Artemisia tridentata subsp. wyomingensis

Figure 1—Flowering Wyoming big sagebrush on the Seedskadee National Wildlife Refuge, Wyoming. Photo by Tom Koerner, courtesy of the Fish and Wildlife Service, U.S. Department of the Interior.

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ABSTRACT

Wyoming big sagebrush is a widely distributed shrub that is native to the western United States. It occupies the largest area of the big sagebrush cover types. Wyoming big sagebrush ecosystems support hundreds of plant and animal species, including sage-grouse and many other sagebrush obligates, and Wyoming big sagebrush may be the single most important plant to sage-grouse. Its distribution has been reduced since European-American settlement, and it may

become further reduced or altered by changes in fire regimes, spread of nonnative plants, conifer expansion, climate changes, and other factors. This review synthesizes the scientific literature on Wyoming big sagebrush biology and ecology throughout its distribution, with an emphasis on how fire affects it and how Wyoming big sagebrush communities respond after fire.

Wildfires in Wyoming big sagebrush communities are stand-replacing because Wyoming big sagebrush plants are easily killed by fire and do not sprout. However, variation in fuels, topography, and weather result in fires that leave patches of unburned vegetation, where big sagebrush plants survive. Postfire seedling establishment rates vary but are typically low. The short-term soil seed bank and surviving plants in and adjacent to burns are seed sources for postfire establishment. Seeds are typically dispersed within 10 feet (3 m) of parent plants in fall and winter. Seedling establishment is episodic and occurs during relatively wet periods. The length of time between a fire and the first establishment pulse may help explain differences in postfire seedling establishment rates among burns.

Wyoming big sagebrush postfire recovery time is influenced by many interacting factors and varies substantially among sites. This review and analysis of Wyoming big sagebrush postfire recovery on 112 burned sites examined in 24 studies found that overall, Wyoming big sagebrush was slow to recover to unburned canopy cover values. While computations of postfire recovery were complicated by small sample sizes of old burns (only 13 of 112 sites were >20 years since fire) and high variability in Wyoming big sagebrush canopy cover among unburned sites, full recovery did not occur within 66 years since fire. A few sites neared recovery, and recovery appeared faster on some sites and in some ecoregions than others. Wyoming big sagebrush communities on warm, dry sites are less resilient to fire and less resistant to postfire nonnative annual grass invasion than those on cooler, moister sites; consequently, they are likely to recover more slowly. However, heavy browsing can slow postfire recovery regardless of favorable weather and site characteristics. Fire characteristics, such as fire severity, season, pattern, and size, are also likely to affect postfire recovery rates by altering the amount and distribution of available seed sources.

In general, prescribed fire is not considered effective for maintaining or restoring Wyoming big sagebrush communities because it can reduce habitat quality for sage-grouse and other sagebrush obligates for long periods and increase opportunities for postfire invasion by nonnative plants (especially cheatgrass). However, some researchers advocate for the continued use of prescribed fire as a management tool in Wyoming big sagebrush communities at sites where fire was relatively frequent historically. They advocate use of prescribed fire only on sites not considered important to sage-grouse and unlikely to convert to cheatgrass grasslands. In areas where native perennial plant cover is depleted, seeding Wyoming big sagebrush and other native perennial plants after fire helps stabilize soils, speed recovery of sagebrush and other shrubs, and prevent establishment and spread of nonnative species.

INTRODUCTORY

FEIS ABBREVIATION:
ARTTRIW
ARTTRI

COMMON NAMES:
Wyoming big sagebrush
Wyoming sagebrush

TAXONOMY:
The scientific name of Wyoming big sagebrush is *Artemisia tridentata* subsp. *wyomingensis* Beetle & Young (Asteraceae) [23,178,258,377,802]. Wyoming big sagebrush is one of six subspecies of big sagebrush (*Artemisia tridentata* Nutt.). Of these subspecies, Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush are the most widely distributed [54,321,378]. In this review, "big sagebrush" refers to all six subspecies. The subspecies are:

Artemisia tridentata Nutt. subsp. *parishii* (A. Gray) H.M. Hall & Clem., Mojave big sagebrush
Artemisia tridentata Nutt. subsp. *spiciformis* (Osterh.) Kartesz & Gandhi, snowfield big sagebrush

Artemisia tridentata Nutt. subsp. *tridentata*, basin big sagebrush
Artemisia tridentata Nutt. subsp. *vaseyana* (Rydb.) Beetle, mountain big sagebrush
Artemisia tridentata Nutt. subsp. *wyomingensis* Beetle & Young, Wyoming big sagebrush
Artemisia tridentata Nutt. subsp. *xericensis* Winward ex R. Rosentreter & R. Kelsey, xeric big sagebrush

Hybridization occurs in zones of overlap among Wyoming big sagebrush and other sagebrush taxa, including mountain big sagebrush, basin big sagebrush, low sagebrush, threetip sagebrush, plains silver sagebrush, and alkali sagebrush [153,278,279,459,464,465,639]. Some sagebrush taxa have recognized or putative hybrid origins with Wyoming big sagebrush [459]. A hybrid of Wyoming big sagebrush and mountain big sagebrush in Utah and Idaho is recognized as Bonneville big sagebrush [279,459]. Lahontan sagebrush may have originated through hybridization of Wyoming big sagebrush and low sagebrush [459]. Wyoming big sagebrush itself may have originated through hybridization between basin big sagebrush and mountain big sagebrush or basin big sagebrush and black sagebrush [460,794]. Hybridization is an important source of new genetic combinations that helped big sagebrush adapt to past climate changes, and such hybridization may help big sagebrush adapt to climate changes in the future [458,465].

Subspecies of big sagebrush differ in ploidy levels. Wyoming big sagebrush is primarily tetraploid, while mountain big sagebrush and basin big sagebrush are either diploid or tetraploid [458,462,464,613].

This review refers to plant species and infrataxa by their common names. See table A1 for scientific names of plants mentioned in this review and for links to FEIS Species Reviews.

SYNONYMS:
Artemisia tridentata var. *wyominensis* (Beetle & Young) Welch [178,220,258,802]
Seriphidium tridentatum subsp. *wyomingense* (Beetle & Young) Weber ([776], cited as a synonym in [258,357]

LIFE FORM:
Shrub

DISTRIBUTION AND OCCURRENCE

SPECIES: Artemisia tridentata subsp. wyomingensis

GENERAL DISTRIBUTION:
Wyoming big sagebrush is native to the western United States and British Columbia. It occurs from southern British Columbia [165,221], Washington, Oregon, and California east to northern New Mexico, Colorado, and extreme western Nebraska, South Dakota, and North Dakota [23,464,734,802]. It occupies the largest area of the big sagebrush cover types [659]. A map of its distribution can be viewed at BONAP's Taxonomic Data Center [1].

The Columbia Basin, the Great Basin, and the Wyoming Basin support most (~70%) sagebrush in North America. The largest areas of sagebrush are in the Columbia Basin, where 32% of all sagebrush occurred in 2005, and the Great Basin, where 28% of all sagebrush occurred. In the Great Basin, Wyoming big sagebrush-basin big sagebrush communities alone comprised 12,930,709 acres (5,232,872 ha) or 18% of the land cover. Mountain big sagebrush communities comprised 3.7% of the land cover, while black sagebrush and low sagebrush communities comprised 5.1% and 1.1%, respectively. All other sagebrush types comprised <1% [701]. According to a review, Wyoming big sagebrush is the most common subspecies of big sagebrush in the northern Great Plains [158].

The area occupied by Wyoming big sagebrush and other sagebrush communities has been reduced and altered by the cumulative and interacting effects of altered fire regimes, livestock grazing and associated land management, proliferation of nonnative invasive plants, woodland expansion, climate changes, agriculture, urban and industrial land uses, and other factors [98,160,306,398,496,503,518,787] (see Changes in Land Cover).

States and provinces [221,258,734]:
United States: AZ, CA, CO, ID, MT, NE, NM, NV, ND, OR, SD, UT, WA, WY
Canada: BC

SITE CHARACTERISTICS AND PLANT COMMUNITIES:

- **Site Characteristics**
  - *Topography*
  - *Climate*
  - *Soils*
    - *Soil order*
    - *Soil moisture*
    - *Soil texture*
    - *Soil fertility*
- **Plant Communities**

Site Characteristics: Topography, climate, and soils affect the distribution of big sagebrush subspecies [360,457,518]. Wyoming big sagebrush most commonly occurs at low to midelevations on warm, dry sites and on shallow to moderately deep soils, commonly on Aridisols and Mollisols (e.g., [285,288,360,361,558,705,706,720,787,802]). Sites occupied by parent taxa and their hybrids may be distinct from one another [266,456,458,486,773,802].

Topography: Wyoming big sagebrush occurs from valleys to high plateaus, including basins, plains, mesas, mountain foothills, slopes, ridges, and high alluvial terraces [23,178,220,258,325,327,582,715,720]. It occurs on a variety of slopes from flat to steeply sloping, on all aspects [582,715,720]. Although Wyoming big sagebrush occurs across a range of wind exposures [123], Wyoming big sagebrush sites are often windy and exposed (e.g., [53,123,237,325,484,515,697]). Wind-exposed sites are highly susceptible to wind erosion when plant cover is removed by disturbances [325], and sites with Wyoming big sagebrush often have evidence of erosion, such as channels and gullies [582]. Wind-driven soil erosion rates of 75 tons/acre (168,128 kg/ha) were measured during the weeks following the Butte City Fire, a severe July wildfire at the Idaho National Engineering Laboratory, U.S. Department of Energy [130].

Wyoming big sagebrush occurs from as low as 820 feet (250 m) in Washington [464] to as high as 8,700 feet (2,650 m) in Colorado [178] (table 1).

Table 1—Elevational range of Wyoming big sagebrush by location.	
Location	Elevation
Arizona	4,820-7,680 feet (1,470-2,340 m) [265,327,464,796]
California	6,630-7,480 feet (2,020-2,280 m) [23,464,711]
Colorado	4,040-8,700 feet (1,230-2,650 m) [79,371,464,582,715,720]
Idaho	2,300-6,550 feet (700-1,995 m) [325,460,464,485,524,819,826]; may occur on southern aspects at >7,000 feet (2,130 m) [523,640].
Montana	890-6,680 feet (270-2,035 m) [165,402,424,464]
New Mexico	7,150-8,300 feet (2,180-2,530 m) [464]
Nevada	4,280-8,200 feet (1,305-2,500 m) [265,464,485,582,711,796,819]
North	

Dakota	2,660-2,710 feet (810-825 m) [464]
Oregon	2,400-5,250 feet (730-1,600 m) [219,464,472,819]; typically uncommon above 6,000 feet (1,830 m) [829].
Utah	5,000-7,910 feet (1,525-2,410 m) [265,464,485,796,802,819])
Washington	820- 3,280 feet (250-1,000 m) [464,472]
Wyoming	4,360-8,040 feet (1,330-2,450 m) [164,464,575,796]
British Columbia	1,300-1,970 feet (400-600 m), with stands on steep, south-facing slopes as high as 2,950 feet (900 m) (McLean 1970, cited in [165]

Climate: Annual precipitation generally averages from 7 to 12 inches (180-300 mm) in areas with Wyoming big sagebrush[288,324,325], although it can be highly variable from year to year (e.g., [777]). Sites receiving <7 inches of annual precipitation may grade into salt desert shrub communities dominated by shadscale saltbush and winterfat, while sites receiving >12 inches of annual precipitation may grade into mountain big sagebrush and pinyon-juniper communities [285,288,324]. In Idaho, mean annual precipitation ranges from 7 to 8 inches (180-200 mm) in the Wyoming big sagebrush/Sandberg bluegrass association, 10 to 11 inches (250-280 mm) in the Wyoming big sagebrush/Thurber needlegrass association, and 7 to 12 inches in the Wyoming big sagebrush/bluebunch wheatgrass association [325]. In Utah, mean annual precipitation ranges from 11 to 13 inches (280-330 mm) in the pinyon-juniper belt where Wyoming big sagebrush, mountain big sagebrush, and Bonneville big sagebrush cooccur [288]. In north-central Nevada, annual precipitation averages 9.9 inches (251 mm) during 30 years and ranges from 4.3 to 28.0 inches (110-711 mm) [777].

The three major big sagebrush subspecies may be found in the same plant community [474], but in general, Wyoming big sagebrush communities occupy the driest sites [495,515,787]. For example, in Utah, mean annual precipitation, cumulative snowfall, and relative humidity were lower in Wyoming big sagebrush communities than basin big sagebrush or mountain big sagebrush communities and solar radiation was higher [515] (table 2).

Seasonal precipitation patterns vary across Wyoming big sagebrush's range. Summer precipitation in sagebrush ecosystems varies from almost none in central Nevada to nearly 40% of the annual total in southern Utah, northern Arizona, and northern New Mexico [178,804]. Big sagebrush is most common in portions of the West where winter precipitation equals or exceeds summer precipitation (Dahl et al. 1976, cited in [751]). Summer storms can be brief and intense, and most precipitation runs off or evaporates [402,554]. Snow accumulation and spring snowmelt are important in sagebrush ecosystems for recharging moisture deep in the soil profile, even on warm, dry sites [630,636]. Wyoming big sagebrush distribution in the northern Great Plains is limited by the relative lack of winter precipitation and relatively greater summer precipitation that favors grass growth [372,401].

Wind often prevents substantial snow accumulation in Wyoming big sagebrush communities [697], and snow may cover some Wyoming big sagebrush sites for only a month [468]. Burke [122] stated that near Saratoga, Wyoming, sagebrush distribution is controlled in part by snow distribution and wind exposure. Mountain big sagebrush occurs on leeward slopes on toeslopes and depressional areas where snow accumulation is moderate to deep; Wyoming big sagebrush occurs on slopes with slightly more windward exposure and less snow accumulation; and black sagebrush occurs on wind-exposed ridgetops where snow accumulation is least. In south-central Wyoming, Wyoming big sagebrush was most common where snow was shallow (<16 inches (40 cm)), and mountain big sagebrush was most common where snow was deep (>15 inches (38 cm)) [699].

Table 2—Climate characteristics of five plant communities in Utah. Values are means (SE) [515].

Characteristics	Wyoming big sagebrush	Basin big sagebrush	Mountain big sagebrush	Mountain shrub	Pinyon-juniper

Frost-free days	115.4 (9.8)	147.2 (7.5)	105.2 (13.0)	102.8 (1.1)	117.5 (6.8)
Temperature (°F)					
maximum January	38.6 (0.9)	39.9 (1.0)	36.0 (1.0)	36.6 (1.3)	38.8 (1.6)
minimum January	12.6 (1.1)	17.2 (1.0)	11.7 (2.6)	13.5 (1.7)	13.8 (0.8)
maximum July	90.4 (1.0)	91.0 (0.9)	85.0 (1.2)	86.9 (1.1)	88.0 (1.2)
minimum July	52.7 (1.5)	58.3 (1.2)	49.6 (2.0)	50.9 (1.8)	53.7 (1.4)
Mean precipitation					
Annual (inches)	10.6 (0.7)	13.8 (1.1)	16.5 (0.7)	19.6 (1.1)	12.3 (0.6)
January-March (%)	25	29	30	32	25
April-June (%)	26	25	24	23	22
July-September (%)	25	20	20	17	28
October-December (%)	24	26	26	26	24
Cumulative snowfall (inches)	38.9 (4.7)	46.7 (5.9)	69.8 (5.5)	95.5 (11.6)	55.4 (7.8)
Cumulative solar radiation (langlays)	510.0 (8.7)	464.1 (11.9)	480.9 (14.3)	480.4 (12.5)	480.5 (16.7)
Annual daily minimum relative humidity (%)	26 (2)	37 (3)	33 (3)	33 (2)	33 (3)
Annual pan evaporation (inches)	64.3 (4.8)	66.1 (2.0)	51.6 (2.3)	52.2 (2.7)	56.8 (2.7)

Soils: Wyoming big sagebrush sites have mostly warm (mesic) soil temperature regimes and dry (aridic) soil moisture regimes, but some sites have cool and dry (frigid and aridic) and warm and moist (mesic and xeric) soil temperature and moisture regimes (fig. 2, table 6). On warm and moist sites, Wyoming big sagebrush may overlap with mountain big sagebrush [142,325,491,492]. Warm and dry soil temperature and moisture regimes are more prevalent in the eastern portion of the sagebrush biome than the western portion [142] (fig. 2). Soils of Wyoming big sagebrush sites are variable in texture, depth, and development (ranging from weakly to strongly developed) due to different soil parent materials and amounts and distribution of precipitation [325] (see Climate). Wyoming big sagebrush grows mostly on shallow to moderately deep, well-drained, moderately acidic to moderately basic soils, which may be noncalcareous to highly calcarious near the surface [67,169,325,327,331,371,402,582,706,787].

