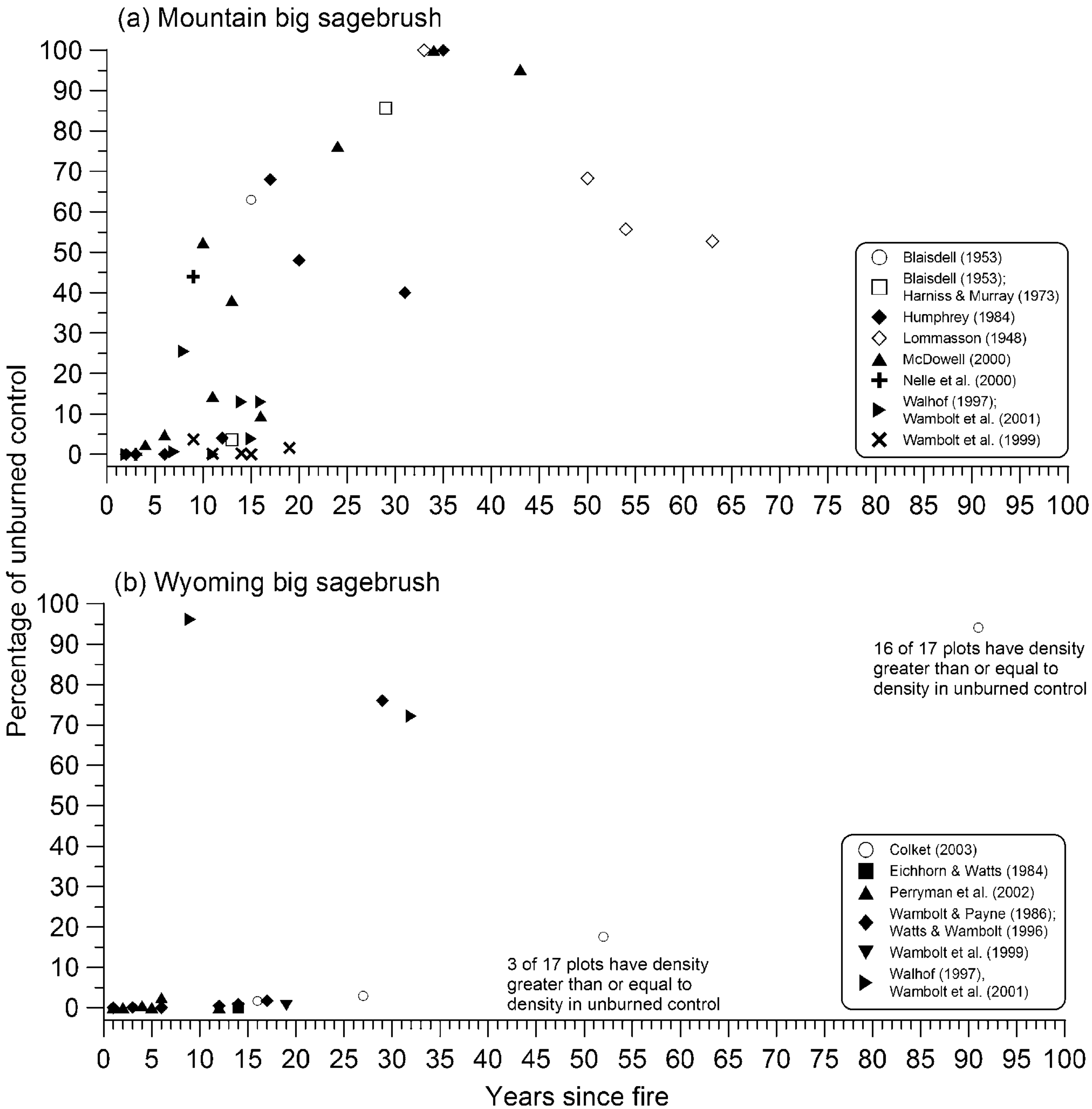

Figure 1. Sagebrush abundance versus time since fire, relative to unburned control areas, for (a) mountain big sagebrush and (b) Wyoming big sagebrush. These graphs include different measures of sagebrush abundance–density is shown as open symbols, cover as closed symbols. When authors did not specify the abundance in an unburned control area, the percentage is of the maximum value during the period covered by the study. When more than one value was reported for a particular time since fire, the mean was used. Many other studies that report recovery only within the first 10 years after fire (e.g., Pechanec and Stewart 1944, Acker 1988) are omitted. Lommasson (1948) does not identify the subspecies of big sagebrush, but it was likely mountain big sagebrush, based on the high elevation of the site. Studies reviewed include all studies conducted in North America over the last century.

Sagebrush has been assumed by some to be a fire-dependent vegetation type, requiring periodic renewal by fire (Winward 1991), although evidence challenging this fire dependence has been presented (Connelly et al. 2000, Welch and Criddle 2003). Fire is an important natural disturbance in sagebrush but does not occur as often as suggested in the past and is only one of many agents. Sagebrush density and cover are also diminished by droughts, insect outbreaks, and competition with native bunchgrasses, and may increase again during wet periods (Lommasson 1948, Maier et al. 2001, Anderson and Inouye 2001, Welch and Criddle 2003).