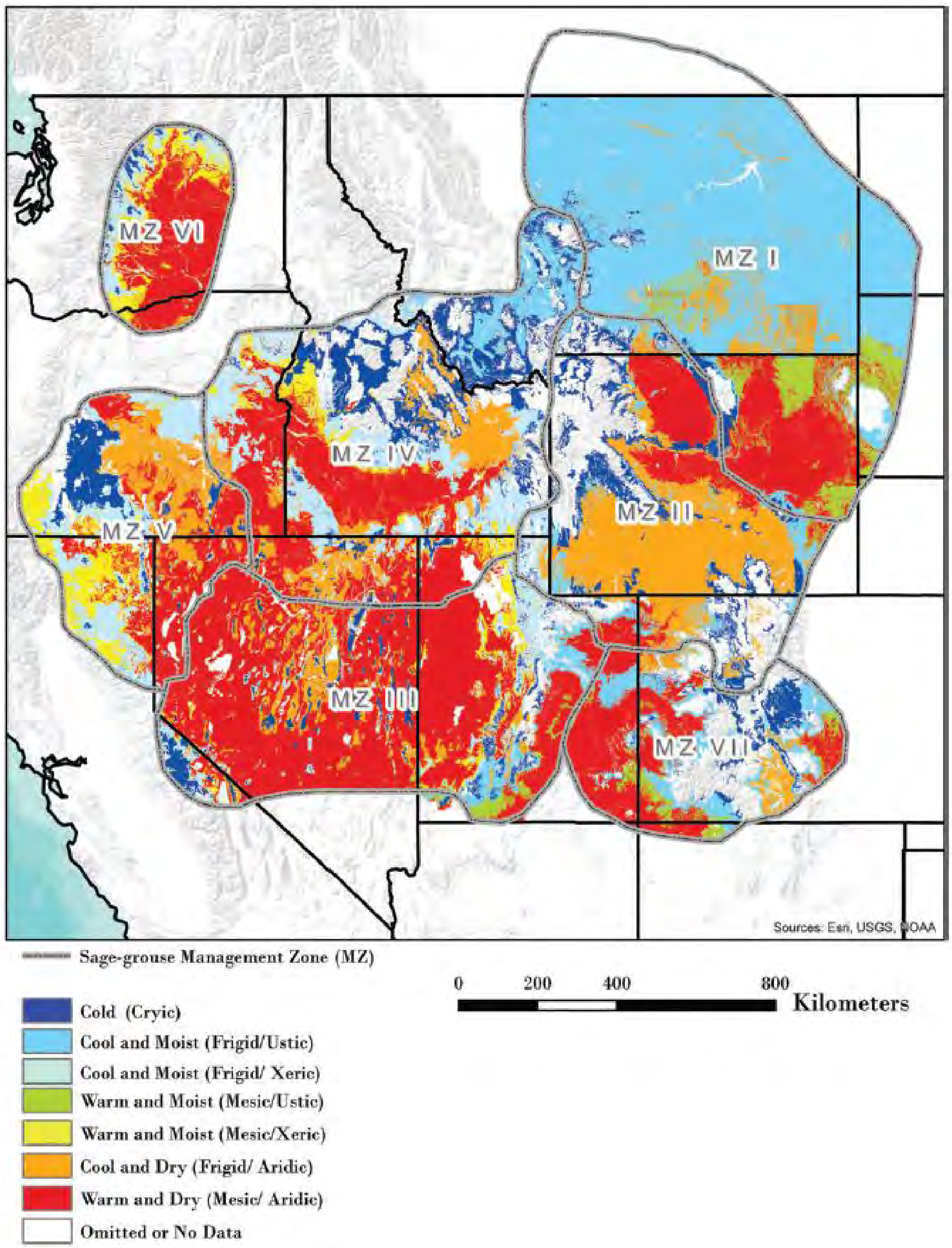


Figure 2—Distribution of soil temperature and moisture regimes in Sage-grouse Management Zones (MZ I-VII) in the western United States [142].

Soil order: Wyoming big sagebrush most commonly occurs on Aridisols and Aridisol-Mollisol intergrades, but also occurs on Mollisols [62,165,285,288,360,361,558,576,705,706] and Vertisols [27,523]. Mollisols develop in areas where grasses have been codominant to dominant for a prolonged period. Aridisols develop where conditions are very dry and potential evapotranspiration typically exceeds precipitation, and they are not associated with specific plant life forms [243]. On Mollisols where Wyoming big sagebrush dominates, mollic epipedon thickness is less than that on Mollisols where basin big sagebrush or mountain big sagebrush dominates [361], but greater than that on sites where black sagebrush dominates [359]. The absence of a thick mollic epipedon indicates that Wyoming big sagebrush communities historically did not have as productive an herbaceous layer as basin big sagebrush and mountain big sagebrush communities [288] (see Fuels).

Soil moisture: Among sites dominated by the three major big sagebrush subspecies, soil moisture availability tends to be lowest on Wyoming big sagebrush sites, and Wyoming big sagebrush is the most drought tolerant of the three

[488,706,828]. In southern Idaho, soil moisture was deficient by mid- to late July in Wyoming big sagebrush stands and by late July or early August in basin big sagebrush stands, while soil moisture was not deficient until September in two mountain big sagebrush stands and did not become deficient in another [828]. In Oregon, all subspecies were water stressed in August, but Wyoming big sagebrush was the least water stressed, followed by basin big sagebrush, and then mountain big sagebrush [488].

All subspecies of big sagebrush grow on well-drained soils [67,169,371,706,773,787]. In general, they cannot tolerate saturated soils [290,787]. Welch [787] suggested that high water tables preclude big sagebrush from many western grasslands.

Soil texture: Wyoming big sagebrush is most common on fine-textured soils, such as silts and clays, but it occurs on loams and sands. Soils are often stony or gravelly [169,219,263,274,325,558,582,666,690,720]. According to Frisina and Wambolt [274], Wyoming big sagebrush does not grow as well on coarse-textured soils.

Where Wyoming big sagebrush and basin big sagebrush overlap, soil texture may help to differentiate Wyoming big sagebrush sites from basin big sagebrush sites [79,169,666]. In eastern Idaho, Wyoming big sagebrush occurred on silty soils and basin big sagebrush on sandy soils, while mixed stands occurred on intermediate sites [666]. The same pattern occurred in western Colorado; however, soil texture did not differentiate mountain big sagebrush sites from Wyoming big sagebrush or basin big sagebrush sites. Instead, elevation and precipitation amounts helped differentiate them. Mountain big sagebrush occurred at the highest elevations receiving the most precipitation [79,169] (see Topography and Climate).

Soil fertility: Wyoming big sagebrush occurs on soils with moderate fertility. On 372 relatively undisturbed sites on the Humboldt National Forest, Nevada, soil organic carbon, nitrogen, and phosphorus levels indicated that black sagebrush commonly dominated the least fertile sites; Wyoming big sagebrush, alkali sagebrush, and low sagebrush commonly dominated soils of moderate soil fertility; and mountain big sagebrush and basin big sagebrush commonly dominated sites with the highest fertility. Mollic epipedon depth, total depth, and water-holding capacity followed a similar pattern, with black sagebrush, Wyoming big sagebrush, alkali sagebrush, and low sagebrush communities having lower mean values than mountain big sagebrush and basin big sagebrush communities [361]. At three sites in northeastern Utah, Wyoming big sagebrush occurred on drier, less fertile soils (i.e., with lower organic carbon, nitrogen, potassium, phosphorus, and cation exchange capacity) than basin big sagebrush [27]. For a review of soil chemistry in big sagebrush communities, see Welch [787].

Plant Communities: Wyoming big sagebrush dominates or codominates many sagebrush steppe and sagebrush shrubland communities. It also occurs in desert shrublands, salt desert shrublands, and shrub-mixed-grass prairie. It is a common component and sometimes an understory dominant in juniper, pinyon-juniper, and ponderosa pine woodlands. Wyoming big sagebrush communities are composed of sagebrush and other shrubs, bunchgrasses, sparse forbs, and often a biological soil crust. Historically, big sagebrush communities had few trees [534], but since the late 1800s, junipers and pinyons have been expanding into some big sagebrush communities [505]. The greatest proportion of conifer expansion has occurred on cool to warm, relatively moist sagebrush sites, which include Wyoming big sagebrush communities at the moister end of their distributions [142] (table 6). See Woodland Expansion for more information.

Wyoming big sagebrush occurs in pure stands or mixed with other shrubs [329]. Its distribution overlaps with that of other sagebrush taxa, including basin big sagebrush, mountain big sagebrush, black sagebrush, low sagebrush, silver sagebrush, and threetip sagebrush [288,311,464,465,582]. Hybrids of these taxa may dominate some areas [288,465]. For example, Collins and Harper [154] describe a common vegetation type on the Curlew National Grasslands, Idaho, dominated by Wyoming big sagebrush × mountain big sagebrush hybrids. Common shrubs in Wyoming big sagebrush communities include antelope bitterbrush [802], broom snakeweed [402,582], green rabbitbrush [371,640,720], rubber rabbitbrush [582], Gardner's saltbush [582], fourwing saltbush [371], black greasewood [371,582,720], shadscale saltbush, winterfat [21,375,582,802], spiny hopsage [21,582], and fringed sagebrush [371,402,582].

Principal understory species in Wyoming big sagebrush communities include bluebunch wheatgrass [21,165,263,325,371,402,500,582,720,725] and Sandberg bluegrass [219,402,582,725]. Other grasses that occur commonly and dominate some sites include Columbia needlegrass [263,720], Idaho fescue [165,219], Indian ricegrass [371,474,725], needle and thread [21,219,325,359,360,402,725], squirreltail [219,325,359,360,725], Thurber needlegrass [25,219,325,725], and western wheatgrass [21,165,263,720].

Associated understory species vary by region and with topography, soil temperature and moisture regimes, and disturbance history [392]. East of the Sierra Nevada in California, Thurber needlegrass is the primary understory grass in Wyoming big sagebrush steppe. On the driest sites, where Wyoming big sagebrush steppe grades into salt desert, desert needlegrass is dominant in the understory. Where Wyoming big sagebrush steppe merges into warm desert, James' galleta is dominant in the understory [25]. Common forbs associated with Wyoming big sagebrush include milkvetch, pussytoes, phlox, fleabane, arrowleaf balsamroot, hawksbeard, lupine, and globemallow [725]. Cacti, such as plains pricklypear, may be present on relatively dry sites [371,402,725]. Cheatgrass is dominant in some Wyoming big sagebrush communities [219], most commonly on warm, dry sites [142] with a heightened disturbance regime [238,325,610]. Evenden [240] described a "highly disturbed" Wyoming big sagebrush/cheatgrass community on a stream terrace in the Trout Creek Mountains of southeastern Oregon where Wyoming big sagebrush and cheatgrass comprised 40% and 28% cover, respectively.

Wyoming big sagebrush occurs in juniper, pinyon-juniper, ponderosa pine, curlleaf mountain-mahogany, and other woodlands, often as a dominant understory shrub [21,165,228,371,582,624,711,807,809]. It is common in western juniper, Utah juniper, and singleleaf pinyon communities throughout their distribution [241,327,490,582,810]. In northern Arizona it is the most abundant big sagebrush subspecies in singleleaf pinyon-Utah juniper communities [327]. Twoneedle pinyon-juniper/Wyoming big sagebrush communities are common throughout northern Arizona, northern New Mexico, western Colorado, and eastern Utah [371,582]. Juniper species in these communities vary with geography and elevation and include oneseed juniper, Utah juniper, and Rocky Mountain juniper [582].

Plant species diversity is lower in Wyoming big sagebrush types than in mountain big sagebrush and many other sagebrush types [191,192,259,263,285,286,420], but the number of species in Wyoming big sagebrush stands fluctuates with annual precipitation [495] and successional stage [58]. For example, in the North Spring Valley watershed, Nevada, the Wyoming big sagebrush type had 41 species, while the low sagebrush type 57 species, the black sagebrush type 70 species, and the mountain big sagebrush type 76 species [259]. Similar results were found in Colorado [263], northeastern Utah [286], and southwestern Wyoming [420]. In southeastern Oregon, the number of species in three Wyoming big sagebrush/Thurber needlegrass communities fluctuated from 27 species during a dry year (50% of average annual precipitation) to 41 species in a wet year (185% of average annual precipitation) [495]. In Wyoming big sagebrush steppe on the Thunder Basin National Grassland, Wyoming, the number of plant species decreased from early to late succession. The early-successional stage had 74 forbs, 30 graminoids, and 11 shrubs, while the late-successional stage had 38 forbs, 18 graminoids, and 5 shrubs [58].

Biological soil crusts are common in Wyoming big sagebrush communities [325,375,582]. Cover of biological soil crusts can be high in Wyoming big sagebrush communities, with >50% cover on some sites [325,375]. Biological soil crust cover typically increases with increasing aridity and is inversely related to vascular plant cover. Biological soil crusts are usually more abundant in relatively warm Wyoming big sagebrush, salt desert, and desert shrub communities than relatively cool mountain big sagebrush and mixed mountain shrub communities [493]. In east-central Idaho, Wyoming big sagebrush communities had about 60% cover of biological soil crusts, while mountain big sagebrush communities had about 40% cover [374].

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Artemisia tridentata subsp. wyomingensis

Reviews and management guidelines describing the biology and ecology of big sagebrush are cited frequently in this review, including the following sources: [49,67,481,482,493,495,496,514,723,784,791,840]. This review includes information on many aspects of Wyoming big sagebrush biology and ecology but focuses on information most relevant to fire.

GENERAL BOTANICAL CHARACTERISTICS:

Botanical Description: This description covers characteristics that may be relevant to fire ecology and is not meant for field identification. Identification keys are available (e.g., [178,258,826]).

Sagebrush taxa are difficult to distinguish from one another based on morphology alone. This is especially true for Wyoming big sagebrush, which is intermediate in several characteristics used to distinguish basin big sagebrush and mountain big sagebrush [325,724,735,826]. In portions of the Great Basin in California, Nevada, Utah, and Idaho, West et al. [809] found that only 32.6% of the sagebrush specimens examined, which included Wyoming big sagebrush, basin big sagebrush, mountain big sagebrush, black sagebrush, and low sagebrush, were correctly identified based on morphology alone. Differences in leaf chemical constituents can help differentiate sagebrush taxa, especially when used in combination with plant morphology [178,464,689,787] and site characteristics (e.g., topography, climate, and soils) [274,464,482]. Infrataxa differences in leaf chemical constituents of big sagebrush include concentrations of coumarins, flavonoids [778,825], and sesquiterpene lactones [384]; these are determined by examining fluorescence of leaves and other plant parts under ultraviolet light [384,650,689,787,825] or by using spectrophotometry to measure ultraviolet absorbance [611,668,681].

Wyoming big sagebrush is an aromatic, evergreen shrub [67]. The main stem branches at or near ground level [53,178,639,723]. Flower stems arise from vegetative stems [787]. The crowns are rounded and uneven [53,178,325,639,723]. They are typically dense and spreading, with the lower part of the crown often close to the ground [285]. Dead stemwood is common in old plants. For example, in southwestern Montana and southern Idaho, 48% of stemwood was dead on Wyoming big sagebrush and mountain big sagebrush plants averaging 36 years old [110].

Wyoming big sagebrush is a tall sagebrush [495]. It occasionally reaches up to 79 inches (200 cm) tall [258,464], but is typically shorter than 40 inches (100 cm) [23,166,220,258,285,325,346,463]. Wyoming big sagebrush may be dwarfed as a result of edaphic conditions [53,582].

Figure 3—Wyoming big sagebrush steppe northeast of Eureka, Utah. Photo by Matt Lavin, courtesy of Wikimedia Commons.

Wyoming big sagebrush has both ephemeral and persistent leaves [501,723,759,787]. Leaves are mostly <0.5 inch (12 mm) long and <0.12 inch (3 mm) wide [23,258,802,828]. The inflorescence is an open, many-flowered spike [53,346].

Researchers have described the one-seeded fruit of Wyoming big sagebrush as both an achene [80,481,653,723,787,858] and a cypsela [258,290,664]. This review uses the term achene. The achene lacks a pappus [787]. It has one small, light seed [482] that ranges from about 0.04 inch (1.3 mm) long and 0.24 inch (0.6 mm) wide [815] to 0.07 inch (1.77 mm) long and 0.03 inch (0.81 mm) wide [311]. Mean weight ranges from about 0.16 mg [815] to 0.58 mg [311].

Wyoming big sagebrush develops a dense root network both in upper and lower soil layers [697,787]. It has many laterals and one or more taproots. About 35% of the total root system occurs in the upper 1 foot (0.3 m) of soil. Some roots may penetrate >6 feet (2.0 m) deep [250,422,697,780]. Soil characteristics such as texture, aeration, and moisture influence root distribution in big sagebrush [290,697]. For example, in south-central Wyoming, root systems of Wyoming big sagebrush were shallower and had greater lateral spread (root system depth: <60 inches (152 cm); lateral spread: 48-60 inches (122-152 cm)) than root systems of mountain big sagebrush plants (root system depth: 72-84 inches (183-213 cm); lateral spread: 36-48 inches (91-122 cm)). Wyoming big sagebrush plants grew on a ridge with a rocky substratum and low water content, while mountain big sagebrush plants grew lower on the slope in soils that lacked rocks [697].

Vesicular-arbuscular mycorrhizal fungi (VAM) colonize Wyoming big sagebrush roots. These include *Glomus microcarpus* and *Gigaspora* spp. [62,354]. VAM may improve Wyoming big sagebrush seedling survival [682] and growth [683] (see Vesicular-arbuscular mycorrhizal fungi).

Stand structure: According to reviews, shrub cover in undisturbed, late-successional Wyoming big sagebrush communities rarely exceeds 25% because of low average annual precipitation [285,495]; however, cover can exceed 25% at upper elevation and relatively high precipitation zones [412], and in small areas (<1.2 acres (0.5 ha)) where moisture is funneled, such as in alluvial soils without restrictive horizons [285]. Using data from ungulate exclosures in Daggett County, Utah, Goodrich et al. [289] concluded that the maximum cover of Wyoming big sagebrush in areas with 8 to 10 inches (200-250 mm) of average annual precipitation is about 22%. In Moffat County, Colorado, cover of Wyoming big sagebrush in undisturbed stands (i.e., sites unaltered by livestock grazing, logging, or other land uses) varied from 8% to 20% [21]. In southeastern Oregon and northern Nevada, 107 "intact", late-successional stands ranged from 3% to 36% Wyoming big sagebrush cover (mean: 12%); 90% of sites had 6% to 20% Wyoming big sagebrush cover [195]. In eastern Montana, Wyoming big sagebrush cover never exceeded 20% even in stands with the oldest (~40 years old) Wyoming big sagebrush plants [165].

Cover of big sagebrush and perennial herbs is related to soil temperature and moisture regimes. As Wyoming big sagebrush steppe grades into drier desert shrub communities, the number of forbs, total plant cover, and plant productivity decline. As it grades into moister mountain big sagebrush communities, the number of forbs, total plant cover, and plant productivity increase [285]. A survey of 106 "intact" big sagebrush sites in southeastern Oregon found that Wyoming big sagebrush sites that averaged 9.7% Wyoming big sagebrush cover, were less diverse, and had less total vegetation cover, density, and biomass production than mountain big sagebrush sites that averaged 23.0% mountain big sagebrush cover [192]. In Wyoming big sagebrush communities in eastern Montana, Wyoming big sagebrush/bluebunch wheatgrass communities had 22% to 35% perennial grass cover (mean = 28%) and were characteristic of the driest sites (11 inches (270 mm) average annual precipitation), while Wyoming big sagebrush/Idaho fescue-western wheatgrass communities had 68% to 80% perennial grasses cover (mean = 74%) and were characteristic of the wettest sites (16 inches (400 mm) average annual precipitation) [167].

Age structure: Wyoming big sagebrush is a long-lived species. Wyoming big sagebrush plants may live >100 years, although most die before they are 50 years old [31,110,249,574,697,723,757,787]. For example, on 27 relatively undisturbed sites throughout Wyoming, the oldest Wyoming big sagebrush plant was 75 years, while the average age was 32 years [574]. In southern Wyoming, the oldest Wyoming big sagebrush plant was 57 years, while the average age was 42 years [697], and in southwestern Montana the oldest plant was 58 years, while the average age was 30 years [757]. The oldest big sagebrush plant in southeastern Idaho was about 130 years old [153].

Because Wyoming big sagebrush seedlings establish episodically, late-successional stands are uneven-aged [345,425]. In Nevada, for example, Wyoming big sagebrush plants in stands that were "relatively free from disturbance" ranged from 2 to 79 years old in Antelope Valley and from 6 to 40 years old in the Santa Rosa Mountains [345]. In northeastern Wyoming, seedlings (5-10 years old) were "common" in late-successional Wyoming big sagebrush stands with "minimal herbivory disturbance" but few plants occurred in some age classes because many years of minimal to no seedling recruitment occurred between years of successful recruitment [574]. See Seedling Establishment for more information.

Raunkiaer [596] Life Form:
Phanerophyte

SEASONAL DEVELOPMENT:
Annual growth of big sagebrush plants begins in early spring and ceases when soil moisture is depleted, usually by mid- to late July [28,52,362,501,723,787,828]. Root growth begins first and continues through late fall [250,787]. Big sagebrush produces two types of stems: long shoots and short shoots [787]. Current-season long shoots produce ephemeral leaves, which develop in spring and senesce, die, and abscise in mid- to late summer [67,723,787], when water stress is high [488,489].

Short shoots, which arise from long shoots, produce longer-lived leaves in early summer. These leaves persist over winter and die the following summer [489,723,787], living for 12 to 13 months [501,787]. Inflorescences are produced on short shoots [787]. Wyoming big sagebrush plants usually flower and are pollinated from midsummer to late fall [28,67,250,258,653,826]. Flowering stops with the onset of cold weather [527]. Flowering has been observed from as early as mid-July [250] to as late as November [23], depending on climate and elevation.

Seeds ripen in late summer and fall [28,250,653,826]. Time of ripening depends on latitude, elevation [67,290,612,723,858], and available moisture [653,828]. Winward [828] stated that Wyoming big sagebrush seeds matured earlier on dry sites than near streams. Near streams, fall frosts often killed flowers before seeds were produced [828]. Big sagebrush seeds ripen asynchronously, so there is an extended period of seed dispersal [858]. Big sagebrush seed dispersal occurs in fall and winter [80,283,527]. Although not reported for Wyoming big sagebrush in particular, the most viable big sagebrush seeds tend to be dispersed earliest, with half-filled seeds dispersed later [290,311]. Booth and Bai [80] noted that viable Wyoming big sagebrush seeds from the western edge of the Great Plains could be harvested in February or even later.

Big sagebrush germination is usually synchronous [481] and occurs in late winter and early spring [481,484,723].

Phenology of Wyoming big sagebrush in the Curlew Valley, northern Utah, at 4,430 feet (1,350 m) was as follows [250]:

> root elongation: April-mid-May
> shoot elongation: May- mid-August
> flowering: mid-July-September
> fruiting: mid-August-September

Phenology of Wyoming big sagebrush at 3 sites from 6,400 to 7,550 feet (1,950-2,300 m) in Utah and Wyoming was as follows [28]:

leaf buds beginning to swell: 15 April
vegetal growth rapid: 13 May-8 July
vegetal growth reduced, reproductive shoots and flower buds developing: by 25 July
flowering: by 5 September
seeds developing: by 23 September

Timing of phenological events depends on big sagebrush subspecies and site characteristics such as soil moisture and elevation. In southern Idaho, timing of phenological development differed among big sagebrush infrataxa. Wyoming big sagebrush and basin big sagebrush began growing earlier and ripened seeds later than mountain big sagebrush (table 3) [826]. In south-central Idaho, Winward [828] concluded that variation in timing of seed maturity between Wyoming big sagebrush and basin big sagebrush was related to available soil moisture because seeds matured earlier on drier sites. However, variation in timing of mountain big sagebrush seed maturity appeared related to timing of fall frost more than soil moisture. Areas with early fall frosts had earlier maturing mountain big sagebrush seeds than areas with late fall frosts [828]. In eastern Montana, big sagebrush growing above 5,900 feet (1,800 m) initiated growth 2 to 3 weeks later and initiated floral bud enlargement, anther development, anthesis, and dissemination 2 weeks earlier than big sagebrush at lower elevations [311].

Table 3—Timing of phenological events for big sagebrush subspecies in south-central Idaho [826].

Event	Wyoming big sagebrush and basin big sagebrush	Mountain big sagebrush
early shoot development	mid-June	early July
medium shoot development	late June to early July	early July
full shoot development	mid-July	mid-July
flowerheads green	late July	mid- to late July
flowerheads yellowing	early September	early August
pollination	mid-October	early September
seed ripening	early November	mid-October

REGENERATION PROCESSES:

Wyoming big sagebrush primarily regenerates from seeds [544], and occasionally vegetatively by layering [311]. Seed production [311] and seedling emergence [497,757,786] are highly variable across years and sites. Due to high rates of mortality, most big sagebrush seedlings that germinate do not establish [311,368,481,599,723]. Seedling establishment is episodic [153,573,574]. The length of time between a fire and the first establishment pulse may explain, in part, differences in postfire seedling establishment rates among burns [153]. Wyoming big sagebrush does not sprout from the root crown or roots after the aerial portion of the plant is killed or removed [311,538].

- **Pollination and Breeding System**
- **Seed Production**
- **Seed Dispersal**
- **Seed Banking**
- **Germination**
    - *Germination rates and dormancy*
    - *Temperature*
    - *Light*
    - *Moisture*
    - *Planting depth*
- **Seedling Establishment**
    - *Overview*
    - *Moisture availability*
    - *Interference and competition*
    - *Postfire seedling establishment*
    - *Vesicular-arbuscular mycorrhizal fungi*

Pollination and Breeding System: Big sagebrush is wind pollinated [783]. Its flowers are self-pollinating [304,456], although outcrossing leads to greater production of viable seeds (McArthur 1984, cited in [783]). Because it self-pollinates, isolated big sagebrush individuals can set seeds [481]. For this reason, Meyer [481] stated that seed set is probably not strongly pollen-limited even in years when flowering is sparse. Information on seed and embryo development and anatomy of big sagebrush can be found in a review by Welch [787].

Seed Production: Wyoming big sagebrush may produce abundant seeds during favorable years, but seed production is highly variable and often low. Like other big sagebrush subspecies, it likely depends on plant characteristics (e.g., size, age, and genetics), site characteristics (e.g., soil temperature and moisture regimes), and weather [290,311,411,481,514,780]. A 19-year-old Wyoming big sagebrush plant in Montana produced an average of 89,700 seeds/year for 3 years, while a 15-year-old plant produced an average of 1,700 seeds/year during the same 3 years [311]. In a review of germination and establishment ecology of big sagebrush, Meyer [481] stated that dry, upland Wyoming big sagebrush stands may set very few seeds except in wet years and suggested that Wyoming big sagebrush plants allocate resources to growth in "high-stress" years and to sexual reproduction in "low-stress" years. In a common garden in Utah, 3- to 5-year-old 'Gordon Creek' Wyoming big sagebrush cultivars produced from 1.4 to 2.3 ounces (39-64 g) of seeds on average during 2 years of cooler and wetter than average weather. They produced fewer seeds on average (1.2 ounces (34 g)) in a year of warmer and drier than average weather [780]. Seed production can be reduced by conditions that are too dry [859] or too wet [185]. Because Wyoming big sagebrush stands may not produce abundant seed crops each year, seed dispersal onto disturbed sites may not occur until years when favorable moisture conditions support seed production and seedling establishment.

Reviews reported that Wyoming big sagebrush typically produces fewer flowers and seeds than mountain big sagebrush or basin big sagebrush, because the latter two subspecies are typically larger and occur on moister sites. Flower and seed production may be similar among subspecies in "unusually wet years" [481,514]. Some Wyoming big sagebrush cultivars may produce as many or more seeds than cultivars of other subspecies. During each of 3 years in a common garden in Utah, 3- to 5-year-old 'Gordon Creek' Wyoming big sagebrush plants produced more seeds on average than 3- to 5-year-old 'Hobble Creek' mountain big sagebrush plants [780].

The few studies that examined age of reproductive maturity of Wyoming big sagebrush found that Wyoming big sagebrush can produce seed anywhere from 2 [780] to >10 years [767] old. In a common garden study, Wyoming big sagebrush plants as young as 2 years old produced seeds [780]. Observations of wild populations [786] and seeded field plots [31] show that some 5-year-old Wyoming big sagebrush plants produce seeds. Production of short shoots on big sagebrush plants (Wyoming big sagebrush, mountain big sagebrush, and their hybrids) was observed 5 years after a high-severity, stand-replacing wildfire near Provo, Utah [786]. A study on the northern Yellowstone winter range found that no Wyoming big sagebrush plants had reached reproductive maturity in 10 postfire years [767].

Reduced competition for resources may increase Wyoming big sagebrush seed production. Stand thinning using chaining resulted in an exponential increase in seed production by surviving Wyoming big sagebrush plants under drought conditions (Davis 1992, personal communication cited in [481]).

Browsing by ungulates and other wildlife can drastically reduce Wyoming big sagebrush seed production [768]. On the northern Yellowstone winter range, Wyoming big sagebrush plants inside 35-year-old ungulate exclosures had greater seed production (44.7 g/plant) and seedhead number (60.3 seedheads/plant) than Wyoming big sagebrush plants outside exclosures (seed production: 10.0 g/plant; seedhead number: 0.08 seedhead/plant) ($P \leq 0.05$ for both comparisons) [768]. Near Glenrock, Wyoming, mature Wyoming big sagebrush plants on mined stands protected from browsing had a 3-year average seed yield of 20.7 g/plant compared to 1.4 g/plant from plants on browsed, mined stands [81]. Insect seed predators and herbivores like thrips, which feed on flower parts, may also reduce seed production [481].

Plant pathogens, such as stem rust fungi, can reduce seed production in cultivated and probably native stands of big sagebrush (Nelson 1992, personal communication cited in [481]).

Seed Dispersal: Wind, water, and animals disperse big sagebrush seeds [52,290,311,482,572,723,858]. Among these, wind may be the most important [290], but it is ineffective for long-distance dispersal [572,789]. Pendleton et al. [572] classified the dispersal mechanism of big sagebrush seeds as "microwind", meaning that the seeds are dispersed by wind because they are light and small but lack any special structures that would allow them to float or travel long distances

[789]. Big sagebrush seeds float in water, aiding in water dispersal [290], and big sagebrush grows along stream banks, gullies, and other water courses [290,527]. Most long-distance dispersal of big sagebrush seeds is attributed to large mammals, because the mucilaginous seedcoat can attach to their fur [311]. Many large animals, such as mule deer and elk, use burned big sagebrush areas [762]; thus, they may disperse big sagebrush seeds to burns. Cattle apparently do not disperse viable seeds by consuming them. A study of cattle fecal samples in Utah found that germinability of Wyoming big sagebrush seeds consumed by cattle was negligible [815]. No big sagebrush seeds were reportedly dispersed by rodents near Reno, Nevada [409].

Most big sagebrush seeds are dispersed within 10 feet (3 m) of parent plants, and most fall under the crown [270,311,723,755,789,858]; however, seedling establishment patterns indicate that some seeds disperse farther (e.g., [270,755]). In general, the maximum distance of big sagebrush seed dispersal by wind is about 100 feet (30 m) from the parent plant [290,493,787]. Most big sagebrush seeds are dispersed on the downwind [153,290,311,755,789,858] or downhill [393] side of plants. Seeds likely disperse farthest on steep or windy sites [393]. While dispersal patterns may be related to wind direction, wind-related establishment patterns are not always evident, likely because other factors are more important in determining establishment patterns [153] (see Seedling Establishment).

Colonization of large burns and other disturbed areas by big sagebrush may be slow because of short dispersal distances [855] and because seeds may not disperse onto disturbed sites until years when favorable moisture conditions support seed production and seedling establishment. Assuming a maximum dispersal distance of 100 feet (30 m) and an age of first reproduction of 2 to 4 years, Welch [787] concluded that big sagebrush could spread 25 to 50 feet (7-15 m)/year, and noted that it would take about 105 to 211 years to spread 1 mile (1.6 km). A Wyoming study on revegetated mined sites found that natural recruitment of big sagebrush was most successful on sites close to a seed source, and big sagebrush density decreased as distance from the seed source increased. Natural recruitment decreased 44-fold when distance to the seed source exceeded 330 feet (100 m) [434].

Seed Banking: Wyoming big sagebrush has short-term persistent (1-5 years) seed banks [31,514,529,644,723,819]. Viability and germinability of Wyoming big sagebrush seeds can be extended to 5 or more years in storage [83,376,653,790]. In the field, most big sagebrush seeds are lost from the seed bank through germination in late winter and early spring [478,514,858], although some persist if suitable conditions are not present to cue germination [481,514,819]. Postdispersal loss of big sagebrush seeds to rodents appears minimal [409], probably because of small seed size [481].

Seed abundance in the soil varies among and within sites and across months and years. The number of Wyoming big sagebrush seeds in the soil seed bank likely varies among sites depending on cover of mature plants [2,26,312,447] and timing of sampling relative to seed dispersal [819]; however, few studies were available that quantified Wyoming big sagebrush seed banks as of 2019. Near Mills, Utah, there was a positive correlation between Wyoming big sagebrush cover and density of viable seeds on unburned plots during 2 years ($P < 0.05$ for both years). Densities of viable Wyoming big sagebrush seeds averaged 1.5 seeds/m² in March [312]. At 6 sites in the Great Basin, densities of viable Wyoming big sagebrush seeds 9 months after dispersal in August ranged from 0 to about 75 seeds/m² in litter and from 0 to about 125 seeds/m² in soil. Overall, seed densities were lower the next year [819]. Differences within and among these two studies and their sites were attributed to the patchy distribution of seeds in soils and in soil disturbances that bury seeds [819] (see Planting depth). Differences among studies may also be attributed to differing rates of seed dormancy among sites and differing methods used for germinating seeds [222].

Establishment of Wyoming big sagebrush and other big sagebrush plants 1 or more years after large, severe fires suggests that big sagebrush seeds may persist in soil seed banks at least 1 year [478,786]. Five years after an August 1999 stand-replacing wildfire near Provo, Utah, 0 to 47 big sagebrush seedlings (mountain big sagebrush, Wyoming big sagebrush, and their hybrids) occurred in 1-acre (0.4-ha) plots along a transect. Because the closest seed source was 0.4 mile (0.6 km) away, the author concluded that these seedlings originated from soil-stored seeds surviving the fire [786]. The author did not report in which of the 5 postfire years the seedlings established.

Establishment of Wyoming big sagebrush seedlings after artificial seeding suggests that Wyoming big sagebrush seeds may remain viable in the soil 2 to 5 [80,82,644,665] or 6 years [665] after fire.

Fire kills many big sagebrush seeds in soil seed banks [3,312] (see Immediate effects on seeds).

Germination: Germination rates of Wyoming big sagebrush seeds vary, but may exceed 90% [311,480,485]. Seeds germinate within a wide range of temperatures [311,468]. Germination requires saturation of the surface soil [290,801], and it occurs shortly before or soon after snowmelt, when moisture availability is high [468,481,484,514,723]. Seedling emergence is highest when seeds are at the soil surface or buried at very shallow depths (≤0.2 inch (5.0 mm) [290,311,510].

- *Germination rates and dormancy*
- *Temperature*
- *Light*
- *Moisture*
- *Planting depth*

Germination rates and dormancy: Germination rates of viable seeds vary, but they may exceed 90% [311,480,485], depending on seed weight and environmental conditions. For example, 74% to 100% of seeds collected from 21 sites in Montana, Wyoming, Utah, Idaho, and Nevada germinated in a laboratory [484]. Heavy seeds germinate more often and more quickly than light seeds [17]. Temperature, light, moisture, and planting depth affect germination rates [311,468,485]. Within populations, germination rates vary from year to year [308,311]. At the U.S. Sheep Experiment Station, Idaho, laboratory germination of Wyoming big sagebrush seeds from a single population averaged 43%, 50%, and 70% over 3 years. Differences among years were not significant because variability in germination within years was high, ranging from 1% to 78% during the first year, 22% to 73% during the second year, and 27% and 91% during the third year [308].