Given the long rotations that characterized pre-EuroAmerican fires in sagebrush, fire exclusion likely has had little effect in most sagebrush communities. A national assessment of fire regimes and fire-related condition classes (Schmidt et al. 2002) placed sagebrush mostly within fire regime II (stand replacement at 0–35-year frequency) and fire regime III (mixed severity at 35–100-year frequency). The source of these estimates is not documented, but they are interpreted to mean that sagebrush has commonly missed several fires since EuroAmerican settlement and, thus, requires prescribed burning for restoration. However, the evidence presented here shows that these fire regimes underestimate the fire rotation, and there is no evidence of mixed-severity fire in sagebrush. Sagebrush instead generally belongs in fire regime V (long rotation, stand replacement). Where cheatgrass now dominates, sagebrush is likely in condition class 3 (fire regimes significantly altered from historical range), with too much fire. Sagebrush that has not entered a cheatgrass–fire cycle should remain in condition class 1 (fire regimes within historical range), not having missed much, if any, fire at this point. Similarly, the invasion of junipers, pinyons, and Douglas-fir into sagebrush areas (Arno and Gruell 1983, Miller and Rose 1999) is likely not generally due to fire exclusion, but to other factors (e.g., overgrazing).

Particularly in Wyoming big sagebrush, a program of prescribed burning is unwarranted or inadvisable if maintaining and restoring sagebrush landscapes and sagebrush-dependent species is the goal. Correcting for fire exclusion by reintroducing fire is likely not a common sagebrush restoration need. Also, little is known about the pattern of a mosaic created by pre-EuroAmerican fires or the importance of particular aspects of this mosaic to viability of wildlife populations (Longland and Bateman 2002). There is, thus, insufficient basis for prescribed burning to restore a mosaic thought to be important for wildlife. For example, in mountain big sagebrush, prescribed burning, even at modest fire rotations (e.g., 55 years in Idaho, Nelle et al. 2000), can adversely impact sage-grouse if the landscape mosaic is not just right (Nelle et al. 2000). A fire mosaic can also increase the ability of cheatgrass to further destroy sagebrush (Knick and Rotenberry 1997).

Burning sagebrush does not assure restoration of a healthy sagebrush ecosystem, and may delay or prevent restoration, since sagebrush itself does not recover for 35 or more years (Figure 1). Restoration of native plants may not require sagebrush thinning (Anderson and Inouye 2001), but if thinning is thought to be needed, fire is inappropriate, as it does not thin sagebrush, but kills it in patches. If fire occurs, successful recovery of the sagebrush ecosystem is enhanced by abundant, healthy native plants (Anderson and Inouye 2001). Restoring native plants is an essential goal before fire is reintroduced or even allowed to continue, if further conversion to cheatgrass is to be avoided (Bunting et al. 2003). Intentional fire suppression is appropriate, at least in Wyoming big sagebrush and the lower elevations of mountain big sagebrush where replacement by cheatgrass is possible (Wambolt et al. 2002). Restoration requires enough solution to the cheatgrass problem to allow some re-seeding or passive re-invasion and increase of native plants, followed by decades of rest or reduced livestock grazing, some fortuitous wet periods, and considerable patience (Anderson and Inouye 2001). Sagebrush ecosystems did not historically burn often or recover quickly, but can be destroyed quickly if we fail to stop the cheatgrass–fire cycle and if we do not focus on restoring the native plants that are essential to maintaining a sagebrush ecosystem that can recover after fire.

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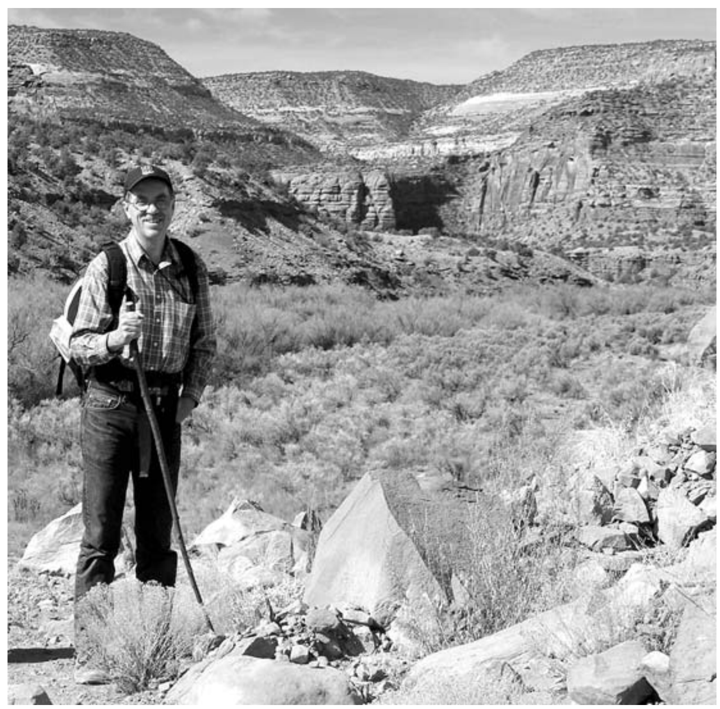

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