Wyoming big sagebrush seeds are mostly nondormant at dispersal and germinate in late winter and early spring when germination conditions are suitable. Some seeds may persist in soil seed banks if moisture is insufficient or other conditions necessary to cue germination are absent [481,484,485,514]. While dormancy of mountain big sagebrush seeds is positively associated with winter severity ($R^2 = 0.58$, $P < 0.001$), dormancy of Wyoming big sagebrush seeds and basin big sagebrush seeds is not associated with winter severity. Climate-related variation in dormancy in mountain big sagebrush apparently prevents precocious germination and favors germination when chances for establishment are greatest. A lack of a relationship between seed dormancy and winter severity in Wyoming big sagebrush was attributed to dry conditions at Wyoming big sagebrush sites in fall, which generally prevent precious germination. A lack of this relationship in basin big sagebrush was attributed to late seed ripening [484]. These differences illustrate the importance of planting big sagebrush seeds that are adapted to the specific climate of a site [482,483,690] (see Value for Restoration of Disturbed Sites).

Temperature: Wyoming big sagebrush seeds germinate within a wide range of temperatures [311,468]. In a laboratory, McDonough and Harniss [468] found no differences in rates of germination across a range of temperatures, but Harvey [311] reported highest germination (96%) from 54 to 57 °F (12-14 °C) [311]. Cold temperatures slow Wyoming big sagebrush germination but may increase its germination rate. In a laboratory, Wyoming big sagebrush germination required 3 to 6 days at most temperatures tested, except it required 13 days at the coldest temperatures tested. Cold stratification increased the rate of germination [468]. In the field, Wyoming big sagebrush germinates in late winter and early spring as soon as temperatures are sufficiently warm and soils moist [368].

Light: Wyoming big sagebrush seeds germinate in light or dark. Cold stratification for <4 weeks increases germination in dark. Germination in light is much faster than germination in dark, regardless of temperature [483,485]. Germination in dark is increased by removal of the pericarp [485] by weathering or soil microorganisms [469].

Moisture: Germination of Wyoming big sagebrush seeds occurs either shortly before or soon after snowmelt, when moisture availability is high [468,481,484,514,723] (see Seasonal Development). Lack of moisture ("moisture stress") slows Wyoming big sagebrush's germination and decreases its germination rate [80]. In general, open, exposed sites are not favorable seed beds for big sagebrush because they dry too rapidly [690]. Litter may provide favorable seed beds by creating moist, protected sites [690], but deep litter inhibits germination [481] (see Planting depth). Big sagebrush seeds can germinate under snow, and snow cover provides a moist environment and may protect germinants from spring frosts. Thus, the amount and timing of precipitation is important for Wyoming big sagebrush germination and seedling survival [690] (see Moisture availability). Big sagebrush seeds require saturation of the surface soil for germination [290,801]. The highest field germination of big sagebrush in Asotin County, Washington, occurred when "the surface of the soil was so saturated that free water appeared when pressure was applied" [290]; no information was provided on the length of time that soils were saturated. The chances of precocious germination are likely reduced by low moisture availability at the soil surface in fall [468].

Early spring snow provides needed moisture for seedling emergence [481,510,514,690]. A study on a revegetated mined site near Battle Mountain, Nevada, found high emergence of Wyoming big sagebrush seedlings following a winter of above-average precipitation and during a spring with abundant early-season moisture. The authors suggested that snow cover in early spring followed by gradual warming presented "ideal" conditions for Wyoming big sagebrush seedling emergence. A lack of seedling emergence at three other sites was "readily accounted for by unusually dry winter conditions" the preceding winter [510].

Mature shrubs and downed trees trap snow, creating favorable seed beds for big sagebrush [481]. At a mined site in a year with average winter precipitation, big sagebrush seedling density was 6 times greater in areas where snow fences increased snowpack depth than in areas where snow fences were absent ($P < 0.05$). This suggested that in years of average or perhaps below-average winter precipitation, big sagebrush seedling emergence might be greater on sites with deep snow than on sites with shallow snow [516], as long as soils are not saturated for too long [698] (see Soil moisture).

Planting depth: Because of small size and limited energy reserves of seeds, Wyoming big sagebrush seedling emergence is highest at the soil surface or when buried at very shallow depths (≤0.2 inch (5.0 mm) [290,311,510]. Big sagebrush seeds have hypocotyl hairs that help facilitate germination and seedling establishment on the soil surface (Young and Martens 1991, cited in [855]). In eastern Montana, Wyoming big sagebrush emergence was 79% when planted at the surface, 75% when planted 0.1 inch (2.5 mm) deep, 31% when planted 0.2 inch (5.0 mm) deep, and 0% when planted 0.3 inch (7.5 mm) deep [311].

Seeds may get buried by freeze-thaw and wet-dry cycles and winnowing [481,789]. Deeper burial can induce secondary dormancy in Wyoming big sagebrush seeds and may protect seeds from lethal temperatures during fire [819] (see Immediate effects on seeds). A study using seed bags placed at varying soil depths at six locations in the Great Basin found that no Wyoming big sagebrush or mountain big sagebrush seeds on the soil surface were viable after 2 years. In contrast, 29% to 36% of Wyoming big sagebrush seeds and 30% to 40% of mountain big sagebrush seeds remained viable when buried 1.2 inches (3 cm) deep [819]. However, viability of soil-stored seeds may only last for 1 to 5 years [31,514,529,644,723,819] (see Seed Banking).

Seedling Establishment:

- *Overview*
- *Moisture availability*
- *Interference and competition*
- *Vesicular-arbuscular mycorrhizal fungi*
- *Response to fire*

Overview: While disturbance is not required for Wyoming big sagebrush seedling establishment [165,166,662,760] (see Successional Status), and one study found better establishment on unburned than burned sites [149]. Wyoming big sagebrush establishment is generally highest when density and cover of other vegetation is low [230,403,514,563,645] (see Interference and competition). However, Wyoming big sagebrush seedling emergence is highly variable (e.g., [497,757,786]), and it can be low even after fire and other disturbances that reduce vegetation cover [165] (see Postfire seedling establishment and growth). Studies of age-class structure at nine undisturbed sites at high elevations in Wyoming suggested that big sagebrush seedling establishment is episodic [153,573,574] (see Moisture availability).

While few examples of seedling mortality in natural populations were available as of 2019, studies of field plantings indicate that seedling mortality is often high [311,368,481,599,723]. For example, in field plantings in eastern Montana, Wyoming big sagebrush seedling survival was only 5.3% in the first year, and mortality was highest within the first 120 days of maximum emergence (mid-April to mid-June) [311]. At two sites in southeastern Wyoming, the percent of Wyoming big sagebrush seedlings alive in field plantings declined steadily from April to September, and only 25% to 30% of Wyoming big sagebrush seedlings alive in April were still alive in September [372].

Moisture availability: Early or prolonged drought is a principal cause of seedling mortality [481]. Because moisture availability is critical for Wyoming big sagebrush emergence (see Germination), Wyoming big sagebrush recruitment is sometimes positively correlated with seasonal or annual precipitation patterns [345,443]. However, specific relationships between recruitment and weather variables are different among sites [345], and some studies found little or no relationship between Wyoming big sagebrush recruitment and precipitation patterns [425]. In southeastern Idaho, big sagebrush (Wyoming big sagebrush, basin big sagebrush, and their hybrids) recruitment in burned and unburned areas occurred after wet periods. Recruitment was slightly positively correlated with precipitation from the October to December prior to big sagebrush establishment ($R^2 = 0.230$, partial $P = 0.003$) and 1 year prior to establishment ($R^2 = 0.194$, partial $P = 0.023$) [153]. At two sites in Nevada, Wyoming big sagebrush recruitment was associated with Pacific

Decadal Oscillation index variables during April and July, suggesting that high soil moisture availability in spring and summer is associated with recruitment [345]. In Wyoming, Wyoming big sagebrush recruitment in relatively undisturbed areas was positively, albeit weakly, correlated with years of above-average December ($r^2 = 0.10$) and January ($r^2 = 0.04$) precipitation after the first growing season ($P < 0.05$). The authors suggested that deep snowpack protected juvenile plants from cold temperatures and high winds and increased spring soil moisture favorable to seedling growth [443] (see Climate). In contrast, in southwestern Montana, recruitment of Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush over 35 years was not strongly associated with seasonal precipitation (previous summer, previous fall, winter, spring, or summer precipitation) in either burned or unburned plots [425].

Because Wyoming big sagebrush sites are typically dry, several to many years may pass before wet weather favoring Wyoming big sagebrush emergence and establishment occurs [652]; thus, recruitment of Wyoming big sagebrush is episodic on many sites [153,518,573,574]. In Wyoming, recruitment episodes in relatively undisturbed Wyoming big sagebrush stands occurred at intervals ranging from 1.9 to 2.7 years [573,574]. The researchers did not provide information on soil temperature and moisture regimes or examine relationships between Wyoming big sagebrush recruitment pulses and weather patterns. In southeastern Idaho, pulses of postfire big sagebrush recruitment (Wyoming big sagebrush, basin big sagebrush, and their hybrids) occurred during wet periods, with recruitment peaking at about 9- to 13-year intervals [153]. In central and southeastern Montana, Wyoming big sagebrush seedlings were absent from at least 8 of 10 burned plots (4 to 67 years since fire) and 5 of 10 unburned plots, indicating that recruitment was infrequent. Two unburned plots had no recruitment for >25 and 40 years. The authors suggested that the dry site conditions and poorly developed soils contributed to the infrequent recruitment [166]. Revegetation efforts in many Wyoming big sagebrush types, particularly in areas that receive <10 inches (250 mm) annual precipitation, are often only partially successful because these types frequently receive too little moisture to sustain new seedlings [690] (see Value for Restoration of Disturbed Sites).

While Wyoming big sagebrush is freeze tolerant, unseasonably cold weather may harm seedlings [481]. For example, severe frosts in mid- to late-March resulted in high seedling mortality in Sanpete County, Utah [483]. Snow cover may protect big sagebrush emergents from damage by late spring frosts [514,690], as well as browsing animals [607].

Wyoming big sagebrush establishment and growth in cheatgrass stands may be low in part because soils in cheatgrass stands can dry rapidly. In northern Utah, Wyoming big sagebrush seedlings in cheatgrass stands encountered moisture stress earlier in the growing season than seedlings in stands of native vegetation, and Wyoming big sagebrush recruitment in cheatgrass stands was less [85].

Interference and competition: Wyoming big sagebrush seedling establishment appears highest on sites with low density and cover of vegetation, such as on revegetated mined sites seeded with Wyoming big sagebrush but not other vegetation [645,665,750,822] or recent burns on relatively moist sites [760] (see Postfire seedling establishment and growth). Initial Wyoming big sagebrush seedling emergence may be high where Wyoming big sagebrush seed densities are high, such as on artificially seeded sites, but mortality rates are high for closely spaced seedlings [260,510,514,552,645], likely because of competition among seedlings for limited soil moisture [260,481]. In the Powder River Basin, Wyoming, revegetated mined sites with the highest Wyoming big sagebrush seeding rates had the highest Wyoming big sagebrush seedling mortality [260]. After artificial seeding on disturbed sites, only about 10% to 15% of seedlings survived due to self-thinning. Self-thinning occurred over a 5- to 10-year period after seeding (reviewed in [514]).

Dense grasses and forbs, both native and nonnative, can reduce Wyoming big sagebrush seedling establishment and growth [230,403,514,563,645,750]. Removal of existing vegetation from plots before planting Wyoming big sagebrush seeds enhanced Wyoming big sagebrush survival from the earliest stages of seedling growth through the end of a 2-year experiment [372]. In northwestern Utah, mortality of transplanted Wyoming big sagebrush seedlings was least when vegetation was removed prior to planting. Mortality was 4.7 times greater when seedlings were transplanted into bluebunch wheatgrass stands and 7.9 times greater when they were transplanted into nonnative desert wheatgrass stands [230]. Because nonnative species, such as cheatgrass, may displace Wyoming big sagebrush and associated understory species after fire, reducing cover of nonnative species prior to seeding Wyoming big sagebrush may increase Wyoming big sagebrush establishment on burns [492] (see Considerations for nonnative invasive plants). Removal of dense grasses and forbs by grazing livestock may result in increased big sagebrush seedling establishment [273]. Historical overgrazing by livestock increased big sagebrush density in many areas [49,172,643,723] (see Livestock grazing).

Establishment of big sagebrush seedlings is infrequent in dense stands of big sagebrush [430,481], and it occurs mainly in canopy openings as mature plants break down or die [430]. In Utah, survival of Wyoming big sagebrush seedlings was lower on sites with adult Wyoming big sagebrush than on sites with either bluebunch wheatgrass or crested wheatgrass [599].

Response to fire: Postfire seedling establishment rates vary but are typically low. For more information, see Postfire seedling establishment and growth.

Vesicular-arbuscular mycorrhizal fungi: VAM may improve Wyoming big sagebrush seedling survival by increasing seedling drought tolerance [682] and total biomass [683]. In a greenhouse study, Wyoming big sagebrush seedlings colonized by VAM from soils collected from a coal mine in northeastern Wyoming tolerated drier soils than uncolonized seedlings ($P < 0.01$) [682]. Total biomass gain of VAM-colonized Wyoming big sagebrush seedlings was 1.4 times greater (0.09 ounces (2.56 g)) than that of uncolonized seedlings (0.06 ounces (1.78 grams)) ($P = 0.05$), and root length of colonized seedlings was 1.2 times greater (66.2 inches (168.2 cm)) than that of uncolonized seedlings (54.9 inches (139.4 cm)) ($P = 0.05$) [683].

VAM associated with Wyoming big sagebrush are killed by fire and may take several years to reestablish [493,818]. See VAM and fire for more information.

Plant Growth and Mortality: Big sagebrush growth is highest in full sun when moisture is plentiful [290]. Wyoming big sagebrush cover declines with increasing overstory cover [624] (see Successional Status).

Wyoming big sagebrush seedlings in greenhouses and common gardens grow rapidly [28,84,265,383]. In a greenhouse, 6-month-old seedlings averaged 9.4 inches (24 cm) tall [84], and roots averaged 34.6 inches (88 cm) long [792]. Stems of Wyoming big sagebrush plants grown in a common garden for 4 months from seeds collected from Arizona, Nevada, Utah, and Wyoming, grew 7.9 to 10.4 inches/year (20.1-26.4 cm/year) during 2 years [265]. Seedling growth varies within and among Wyoming big sagebrush populations [323,383]. Seedlings grown from seeds collected from three sites in Montana and planted in a common garden averaged 0.9 to 1.3 inches (2.4-3.2 cm) tall at the end of their second growing season [383].

Early shoot growth rates of Wyoming big sagebrush are generally slower than those of mountain big sagebrush and basin big sagebrush [28,84,265,466,477,675,795], and maximum growth rates are obtained at a younger age than mountain big sagebrush and basin big sagebrush [84]. These differences possibly enhance the ability of Wyoming big sagebrush seedlings to survive on dry sites [84] and sites that dry quickly in spring [481]. Differences in growth rates among the three subspecies parallel their differences in absolute size at maturity, with Wyoming big sagebrush the shortest, mountain big sagebrush intermediate, and basin big sagebrush the tallest [481,783]. Slower growth of Wyoming big sagebrush than basin big sagebrush in south-central Idaho was attributed to the drier sites occupied by Wyoming big sagebrush [828]. However, in one study, seedling growth rates were similar among the three big sagebrush subspecies [309].

Fire may result in favorable growing conditions for Wyoming big sagebrush seedlings [842]. See Postfire seedling establishment and growth for details.

Wet weather may increase Wyoming big sagebrush abundance (cover, density, and/or production); however, the relationship between weather and Wyoming big sagebrush abundance is inconsistent and varies by soil temperature and moisture regimes [6,251,395]. Models showed that Wyoming big sagebrush abundance (cover or production) on 131 sites in the western United States decreased during wetter than average years at dry sites but increased during wetter than average years at wet sites. Wyoming big sagebrush abundance increased during warmer than average spring temperatures at warm sites but decreased during warmer than average temperatures at cold sites. The authors suggested that the negative correlation between Wyoming big sagebrush abundance and wetter than average years at dry sites was due to either increased competition with perennial grasses that benefit from increased precipitation or to the subspecies' sensitivity to saturated soils. They suggested the negative correlation between Wyoming big sagebrush abundance and warm spring temperatures at relatively cold sites was due to either earlier snowmelt or earlier leaf out that exposes plants to more freezing damage in spring [395]. Cover and production of big sagebrush may increase following wet weather on some sites [185,249].

Wyoming big sagebrush growth and survival can be adversely impacted by precipitation extremes. Early or extended drought can be an important cause of mortality [6,481,791]. Big sagebrush seedling and young plant (<3 years old) mortality can be high under drought conditions [494]. Cawker [136] suggested that conditions favorable for high growth rates early in summer—such as high spring temperatures and summer precipitation—may be necessary for seedlings to develop a root system adequate to cope with late summer droughts. In a greenhouse study, Wyoming big sagebrush seedlings had roots long enough to access the entire soil profile 45 to 50 days after germination, in time for summer drought in the field [792]. Jones [372] assumed that because Wyoming big sagebrush seedlings grow deep roots quickly, they would be large enough after 2 years to take advantage of deep soil water recharge. Thus, Wyoming big sagebrush seedlings may be most vulnerable to drought during their first year or two. Although it is unknown to what extent Wyoming big sagebrush was affected, extensive big sagebrush mortality from drought occurred during the 1930s in Idaho [561], Montana [4,233], and Wyoming [4]. Wyoming big sagebrush appears intolerant to flooding and high water tables. All Wyoming big sagebrush plants around Malheur Lake in Oregon died after 21 to 28 days of inundation due to rising water levels, and many died when the water table came within 2.4 to 3.9 inches (6-10 cm) of the soil surface [537].

Parasitic snow mold occurrence increases as snow depth increases [699,788]. Because snowpack tends to be shallower on Wyoming big sagebrush sites than on mountain big sagebrush sites [515] (see Climate), Wyoming big sagebrush plants are not as susceptible to parasitic snow molds as mountain big sagebrush plants [699,788]. For a review of snow mold disease and other parasitic diseases of big sagebrush, see Welch [788].

Herbivory by wildlife and livestock also decreases growth and increase mortality of Wyoming big sagebrush. For more information, see Herbivory.

Vegetative Regeneration: Wyoming big sagebrush does not sprout from roots or root crowns after top-kill [311,538]. It occasionally reproduces by layering [311], although many publications state that it does not layer [54,67,460,639]. Harvey [311] described layering by Wyoming big sagebrush as "rare"; he found three cases of layering in Rosebud County, Montana. In a field experiment, 10% of branches secured to the soil showed adventitious root development [311].

Some Wyoming big sagebrush hybrids may reproduce vegetatively. Silver sagebrush sprouts after top-kill, and Wyoming big sagebrush × plains silver sagebrush hybrids usually also sprout after top-kill [461]. A Wyoming big sagebrush × alkali sagebrush hybrid has a tendency to layer [465].

SUCCESSIONAL STATUS:

Big sagebrush tolerates shade, but growth is highest in full sun [290]. Its cover declines as tree cover increases (e.g., [624]) and increases when tree cover is removed [517,624]. In central Oregon, big sagebrush (Wyoming big sagebrush, mountain big sagebrush, or both) biomass increased 1 year after ponderosa pine was thinned and western juniper was removed [624].

Wyoming big sagebrush is a late-successional dominant or "climax" species in sagebrush steppe and shrubland communities (e.g., [53,299,325,523,720]). Large-scale disturbances in Wyoming big sagebrush communities include fire, herbivory, disease, and drought [243,481,788]. On many sites, big sagebrush dominates in late-successional stages in the absence of fire or other large-scale disturbances [430]. Without disturbances for long periods, relatively moist Wyoming big sagebrush stands adjacent to woodlands may succeed to woodlands (e.g., [176,299,623,863]).

Postfire successional patterns in sagebrush communities are considered "predictable", although the composition of postfire communities and rates of postfire succession vary considerably [245,296], depending on numerous interacting variables including prefire plant community and seed bank composition; site characteristics and management history; fire size, severity, and patchiness; and postfire weather [492,493,661] (see Plant Response to Fire). Typically, annual herbaceous plant cover increases soon after fire in sagebrush communities. Perennial grasses, forbs, and sprouting shrub species, when present, increase and dominate. Because big sagebrush establishes only from seeds, it dominates the postfire plant community much later in succession than grasses, forbs, and sprouting shrubs [58,296,352]. If cheatgrass and other nonnative annual grasses invade a large proportion of the burned area, Wyoming big sagebrush may not be able to reestablish prior to subsequent fire [493] (see Consequences of annual grass invasion). The timing of Wyoming big sagebrush seedling establishment is highly variable, but it may occur within the first few postfire years under favorable conditions [497,662,757,786]. On sites with early postfire big sagebrush establishment, establishment typically slows after the first few postfire years because of depleted soil seed banks [866] and increased competition for resources with grasses and forbs [66]. Secondary peaks in establishment may occur when big sagebrush individuals that established soon after fire mature and produce seeds [156]. Thereafter, establishment may be episodic [345,573,574] (see Seedling Establishment).

Shrub cover in undisturbed, late-successional Wyoming big sagebrush communities is typically <25% [285,495] (see Stand structure). On shallow to moderately deep loamy to clayey soils with mesic soil temperature regimes and aridic soil moisture regimes in southeastern Oregon, Evers [243] identified four general successional stages, with Wyoming big sagebrush cover as follows:

1. early-successional stage: grasses and forbs dominant with Wyoming big sagebrush seedlings present: <1%;
2. midsuccessional, open stage: grasses and forbs dominant with Wyoming big sagebrush subdominant: 1% to 8%;
3. late-successional, open stage: grasses, forbs, and Wyoming big sagebrush codominant: 8% to 20%; and
4. late-successional, closed stage: Wyoming big sagebrush dominant: >20% [243].

In Thunder Basin National Grassland, Benkobi et al. [59] classified Wyoming big sagebrush/western wheatgrass-blue grama shrub steppe into four successional stages, with Wyoming big sagebrush cover in each stage as follows:

1. early-successional stage: 17%;
2. early- to midsuccessional successional stage: 7%;
3. mid- to late-successional stage: 22%; and
4. late-successional stage: 55%.

Graminoids dominated all stages except the late-successional stage [59]. The Wyoming Interagency Vegetation Committee [845] classified early-successional Wyoming big sagebrush communities as having 0% to 5% Wyoming big sagebrush cover, midsuccessional communities as having 5% to 15% cover, and late-successional communities as having >15% cover.

Several researchers documented decreases in perennial grass cover and herbaceous plant abundance as Wyoming big sagebrush cover increased above 12% to 15% (e.g., [289,617,724,731,827]), but the relationship likely depends on disturbance history (especially livestock grazing intensity), successional stage, soil type, annual precipitation, and grass species present [153,583,791]. For example, in southern Idaho, basal area cover of Thurber needlegrass and Sandberg bluegrass decreased from 2.4% to 0.2% and 4.8% to 2.3%, respectively, while Wyoming big sagebrush cover increased from 12% to 21% [724], and in northeastern and central Nevada, basal area cover of needle and thread decreased from 7.5% to 1.4% as Wyoming big sagebrush cover increased from 1.3% to 13.5% [731]. In Daggett County, Utah, Goodrich et al. [289] estimated a 3.8% decrease in understory herbaceous production for every 1% increase in Wyoming big sagebrush cover using two Wyoming big sagebrush stands with 0% to 8% Wyoming big sagebrush cover, but acknowledged that the relationship between Wyoming big sagebrush cover and herbaceous plant production is unlikely to be linear. They expected a further reduction in the rate of understory herbaceous production as Wyoming big sagebrush cover increased above ~5% [289].

Some authors question the inverse relationship between big sagebrush abundance and perennial grass cover [153,184,791]. Welch and Criddle [791] found no correlation between big sagebrush cover and perennial grass cover using data from 33 transects in Idaho, Oregon, Utah, Washington, and Wyoming [791], although the subspecies of big sagebrush included in their analyses were not specified and the examples given in support of their results were largely from mountain big sagebrush communities or were not specified. Colket [153] examined the response of total perennial grass cover to increasing Wyoming big sagebrush density after fire and found no relationship. When cover of individual perennial grass species was examined, Sandberg bluegrass was the only species for which total cover was correlated with Wyoming big sagebrush density ($P = 0.04$). The relationship was positive, and was likely due to the fact that both Sandberg bluegrass and Wyoming big sagebrush are late-successional species in Wyoming big sagebrush steppe [153].

The time required for Wyoming big sagebrush communities to advance to late succession varies substantially among sites. My analyses of Wyoming big sagebrush postfire recovery data showed slow postfire recovery of Wyoming big sagebrush cover, overall. When postfire recovery values were averaged within 5-year time-since-fire bins, full recovery did not occur within 66 years since fire, although a few sites neared recovery (see Analysis of postfire recovery studies). In a model, Wyoming big sagebrush communities in southeastern Oregon reached the late-successional, closed canopy stage in about 78 years in the absence of disturbance. When disturbances from fire, insects, pronghorn, and drought were included in the model, it took 83 years to reach that stage [243].

At some locations, conifers can expand into Wyoming big sagebrush communities when the interval between fires becomes long enough for trees to establish and mature [496], converting them to woodlands [623,738]. Conifer expansion is most common in Wyoming big sagebrush communities on relatively warm, moist sites [367,493,496] (table 6) (see Woodland Expansion). Where soil temperature and moisture regimes are suitable, big sagebrush and other woody plants act as nurse plants that facilitate establishment of junipers and pinyons [125,228,297,490,498,680].

Miller et al. [490,502] categorized succession from mountain big sagebrush communities to western juniper woodlands in three phases, and subsequent researchers have applied these phases to woodland succession in Wyoming big sagebrush communities (e.g., [176,863]):

- early-successional stage (Phase I): shrubs and herbs dominant, and few trees present
- midsuccessional stage (Phase II): trees codominant with shrubs and herbs
- late-successional stage (Phase III): trees dominant, shrubs reduced ≥75% [490,502]

A fourth late-successional, closed stage or "mature" phase (Phase IV), is sometimes included in woodland succession where trees are dominant, shrubs and herbaceous plant cover is minimal or absent, and shrubs are ≥90% dead [502,508]. The time required to transition between phases in woodland succession is variable and depends on the sagebrush taxon and site characteristics. Although not reported for Wyoming big sagebrush communities, successional advancement from mountain big sagebrush and low sagebrush communities to western juniper woodlands (Phase I to Phase III) varied from 60 to 80 years on cool, moist sites to >125 years on warm, dry sites in southeastern Oregon and southwestern Idaho [367,493]. Johnson and Miller [367,493] developed a chart for mountain big sagebrush communities with varying productivity that hypothesizes the time necessary to transition from initial western juniper establishment to development of late-successional woodlands. Rates of succession varied with elevation and insolation exposure, with fastest development on high-elevation, low-exposure sites (i.e., cool, relatively moist sites, ~70 years) and slowest development on low-elevation, high-exposure sites (i.e., warm, dry sites, ~130 years) (fig. 4). This suggests that Wyoming big sagebrush communities on warm, dry sites would also take longer—likely >125 years—to succeed to late-successional western juniper woodlands than those on cooler, moister sites. In big sagebrush communities, the transition from midsuccessional to late-successional woodlands causes a shift from shrub and herbaceous fuels to a predominance of tree canopy fuels. With these changes, the potential for surface fires burning under moderate weather conditions declines and the potential for crown fires burning under extreme weather conditions increases [216,493,504,623,846,863] (see Fuels).

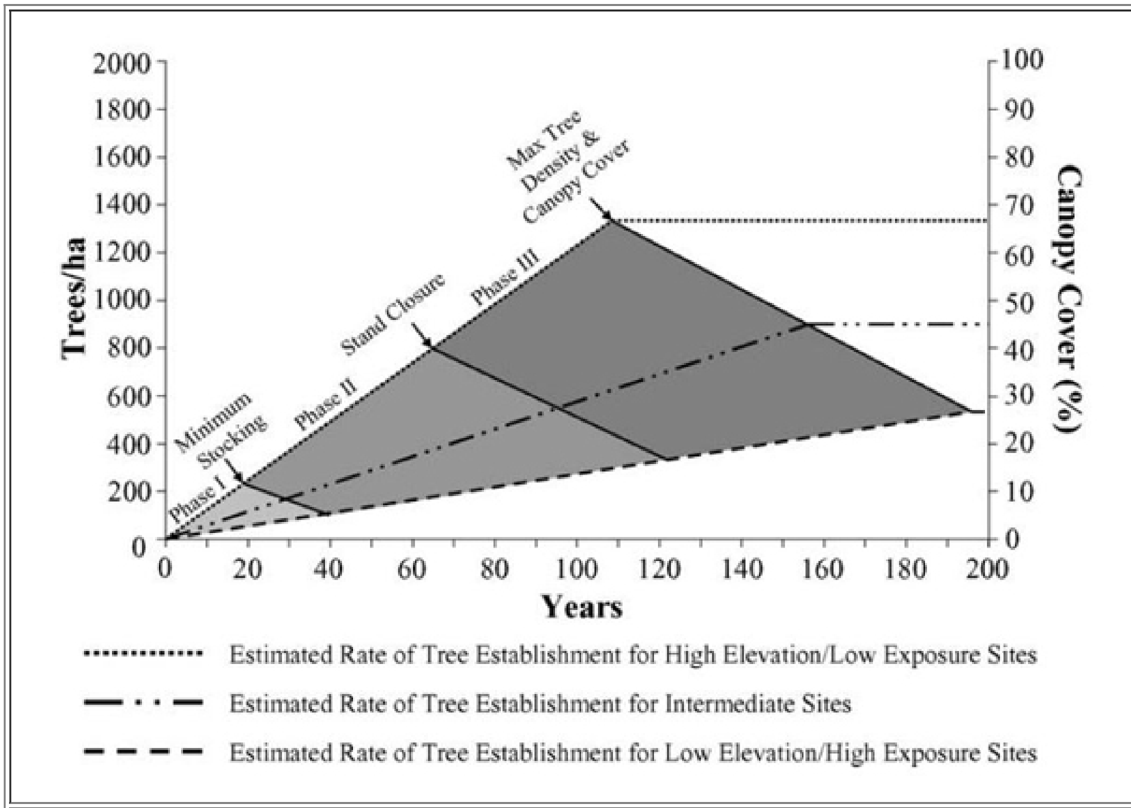


Figure 4—Hypothesized time periods from initial western juniper establishment (early Phase I) to development of late-successional woodland (Phase III), and estimated maximum density and cover of western juniper on mountain big sagebrush sites with varying elevation and insolation exposure (i.e., a gradient of relatively cool/moist to warm/dry sites) [367,493].

Researchers have developed numerous state-and-transition models that describe successional processes and model community transitions following natural and human-caused disturbances in Wyoming big sagebrush communities, including the establishment and spread of cheatgrass and the expansion of juniper woodlands into Wyoming big sagebrush communities (e.g., [141,142,176,242,314,714,803]). For more information, see State-and-transition models.

FIRE EFFECTS AND MANAGEMENT

SPECIES: Artemisia tridentata subsp. wyomingensis

FIRE EFFECTS:

Figure 5—A wildfire in a Wyoming big sagebrush community in southern Idaho with a nonnative invasive annual grass understory. Photo by Douglas Shinneman. Image from A Legacy of Sagebrush Science Photo Gallery.

Immediate Fire Effects:

Immediate effects on plants: Fire typically kills Wyoming big sagebrush; thus, fire reduces its cover and density (e.g., [19,66,425,567,576]). Wyoming big sagebrush branches are typically low to the ground (fig. 2). Because the wood, bark, and foliage are highly flammable [110,285,392,530,539], plants are easily killed by fire (e.g., [66,118,129,150,229,257,520,567,591]. Cooper et al. [165] commented that fire spreading through Wyoming big sagebrush/thickspike wheatgrass communities in eastern Montana tends to completely consume Wyoming big sagebrush; severe fire burns out the stem at ground level. Clark and Starkey [148] stated that a fire intense enough to scorch the foliage kills big sagebrush plants. Fires tend to leave patches of unburned vegetation, where big sagebrush plants survive [66,563].

Immediate effects on seeds: Fire kills many big sagebrush seeds in soils, although some may survive [3,144,145,312,313]. Big sagebrush seeds lack a thick seed coat or other adaptations to survive fire [217]. Seeds on the soil surface are exposed to the highest temperatures during fires [791], and are the most vulnerable to fire-caused mortality. Repeated burning is likely to deplete Wyoming big sagebrush seed banks and increase the postfire recovery period [148].

Few data were available for quantitatively assessing fire effects on Wyoming big sagebrush seed banks. Studies of big sagebrush seed structure, dispersal, and postfire seed banks indicate that fire likely reduces the abundance of viable Wyoming big sagebrush seeds in soil seed banks [3,312,791,858]. For example, 2 months after a wildfire near Mills, Utah, density of viable Wyoming big sagebrush seeds averaged 1.8 seeds/m² on burned plots in September, while density averaged 3.7 seeds/m² on paired, unburned plots. The density of seeds on burned plots remained lower than the density on the unburned plots for at least a year (table 4) [312]. However, one frequently cited study suggested that fire may have little effect on germination of Wyoming big sagebrush seeds in the soil. This study showed that Wyoming big sagebrush emergence in a greenhouse was similarly low (<5 seedlings/m²) in 2-inch (5-cm) deep soil samples from unburned plots and plots burned at low or high severity with a propane torch prior to collection. The low-severity plots reached a maximum soil surface temperature of 219 °F (104 °C) after 30 seconds, and the high-severity plot reached a maximum soil surface temperature of 781 °F (416 °C) after 60 seconds. Sites were treated sometime between July and September and germinated in a greenhouse sometime between January and October [144,145].

Table 4—Density of viable Wyoming big sagebrush seeds (seeds/m² (SE)) in the upper 2 inches (5 cm) of soil on unburned and burned sites near Mills, Utah, for several collection dates following a 26 July 1981 prescribed fire. Soil samples (*n* = 20) were 2.1 inches (5.4 cm) in diameter and 2.0 inches (5.0 cm) deep [312].

Site	Sampling date				
	September 1981	December 1981	March 1982	June 1982	September 1982
Unburned	3.7 (1.9)	5.8 (4.0)	1.5 (1.2)	0.3 (0.3)	0.7 (0.7)
Burned	1.8 (1.5)	0	0.3 (0.5)	0	0.3 (0.5)

Most big sagebrush seeds are located in the litter under parent shrubs [311] (see Seed Dispersal). Litter is typically consumed during fire, and the soil surface can reach lethal temperatures even during low-intensity fire [3]. Lethal temperatures for plant tissues generally range from about 104 to 158 °F (40-70 °C), although some seeds can survive exposure to higher temperatures. The temperature at which plant tissues die decreases as exposure time increases (e.g., [353,427]). Large, severe wildfires may leave few to no viable big sagebrush seeds in soil seed banks [538]. On the Hart Mountain National Antelope Refuge, Oregon, most Wyoming big sagebrush seeds and seedlings were killed by a high-intensity (mean fireline intensity: 1,321 kW/m²), September prescribed fire, but some seeds apparently survived and germinated the following spring [842].

Fire effects on big sagebrush seeds depend on location of seeds, including depth of burial and the magnitude and duration of soil temperatures reached during fire, which are spatially heterogeneous due to variability in fuel loads [41,404]. Buried seeds are more protected from lethal temperatures during fire than seeds in litter or on the soil surface [51,284]. Based on the data in table 5, Miller et al. [493] concluded that big sagebrush seeds in soil seed banks are least likely to survive fire underneath woody plant canopies and that seeds located on the soil surface or in litter have a high probability of being consumed or exposed to lethal temperatures during fire.

Table 5—Average and peak soil surface and subsurface temperatures measured in big sagebrush, cheatgrass, and pinyon-juniper communities in the western United States.

Location	Plant community	Fire characteristics	Site characteristics	Average soil surface temperatures, unless otherwise noted	Source

Idaho	mountain big sagebrush with western juniper	late October prescribed fire	tree or shrub interspaces	174-399 °F (79-204 °C)	[41]
			tree canopy litter	399-1,292 °F (204-704 °C)	
Nevada	mountain big sagebrush and Wyoming big sagebrush	early October prescribed fires	bare ground	590 °F (310 °C)	[404]
			under grasses	585 °F (307 °C)	
			under shrubs	718 °F (381 °C)	
Utah		mid-November prescribed fires	bare ground	487 °F (253 °C)	
			under grasses	570 °F (299 °C)	
			under shrubs	639 °F (337 °C)	
	double-chained and seeded pinyon-juniper	early September prescribed fire	under grasses	369 °F (187 °C)	[284]
				<131 °F (55 °C) at 1.0-inch (2.5-cm) deep	
			under juniper and pinyon debris pile	>1,431 °F (777 °C)	
				>550 °F (288 °C) at 1.0-inch (2.5-cm) deep	
	"near monocultures" of cheatgrass in big sagebrush steppe	early July prescribed fire	under grasses	248 °F (120 °C) peak temp on surface	[51]
				167 °F (75 °C) peak temp. at 0.4-inch (0.1-cm) deep	
Washington		early June prescribed fire		293 °F (145 °C) peak temp. on surface	
				140 °F (60 °C) peak temp. at 0.4-inch (0.1-cm) deep	

Postfire Regeneration Strategy [691]:
Shrub without adventitious buds and without a sprouting root crown
Ground residual colonizer (on site, initial community)
Initial off-site colonizer (off site, initial community)
Secondary colonizer (on- or off-site seed sources)

Fire Adaptations: Wyoming big sagebrush is poorly adapted to survive fire [614,765,786,830]. Plants are easily killed by fire (e.g., [66,118,129,150,229,257,496,538,567,770,840]); they do not sprout [311,538]. Big sagebrush seeds lack a thick seed coat or other adaptations to survive fire [217].

Hybrids: Wyoming big sagebrush × plains silver sagebrush hybrids usually sprout after top-kill by fire [461].

Plant Response to Fire:

- *Overview*
- *Postfire seedling establishment and growth*
- *Analysis of postfire recovery studies*
- *Vegetation and site characteristics*
    - *VAM and fire*
- *Fire characteristics*
- *Postfire weather*
- *Postfire herbivory*

Overview: Postfire establishment of big sagebrush is from on-site and off-site seed sources [403,495,529,723,866,867]. Fires can create favorable conditions for Wyoming big sagebrush germination and seedling establishment by releasing nutrients and reducing cover of vegetation, which increases available growing space and the amount of sunlight reaching the soil surface (e.g., [68,69,70,196,363,493,595], but see [70]). Postfire seedling establishment is variable, but often low [1,35,36,165,662,774,807]. Several to many years may pass before moisture conditions are favorable for Wyoming big sagebrush emergence and establishment [652], and a principal cause of Wyoming big sagebrush seedling mortality is early or prolonged drought [481]. If postfire moisture conditions are favorable and Wyoming big sagebrush establishes soon after fire, its rate of postfire recovery may be relatively rapid. If Wyoming big sagebrush does not establish soon after fire, other species may establish first and reduce the availability of suitable sites for Wyoming big sagebrush germination, thus slowing the rate of postfire recovery [153].

Postfire seedling establishment and growth: Wyoming big sagebrush establishes from seeds in soil seed banks and from unburned plants (on-site or off-site) after fire [129,529,723,786]. Because seeds disperse relatively short distances, are relatively short-lived**,** and easily killed by fire, distribution of seed sources is an important driver of big sagebrush postfire establishment. Within the first few postfire growing seasons, seeds in the soil and from unburned plants are critical to big sagebrush seedling establishment. As succession proceeds, big sagebrush that established soon after fire mature and contribute seeds for subsequent establishment [156,392]; however, seedling establishment within the first few postfire years may not occur in Wyoming big sagebrush communities despite the availability of seed sources because of unfavorable moisture availability, competition for resources with grasses and forbs, lack of VAM, or other factors. The length of time between a fire and the first establishment pulse may explain, in part, differences in postfire Wyoming big sagebrush seedling establishment rates [153].

Several studies show Wyoming big sagebrush seedling establishment occurs within the first few years after fire [497,567,662,757,811,856]. However, the timing of peak postfire establishment varies among sites (e.g., [153,567]), and postfire seedling establishment may be absent or limited on some sites for many years even when seed sources are located nearby (e.g., [35,153,165,166,452,567,770,774,807,811]). One study of big sagebrush (Wyoming big sagebrush, basin big sagebrush, and their hybrids) in sixteen 5- to 28-year-old burns in the Columbia Basin found that initial seedling establishment on most burns occurred within the first few postfire years. It occurred within the first or second postfire year on 12 burns and within 4 postfire years on three burns; only one ~14-year-old burn had no big sagebrush reestablishment. The fire on the 14-year-old burn occurred during a year of below-average winter precipitation (66%–77% of normal) [662].

Studies that examined postfire establishment of Wyoming big sagebrush in the first few postfire years often found very low seedling establishment**.** Many studies found no establishment in the first few postfire years [35,229,452,567,770,774,807], or even a decade or more after fire [165,452,662]. On the northeastern flank of the Canyon Mountains, Utah, a "few" Wyoming big sagebrush seedlings were present 3 years after a July wildfire in a late-successional Wyoming big sagebrush community. The authors stated that Wyoming big sagebrush "was slow to reestablish" despite nearby unburned patches with mature Wyoming big sagebrush plants [811]. In the Sheepshead Mountains in southeastern Oregon, no Wyoming big sagebrush seedlings occurred in burned plots the first 2 postfire years after a large August wildfire [35]. In postfire year 3, only "a few scattered seedlings" were observed [36]. The authors suggested that there might have been a limited seed pool and/or poor establishment conditions that limited Wyoming big sagebrush establishment [35,36]. Young and Evans [856] observed no big sagebrush (probably Wyoming big sagebrush) seedlings 1 year after a wildfire near Reno, Nevada, and low seedling establishment in postfire years 2 to 4 ($\leq$0.02 seedling/10 m^2). Near Tooele, Utah, no Wyoming big sagebrush seedlings were present 20 months after an October prescribed fire in Wyoming big sagebrush communities in the early stage of Utah juniper expansion [774]. In southwestern Montana, Wyoming big sagebrush seedlings were still absent from a Wyoming big sagebrush stand 6 years after prescribed fire. Wyoming big sagebrush cover was only 1.8% in postfire year 17 [770]. Wyoming big sagebrush plants did not occur in a Wyoming big sagebrush/western wheatgrass stand 14 years after a wildfire in the Missouri River Breaks region of central Montana [229].

Fire may result in favorable growing conditions for Wyoming big sagebrush seedlings along unburned perimeters. On the Hart Mountain National Antelope Refuge, Wyoming big sagebrush seedlings along the unburned perimeter of a September prescribed burn were taller (2.0-9.8 inches (5-25 cm)) than those in unburned interior areas (0.4-1.2 inches (1-3 cm)). In addition, flowering shoots of Wyoming big sagebrush were more numerous on plants located along the unburned perimeter than on plants in unburned interior areas. These results were attributed to likely greater nutrient and water availability along the burn perimeter than in unburned interior areas [842].

Analysis of postfire recovery studies:

Analyses in this publication showed that postfire recovery of Wyoming big sagebrush cover is generally slow. Overall, Wyoming big sagebrush cover on burned sites was less than that on unburned sites. However, cover varied among sites, particularly for sites 26 to 35 years since fire (fig. 7A). When postfire recovery was averaged within 5-year, time-since-fire bins, full recovery did not occur within 66 years since fire, although a few sites neared recovery (fig. 7B), suggesting that Wyoming big sagebrush postfire recovery may be faster on some sites and in some ecoregions than in others (fig. A1). Computations of postfire recovery were complicated by small sample sizes of old burns (only 13 of 112 sites were >20 years since fire) and high variability in Wyoming big sagebrush cover among unburned sites, which ranged from 1% to 49%.

The length of time for Wyoming big sagebrush cover to return to prefire or unburned values (i.e., postfire recovery time) has been the focus of numerous studies (table A3) due to concerns regarding habitat requirements for sagebrush obligates like sage-grouse. Postfire recovery time is determined by comparing Wyoming big sagebrush abundance (usually cover, but also density and height) on burned sites to its abundance before fire or on similar, unburned sites over time. This presumably indicates the time needed for big sagebrush to "regain full coverage and maturity" after fire [20]. Estimates of postfire recovery time are strongly influenced by cover values on unburned sites, which vary substantially. Some of this variability stems from site characteristics (e.g., poor growing conditions leading to low potential cover, or the reverse) while some may be due to past land uses (e.g., livestock grazing or fire exclusion that increased shrub cover) [20,600]. Thus, the assumption that unburned sites consistently represent full recovery may be inaccurate. This is an important consideration because postfire recovery time is sometimes used to estimate fire frequency in Wyoming big sagebrush communities, based on the premise that Wyoming big sagebrush communities did not burn, on average, more frequently than the time required for them to recover [20,839] (see the FEIS synthesis Fire regimes of Wyoming big sagebrush and basin big sagebrush communities for more details). For example, in John Day Fossil Beds National Monument, Oregon, plots burned under prescription in fall had 8% prefire cover of Wyoming big sagebrush and only 0% to 3% cover in postfire year 15, suggesting poor recovery. However, prefire cover on unburned plots ranged from 9% to 18%, but similarly declined to 1% to 3% in postfire year 15. Without considering prefire data, comparison of burned and unburned plots in postfire year 15 might have suggested that Wyoming big sagebrush cover was nearing recovery, because cover on burned and unburned plots in postfire year 15 was relatively similar. The authors did not know why cover on unburned plots had declined, but cheatgrass invasions, browsing by native ungulates, insect outbreaks, or other unknown causes might have contributed [452].

In order to synthesize information on Wyoming big sagebrush postfire recovery time, I obtained data on Wyoming big sagebrush cover and postfire recovery from 112 burned sites (fig. 6) examined in 24 published studies (table A3). I obtained most data from publications, but for two studies I obtained site-level data directly from researchers [168,423]. In most studies, researchers compared Wyoming big sagebrush cover on burned sites to cover on nearby unburned sites. Burned sites ranged from 1 to 66 years since fire, with mean Wyoming big sagebrush cover values ranging from 0% to 26%. Mean cover values on unburned sites also ranged widely (1%-49%) and averaged 13% cover [38,39,43,46,72,129,149,165,168,196,221,229,234,317,423,452,474,567,716,760,770,775,807,842]. In three studies, postfire Wyoming big sagebrush cover was compared with prefire cover [129,452,567].

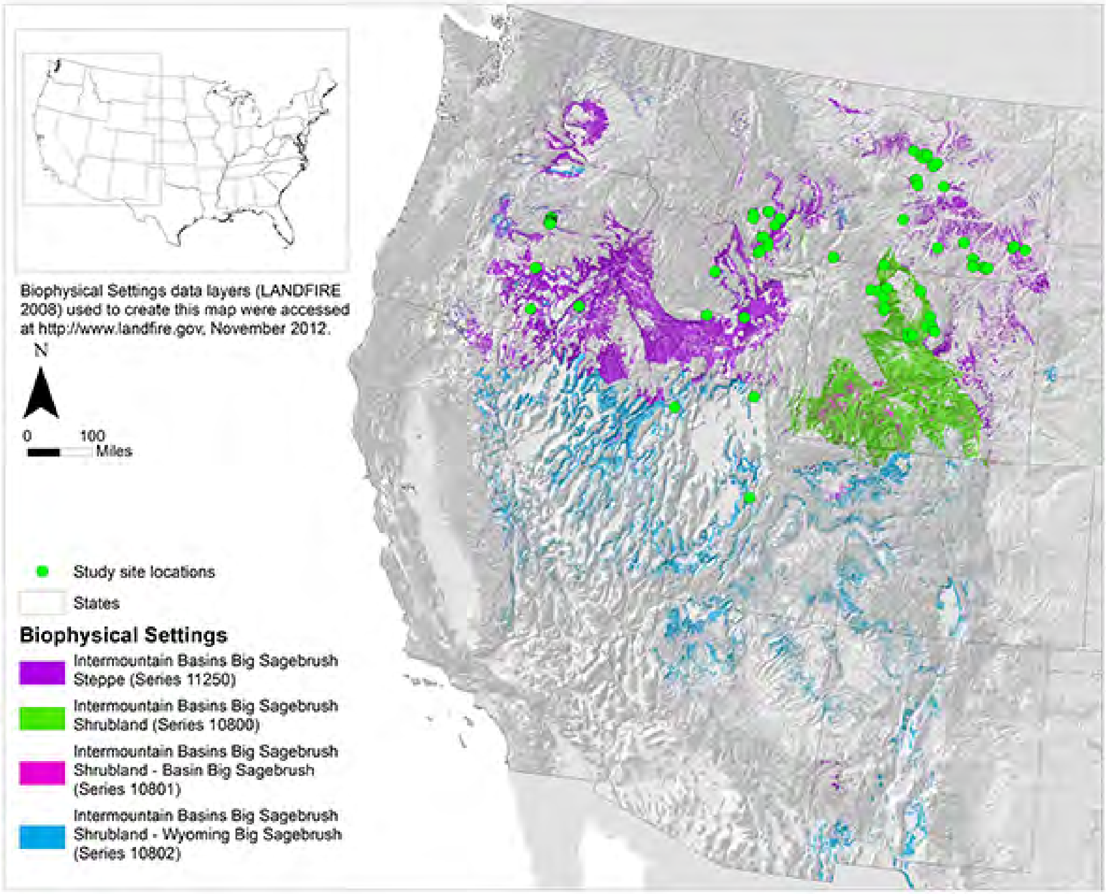


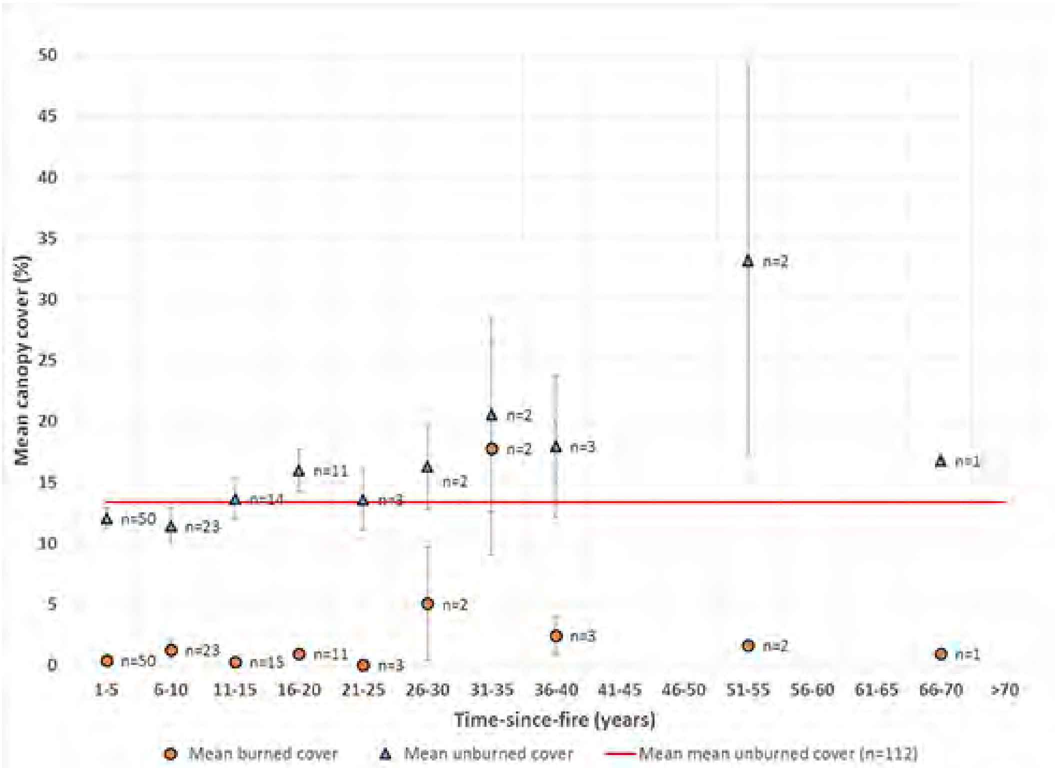
Figure 6—Approximate locations of postfire recovery study sites in Wyoming big sagebrush communities. In one case [129], study site locations could not be identified. A study site location in south-central British Columbia is not shown [221]). Distribution of Wyoming big sagebrush Biophysical Settings is based on LANDFIRE data [416]. Click on the map for a larger image.

Methods: To assess changes in mean cover and postfire recovery across all 112 sites over time, I averaged data in 5-year, time-since-fire bins and plotted mean cover (fig. 7A) and recovery (the ratio of burned to unburned cover) (fig. 7B) versus time-since-fire. To explore whether changes in cover and postfire recovery over time differed geographically, I plotted mean cover and postfire recovery by time-since-fire for each of seven ecoregions (fig. A1). Data and site descriptions were insufficient to statistically examine the relationship between postfire recovery times and soil temperature and moisture regimes or other site characteristics.

Results: Mean Wyoming big sagebrush cover on burned sites remained below that of the average of all unburned sites (13.4%) on all but one site, but cover on burned sites varied, particularly for sites 26 to 35 years since fire (fig. 7A). Variability in cover among these burned sites was likely high because of small sample sizes. Of the 112 burned sites examined, only 4 (4%) were 26 to 35 years since fire, and cover on those sites ranged from 0.4% 26 years since fire to 26.4% 33 years since fire.

Wyoming big sagebrush cover recovered slowly (fig. 7B). Averaged in 5-year time-since-fire bins, full recovery of unburned cover did not occur within 66 years since fire. None of the 112 burned sites were recovered. Only three burned sites neared recovery (93%-96% of unburned values), and all of these were located near Wisdom in southwestern Montana. One burned site recovered to 26.4% cover by postfire year 33, which was 93% of a paired, unburned site with 28.5% cover [423]. This was the only burned site that exceeded 20% cover of Wyoming big sagebrush, which is the amount of sagebrush cover typically found in sage-grouse winter habitat [15,160,173,619]. The two other burned sites neared recovery with 11.1% and 13.4% Wyoming big sagebrush cover 9 years since fire. These sites were compared with paired, unburned sites that had 11.6% and 13.9% Wyoming big sagebrush cover [760]. Only two other burned sites exceeded ~40% postfire recovery. One site had 72% recovery in postfire year 32 [760], and the other had 76% recovery in postfire year 29 [775]. Researchers considered postfire recovery rates on these five burned sites "atypical" [757] and "exceptional" [19]. Postfire recovery might have been relatively rapid on these sites because they were relatively moist. Average annual precipitation was ≥12 inches (300 mm) at these sites [426,760,775] (see Vegetation and site characteristics). In addition, these sites were burned under prescription [423,760,775], and recovery may be faster after prescribed fires than wildfires if prescribed fires are smaller and patchier [392,520] (see Fire characteristics). None of the remaining 107 burned sites exceeded 5.4% Wyoming big sagebrush cover up to 66 years since fire. Most (83 of 112) had <1% cover. The 6 oldest sites ranged from 36 to 66 years since fire. These sites were only 0% to 18% recovered [168], were located where annual precipitation averaged 10.8 to 16.35 inches (274-415 mm), and were burned by wildfires [166].

A)



B)

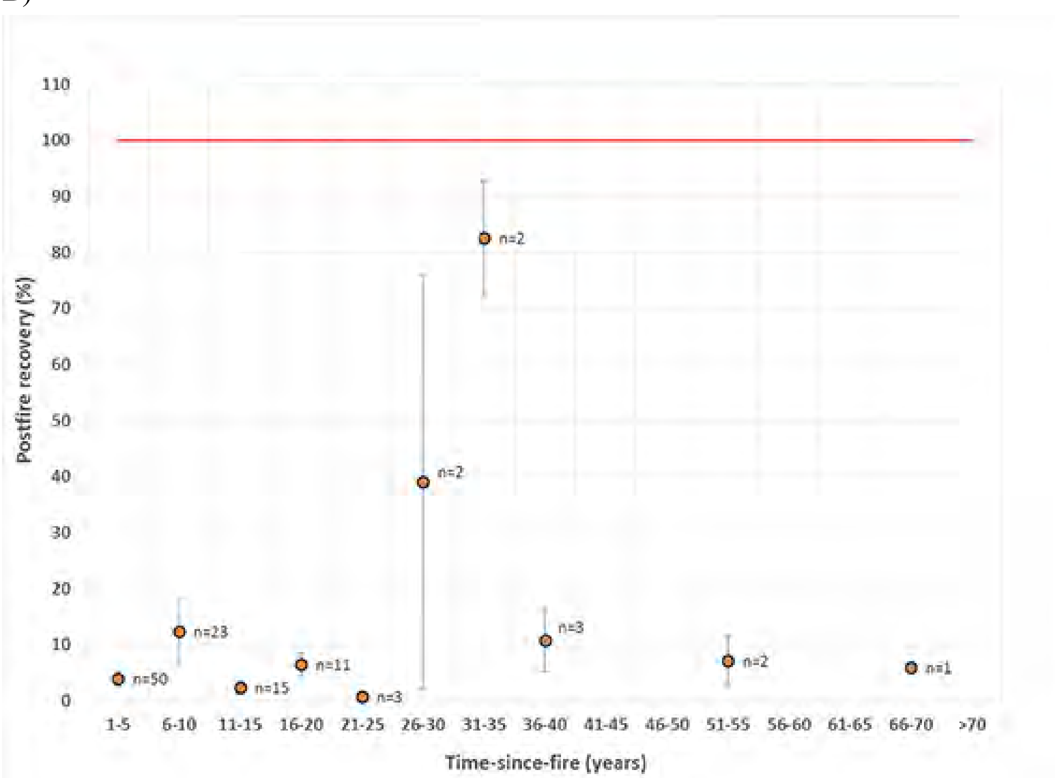


Figure 7—Wyoming big sagebrush cover and postfire recovery versus time-since-fire in Wyoming big

sagebrush communities. A) Mean cover (SE) of Wyoming big sagebrush on burned sites (circles) in 5-year, time-since-fire bins plotted with mean cover of paired, unburned sites (triangles); B) Mean ratio (SE) of burned to unburned (or prefire) cover (i.e., "postfire recovery") of Wyoming big sagebrush in 5-year, time-since-fire bins.

Considering the widespread distribution and importance of Wyoming big sagebrush communities, postfire recovery studies are limited geographically. Wyoming big sagebrush communities, as represented by LANDFIRE's Biophysical Settings [415], occur in 24 of the Level III ecoregions mapped by Omernik and Griffith [549]. Postfire recovery data were available from seven of these ecoregions, although the number of burned study sites in each varied from 3 in the Snake River Plain to 29 in the Northwestern Great Plains, and only four ecoregions had >10 study sites each. Data were lacking on sites exceeding 20 years since fire, with only 13 of 112 sites >20 years since fire. Only two ecoregions had study sites that exceeded 20 years since fire: the Middle Rockies and the Northwestern Great Plains ecoregions. More data are needed on postfire recovery of Wyoming big sagebrush on sites that are >20 years since fire.

When Wyoming big sagebrush cover and postfire recovery were plotted against time-since-fire for each ecoregion, postfire recovery appeared slow on all sites in all ecoregions, except three sites in the Middle Rockies ecoregion that neared recovery (fig. A1). However, differences in the number of study sites and time-since-fire made it difficult to compare recovery among ecoregions. For example, time-since-fire exceeded 20 years in only two of the seven ecoregions, and postfire recovery of Wyoming big sagebrush within 20 years is unlikely. However, differences in the number of study sites and time-since-fire made it difficult to compare recovery among ecoregions. For example, time-since-fire exceeded 20 years in only two of the seven ecoregions, and postfire recovery of Wyoming big sagebrush within 20 years is unlikely. In these two ecoregions, 3 of 27 sites in the Middle Rockies neared recovery (>90% recovery) 9 to 33 years since fire [423,760,775], while no sites in the Northwestern Great Plains recovered or neared recovery within 66 years since fire [72,165,168,229]. While most sites in the Middle Rockies were slow to recover, sites in the Middle Rockies nearing recovery were relatively moist [426,474,760,775], suggesting that Wyoming big sagebrush cover may occasionally recover on relatively moist Wyoming big sagebrush sites within about 33 years. While some sites in the Northwestern Great Plains were dry, others were relatively moist [72,165,166,229], yet no sites >20 years since fire had recovered [168]. Heavy browsing of Wyoming big sagebrush by wild ungulates may have contributed to slow recovery on some sites in the Middle Rockies ecoregion (e.g., [474]) (see Postfire herbivory). Similarly, slow postfire recovery was attributed to heavy browsing by wild ungulates at mountain big sagebrush sites in this ecoregion [329,474,767]. Heavy postfire browsing by wild ungulates was not mentioned in studies of Wyoming big sagebrush with the highest postfire recovery [425,760,775].

Baker [20] reviewed 10 postfire recovery studies with cover and density data from ~70 Wyoming big sagebrush sites in the Colorado Plateaus (n = 1 study), Middle Rockies (n = 6 studies), Northwestern Great Plains (n = 1 study), and Snake River Plain (n = 2 studies) ecoregions. He concluded that Wyoming big sagebrush postfire recovery is highly variable and often slow. He estimated that Wyoming big sagebrush takes 50 to 120 years to recover after fire, with faster recovery possible in some "exceptional" sites. However, he acknowledged that "evidence is too limited to accurately estimate the time for full recovery of Wyoming big sagebrush after fire" [20]. Baker used different criteria for inclusion of studies than I did (e.g., I did not include studies that did not specify the age of the burn, the subspecies of big sagebrush studied, or provide Wyoming big sagebrush cover) and only six studies were included in both his and my analyses, so our results are not directly comparable. Nonetheless, my analyses agree with that of Baker [20]. I too found that data are too limited to accurately estimate Wyoming big sagebrush postfire recovery time and that postfire recovery varies widely among sites, but is typically slow.

Wyoming big sagebrush cover requires a longer time to recover than mountain big sagebrush because it occurs on warmer, drier sites [90,105,118,474] (see Vegetation and site characteristics). Analyses by Innes [356] in the FEIS Species Review about mountain big sagebrush showed full recovery of mountain big sagebrush cover began around 26 to 30 years since fire, when data were averaged in 5-year time-since-fire bins. The same analyses of Wyoming big sagebrush show that full recovery did not occur within 66 years since fire, although a small proportion (<3% of sites) neared recovery.

Sites with sprouting Wyoming big sagebrush hybrids likely recover faster than those without such hybrids, but no studies reported postfire recovery times of cover for hybrids. Studies of postfire recovery of big sagebrush cover that combined data for Wyoming big sagebrush, other big sagebrush taxa, and their hybrids [662,786] showed high variability among sites. For example, Shinneman and McIlroy [662] examined recovery of big sagebrush (Wyoming big sagebrush and/or basin big sagebrush communities and possibly their hybrids) 5 to 28 years since fire in the northern Columbia Basin. They found that big sagebrush cover on only 1 of 16 burned sites had recovered to unburned values in 28 years since fire. Models predicted that big sagebrush cover would average only ~6% in postfire year 28 compared with an average of ~16% cover on unburned sites, with model uncertainty increasing over time. The rate of recovery was largely explained by precipitation patterns after fire [662] (see Postfire weather).

The following sections discuss factors that influence postfire recovery of big sagebrush including prefire plant community and seed bank composition; fire characteristics such as fire severity, season, pattern, and size; postfire weather; and postfire herbivory [492,493].

Vegetation and site characteristics: Warm, dry sites typically characterized by Wyoming big sagebrush communities tend to be less resilient to fire and other disturbances and less resistant to postfire nonnative annual grass invasion than cold and cool, relatively moist sites characterized by mountain big sagebrush and mountain shrub communities (table 6, fig. 8) [142,491,492]. Warm, dry sites are less favorable for native plant growth and reproduction, and nonnative annual grasses—primarily cheatgrass—are more invasive. Warm, dry sites typically occur at lower elevations than cool, moist sites, but this relationship is modified by slope and aspect, due to their influence on soil temperature and moisture regimes [141,142,493].

Table 6—Sagebrush ecological types and their resilience to disturbance and resistance to nonnative annual grass invasion ([142], modified from [491,492]). Ecological types characterized by Wyoming big sagebrush are highlighted in yellow.

Ecological type (soil temperature regime/ soil moisture regime)	Mean annual precipitation	Typical shrubs	Resilience to disturbance	Resistance to nonnative annual grass invasion
Warm and dry (mesic/aridic)	8-12 inches (203-305 mm)	Wyoming big sagebrush, black sagebrush, and/or low sagebrush	**Low.** Low effective precipitation limits site productivity.	**Low.** Climate suitability for nonnative annual grasses is high.
Cool and dry (frigid/aridic)	6-12 inches (152-305 mm)	Wyoming big sagebrush, black sagebrush, and/or low sagebrush	**Low.** Effective precipitation limits site productivity.	**Moderate.** Climate suitability for nonnative annual grasses is moderate.
Warm and moist (mesic/xeric)	12-16 inches (305-406 mm)	Wyoming big sagebrush, mountain big sagebrush, Bonneville big sagebrush, and/or low sagebrush (potential for juniper and pinyon expansion in some areas)	**Moderate.** Precipitation and productivity are moderately high.	**Moderately low.** Climate suitability for nonnative annual grasses is moderately high.
Cool and moist (frigid/xeric)	12-22 inches (305-569 mm)	mountain big sagebrush, low sagebrush, antelope bitterbrush, and/or snowberry (potential for juniper and pinyon expansion in some areas)	**Moderately high.** Precipitation and productivity are generally high.	**Moderate.** Climate suitability for nonnative annual grasses is moderate.
Cold and moist (cryic/xeric)	≥14 inches (356 mm)	mountain big sagebrush, snowfield big sagebrush, snowberry, serviceberry, silver	**Moderately high.** Precipitation and productivity are generally high. Short growing seasons can	**High.** Climate suitability for nonnative annual grasses is low.

		sagebrush, and/or low sagebrush	decrease resilience on the coldest sites.	

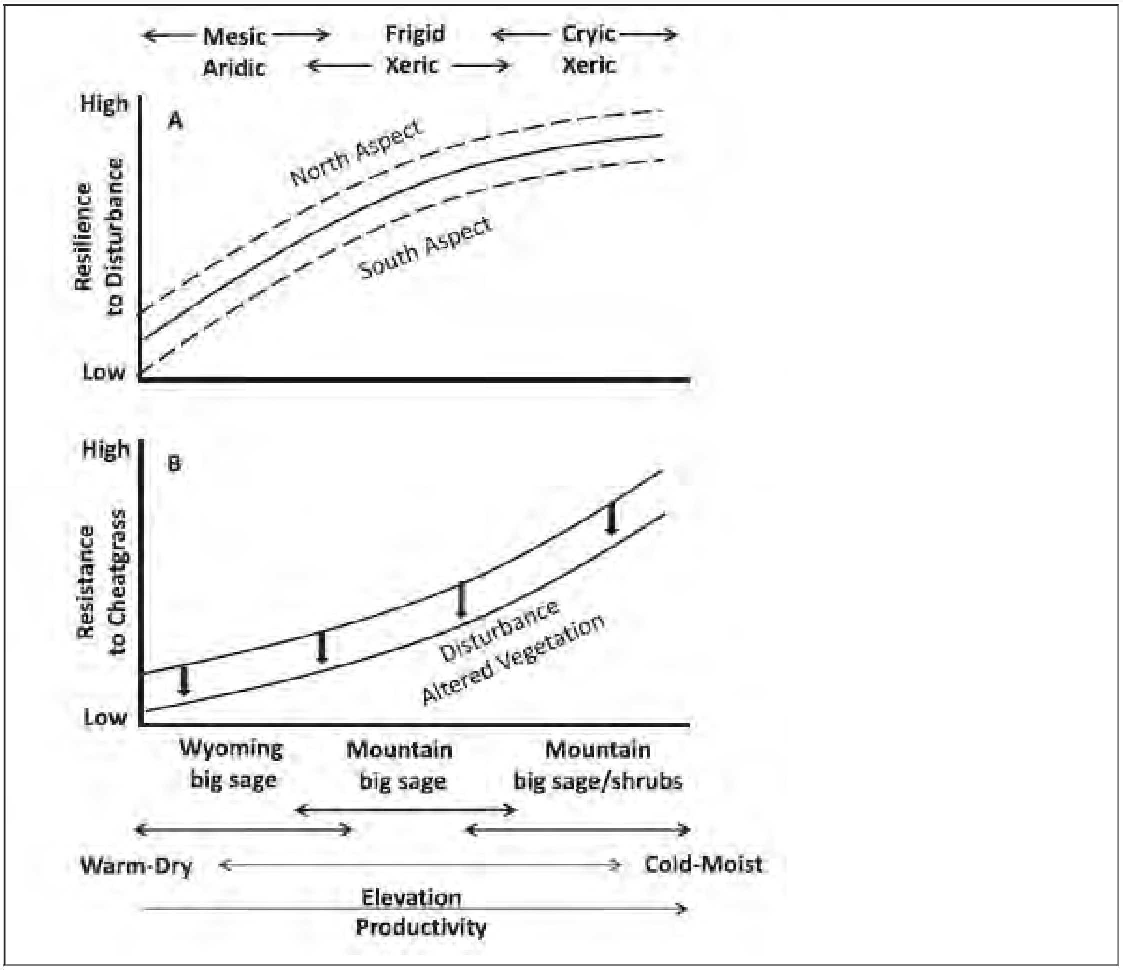


Figure 8—A conceptual model of A) resilience to disturbance and B) resistance to cheatgrass invasion as they relate to soil temperature and moisture regimes, elevation, and productivity gradients in the Great Basin. Predominant sagebrush types that occur along this continuum include Wyoming big sagebrush on warm, dry (mesic/aridic) sites; mountain big sagebrush on cool, moist (frigid/xeric) sites; and mixed mountain shrublands with mountain big sagebrush and sprouting shrubs on cold, moist (cryic/xeric) sites. As environmental gradients move from left to right, resilience, resistance, and biomass (i.e., fuels) increase ([142,493], adapted from [139,141]).

Among the three major big sagebrush taxa, Wyoming big sagebrush generally recovers slowest because it grows more slowly [118] (see Plant Growth and Mortality) and occurs on the driest sites [103,425,493,538]. Mountain big sagebrush and basin big sagebrush recover more rapidly [425,767].

Because soil temperature and moisture regimes vary among Wyoming big sagebrush sites and include warm and dry, cool and dry, and warm and moist soil temperature and moisture regimes [142,493] (table 6), establishment and recovery of Wyoming big sagebrush is likely to vary among these sites, with recovery on warm and dry sites slower than that on cooler and moister sites [19,20]. However, a study of postfire recovery of Wyoming big sagebrush in central and southeastern Montana did not find a relationship between average annual precipitation and Wyoming big sagebrush postfire recovery time. This study examined postfire recovery of Wyoming big sagebrush on 24 sites with average annual precipitation ranging from 10.8 to 16.4 inches (274-415 mm). It found that Wyoming big sagebrush recovered very slowly, even on sites with the highest average annual precipitation [166] (see Postfire weather).

High prefire cover of big sagebrush may increase its postfire recovery rate [128,287], perhaps because sites with high prefire cover also have favorable moisture conditions for seedling establishment [128]. For example, on the Deerlodge National Forest, Montana, postfire cover of mountain big sagebrush seedlings was greatest on relatively moist sites that had high prefire mountain big sagebrush cover [128]. Mountain big sagebrush recovered more rapidly after fire in northeastern Utah on sites with ≥20% prefire mountain big sagebrush cover than sites with <20% prefire cover [287]. However, few studies had reported on this relationship for Wyoming big sagebrush as of 2019.

Cheatgrass is very problematic in Wyoming big sagebrush communities, and its invasion has resulted in cheatgrass monocultures in many arid, low-elevation sites that were formerly Wyoming big sagebrush communities, particularly in eastern Washington, Oregon, southern Idaho, Nevada, and Utah [496] (fig. 17). Wyoming big sagebrush sites where cheatgrass has become dominant after fire may not recover to native grass dominance for many years [1,326,451,522,597,811], and may not recover if a grass/fire cycle establishes or if sites are heavily grazed [451]. Resistance of Great Basin sagebrush ecosystems to cheatgrass invasion depends on site characteristics, particularly soil temperature and moisture regimes, and cover of perennial grasses prior to and soon after fire [143,493,595]. Soil temperatures are often optimal for cheatgrass germination, growth, and reproduction in relatively warm, dry Wyoming big sagebrush communities, while low soil temperatures constrain cheatgrass germination, growth, and reproduction in mountain big sagebrush and mountain shrublands [142]. Native perennial grasses and forbs can limit growth and reproduction of cheatgrass by competing for water and nutrients. Because warm, dry Wyoming big sagebrush sites typically have less native perennial cover than cool, moist sites, they are more susceptible to cheatgrass invasion when soil water is available [143]. Slope, aspect, and soil characteristics modify soil temperature and moisture and influence resistance of sagebrush communities to cheatgrass establishment and spread at plant community to landscape scales [24,141,142,143,156,403,493,622] (fig. 7B). For example, 3 years after wildfire at a high-elevation site (7,700-7,900 feet (2,350-2,400 m)) in Wyoming, cheatgrass cover was considerably greater on a southwestern aspect (20%) with Wyoming big sagebrush than an northeastern aspect (<3%) with mountain big sagebrush [164]. For more information about fire effects on cheatgrass, see Considerations for Nonnative Invasive Plants, Miller et al. [493], and the FEIS Species Review about cheatgrass.

High cover of native perennial grasses prior to and soon after fire increases resistance to nonnative annual grass establishment [50,142,143,234,493,595,605,704]. Sites with less than ~20% prefire perennial herbaceous cover [141] and >15% cheatgrass cover [704] appear least resistant to cheatgrass invasion. When nonnative annual grass seed sources are available, burning Wyoming big sagebrush communities with depleted understories of native herbs often results in large increases in nonnative annual grasses such as cheatgrass [143,854] and medusahead [36], while burning Wyoming big sagebrush communities with intact understories of native herbs may result in limited nonnative annual grass invasion [43,196,205]. In Wyoming big sagebrush and mountain big sagebrush communities in Nevada and Utah, Chambers et al. [143] found that 2 years after treatments, cheatgrass biomass and seed production increased 2- to 3-fold after killing native perennial herbs with herbicide, 2- to 6-fold after prescribed fire, and 10- to 30-fold after herbicide and fire combined [143]. In contrast, Davies et al. [196] found minimal nonnative annual grass cover (0.04%) and full recovery of perennial bunchgrass cover 2 years after fall prescribed fires in Wyoming big sagebrush stands in southeastern Oregon. Before the fires, the sites lacked a "readily available source of noxious weed propagules" [196]. Factors that result in depletion of native perennial herbs, such as overgrazing by livestock and expansion of junipers and pinyons, increase invasibility of Wyoming big sagebrush communities [143]. Deferred grazing after fire may promote perennial herb recovery [749] (see Managing postfire livestock grazing).

High prefire cover of shrubs, including Wyoming big sagebrush, may promote postfire recovery of perennial grasses [26,89], and burned areas under shrub canopies may be a more conducive environment for native and nonnative perennial grass seedling establishment than burned interspaces [89]. In the year after a July wildfire near Burns, Oregon, density of native perennial grasses under burned shrub canopies in Wyoming big sagebrush sites was 24 times greater than density in paired, burned interspaces ($P = 0.0016$). Density of nonnative perennial grasses was 6 times greater under burned shrub canopies than in burned interspaces ($P < 0.001$). The sites were seeded with native and nonnative species with a drill the fall after the fire [89]. Shrub cover was one of the two best predictors of aboveground native species richness in sagebrush steppe in northern Nevada, with the richness of native species increasing with increasing cover of big sagebrush ($P = 0.041$) and yellow rabbitbrush ($P = 0.047$) [26].

VAM and fire: Abundance of VAM associated with big sagebrush is reduced by heating or chemical alteration of the soil, and they may take several years to reestablish after fire or other soil-altering disturbance [493,818]. Because VAM may improve Wyoming big sagebrush seedling survival [682] and growth [683], their reduction may slow postfire recovery of Wyoming big sagebrush. Abundance of VAM in soils from 4 burns in mountain big sagebrush communities in south-central Wyoming that were 3, 7, 21, and 39 years since fire was similar in the youngest and oldest burns, suggesting that VAM populations can recover to levels similar to that in older burns within the first few postfire years. However, the highest abundance occurred in the 7-year-old burn [183]. As of 2019, no studies examined postfire establishment of VAM in Wyoming big sagebrush stands.

The effect of fire on VAM associated with big sagebrush likely depends on fire severity and duration [396,493,818]. At the Morley Nelson Snake River Birds of Prey National Conservation Area, Idaho, fewer of the VAM infecting Wyoming big sagebrush roots were killed by a low-intensity fire (67% of Wyoming big sagebrush roots infected) than by a relatively higher-intensity fire (18% of roots). The percent of VAM infecting Wyoming big sagebrush roots on unburned sites was not provided [818].

Fire characteristics: As of 2019, few studies examined the effects of fire characteristics (e.g., severity, season, pattern, and size) on Wyoming big sagebrush postfire recovery. Because Wyoming big sagebrush regenerates from seeds after fire, fire characteristics that affect the amount of soil-stored seeds consumed by fire (severity and timing), the number and distribution of surviving adult plants (severity and pattern), and the distance downwind from parent plant seed sources to the burn (pattern and size) are likely to strongly influence the rate of Wyoming big sagebrush postfire recovery [544]. For more detailed information about fire severity, season, pattern, and size in Wyoming big sagebrush communities, see the FEIS synthesis Fire regimes of Wyoming big sagebrush and basin big sagebrush communities.

Wildfires in Wyoming big sagebrush communities are standing replacing [19,20] because fire easily kills Wyoming big sagebrush plants (see Fire adaptations). However, fire severity on other ecosystem components (e.g., understory vegetation and soil) varies due to variation in fuels, topography, and weather and results in burned and unburned patches [20]. Within burned patches, nearly all Wyoming big sagebrush plants are killed (e.g., [37,38,75,149,234,256,580,770,837,843]). Unburned patches provide seed sources for Wyoming big sagebrush postfire recovery. Differences in soil burn severity affect the amount of soil-stored big sagebrush seeds, and may, in part, account for variable big sagebrush recovery after fire [840], although few studies reported on this topic (see Immediate effects on seeds).

Big sagebrush communities are likely to recover fastest after small, patchy fires and slowest after large, uniformly high-severity fires because most big sagebrush seeds come from unburned plants or are dispersed onto burns from off-site sources [392,529,562,723,784]. Baker [20] did not provide estimates for Wyoming big sagebrush recovery after small and large fires, but concluded that mountain big sagebrush cover could recover to ≥85% of unburned values within 25 to 35 years after "small" fires, but would take ≥75 years after a "large", uniformly high-severity fires [20]. Because postfire recovery estimates are longer for Wyoming big sagebrush than mountain big sagebrush, estimates for recovery from "small" and "large" fires are also likely to be longer. In Idaho, Wyoming big sagebrush seedlings were observed in Wyoming big sagebrush communities 2 years after 7 small (0.1-1.1 acre (0.05-0.45 ha)) September prescribed fires, but “little reestablishment” was observed 15 years after a July wildfire (size not provided). The authors hypothesized that in part, Wyoming big sagebrush may have established faster following the prescribed fires than the wildfire because the prescribed fires were smaller [567]. In southeastern Idaho, Wyoming big sagebrush postfire recovery did not exceed 3% Wyoming big sagebrush cover in postfire year 35. The authors suggested that Wyoming big sagebrush at this site might remain at low levels for up to 75 years after patchy prescribed fires or longer after less patchy wildfires [520].

If big sagebrush seeds are not present within the burn perimeter, colonization of large burns may be slow because of the short dispersal distances of seeds [855] (see Seed Dispersal). However, many researchers observed no or limited Wyoming big sagebrush postfire seedling establishment even when Wyoming big sagebrush seed sources were located nearby (e.g., [166,770,811]). For example, nearby seed sources did not hasten recovery of Wyoming big sagebrush on 24 burned sites in central and southeastern Montana [166], and there was no Wyoming big sagebrush establishment 6 years after a prescribed fire in southwestern Montana despite nearby seed sources [770].

Because some prescribed fires create a mosaic of burned and unburned patches in Wyoming big sagebrush communities (e.g., [843]), some researchers suggested that big sagebrush recovery may be faster after prescribed fire than wildfire (e.g., [392,520]). However, in central and southeastern Montana, Cooper et al. [166] found that Wyoming big sagebrush recovered slowly after both prescribed and wildfires at all sites ($n = 24$), in part because both types of fires typically resulted in complete mortality of Wyoming big sagebrush. Similarly, a study of 28 mountain big sagebrush sites in southwestern Montana found no difference in postfire recovery between sites burned under prescription and those burned by wildfire ($P = 0.15$), even though there were often more surviving mountain big sagebrush plants on sites burned under prescription [425].

Postfire weather: Moisture availability is critical for Wyoming big sagebrush seedling establishment, and Wyoming big sagebrush recruitment is sometimes positively correlated with seasonal or annual precipitation patterns [345,443] (see Moisture availability). This suggests that Wyoming big sagebrush postfire recovery is correlated with precipitation patterns, which was found in one study [662], but not another [166]. Models suggest that the rate of big sagebrush (Wyoming big sagebrush and/or basin big sagebrush and possibly their hybrids) recovery on sixteen 5- to 28-year-old burns in the northern Columbia Basin was largely explained by precipitation patterns and available soil water. Model results suggested that wet conditions the winter after fire provides growing conditions favorable for Wyoming big sagebrush recruitment, while dry conditions for two winters after fire may have benefitted big sagebrush recovery by decreasing competition with other plants, particularly cheatgrass, that depend on winter and early growing season water availability at shallow soil depths [662]. In central and south-central Montana, a linear regression model incorporating time-since-fire, heat load index (a metric including slope and aspect), and mean annual site precipitation explained 30% of the variation in the rate of recovery of Wyoming big sagebrush cover; however, almost all of this explained variation was attributable to using years since fire as a covariate because neither precipitation nor heat load index alone were related to postfire recovery [166].

Postfire herbivory: After fire, heavy browsing by wild ungulates may slow big sagebrush recovery (e.g., [474,760,762,767,771]) by concentrating browsing on surviving or establishing shrubs [329]. Nineteen years after a wildfire in the Gardiner Basin, Montana, mean cover of Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush in burned stands was 1% to 20% of that in adjacent, unburned stands, which were already in decline from historically heavy wild ungulate browsing. Recovery of Wyoming big sagebrush cover was slower than that of basin big sagebrush and mountain big sagebrush [474].

Big sagebrush density and cover tend to increase and herbaceous species abundance tend to decrease following heavy livestock grazing in burns because most of the herbaceous species are more palatable to livestock than big sagebrush, especially during the growing season [49,172,232,643,723] (see Livestock grazing). In southeastern Idaho, density of big sagebrush and threetip sagebrush was greater on a heavily grazed 9-year-old prescribed burn (55 plants/100 feet²) than on a "conservatively" grazed 12-year-old prescribed burn (5 plants/100 feet²). Greater big sagebrush density on the heavily grazed site may have also been due to decreased competition for soil water and other resources with grasses and forbs on the heavily grazed site [563].

FUELS AND FIRE REGIMES:

- **Fuels**
- **Fire Regimes**

Fuels: Big sagebrush foliage is highly flammable [110,539]. During the growing season, foliar heat content (maximum amount of energy generated by burning leaves) increases while live fuel moisture content decreases [593]. Wright and Prichard [837,841] provide models for predicting shrub, nonshrub, and total aboveground biomass consumption based on data from spring and fall prescribed fires in Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush communities in California, Nevada, Oregon, and Montana.

Biomass, and thus fuel loading and often fuel continuity, generally increase along an environmental gradient from warm and dry to cold and moist sagebrush sites. While Wyoming big sagebrush sites occur along the drier end of the gradient, soil temperature and moisture regimes vary and include soils that are warm and dry, cool and dry, and warm and moist [142] (table 6, fig. 8). Thus, productivity "varies rather widely" among Wyoming big sagebrush sites [640]. A review by Miller and Eddleman [495] reported that total annual herbaceous production in Wyoming big sagebrush stands across the West ranged from 390 to 690 pounds/acre (440-770 kg/ha), while that in basin big sagebrush stands ranged from 770 to 2,100 pounds/acre (87-2,350 kg/ha) and that in mountain big sagebrush stands ranged from 630 to 2,450 pounds/acre (700-2,750 kg/ha). Schlatterer [639] approximated that the least productive Wyoming big sagebrush sites in the Great Basin and surrounding areas produce <400 pounds/acre (450 kg/ha) of herbs annually, while the most productive sites produce up to 900 pounds/acre (1,000 kg/ha)). In northern Utah, southern Idaho, northeastern Nevada, and west-central Wyoming, total annual production in Wyoming big sagebrush communities ranged from 460 to 990 pounds/acre (520-880 kg/ha) [558]. Average annual production of graminoids, forbs, and shrubs in the least productive Wyoming big sagebrush stand on the Shoshone National Forest, Wyoming, was 278, 133, and 328 pounds/acre, respectively (312, 149, and 368 kg/ha), and in the most productive stand was 427, 231, and 206 pounds/acre, respectively (479, 259, and 231 kg/ha) [732].

Precipitation is highly variable year to year in many Wyoming big sagebrush sites (e.g., [777]) (see Climate), and it affects the amount of fuels (biomass and plant cover) on these sites [493,504]. Fuels can be sparse in Wyoming big sagebrush communities [118,830], especially in dry years. This can make prescribed burning difficult [127] (see Fire Management Considerations: Considerations for Fuels). In southeastern Oregon, total herbaceous biomass in 3 Wyoming big sagebrush/Thurber needlegrass communities ranged from 100 pounds/acre (110 kg/ha) during a dry year (50% of average annual precipitation) to 520 pounds/acre (580 kg/ha) during a wet year (185% of average annual precipitation). Forb biomass changed up to 4-fold between dry (17 pounds/acre (19 kg/ha)) and wet (67 pounds/acre (75 kg/ha)) years [495]. In central Utah, mean total plant cover in Wyoming big sagebrush stands ranged from 37% to 79% during 20 years. The correlation of total live plant cover to total precipitation the preceding year was not significant, although nearly so ($R^2 = 0.42$; $P = 0.07$), and total live plant cover appeared to increase during wet periods and decline during droughts [811]. In central Nevada, comparisons of peaks in charcoal abundance with climate records suggest a positive correlation between fire occurrence and relatively wet periods in landscapes now dominated by Wyoming big sagebrush and basin big sagebrush, implying that these big sagebrush communities are fuel-limited, where fine-fuel biomass increases during relatively wet periods and is then ignited during relatively dry years [476].

Figure 9—A Wyoming big sagebrush/needle and thread association in eastern Oregon with 10% Wyoming big sagebrush cover, 1,789 pounds/acre of live Wyoming big sagebrush biomass, and 248 pounds/acre of total herbaceous biomass. Image and fuels data courtesy of the Forest Service, Fire and Environmental Research Applications Team, U.S. Department of Agriculture's Digital Photo Series.

When nonnative annual grasses establish and spread into big sagebrush communities, the abundance and continuity of fine surface fuels is likely to increase—especially following years with abundant precipitation—which can increase fire activity on invaded sites [813] (see Consequences of annual grass invasion). Fire may spread into Wyoming big sagebrush communities from adjacent, cheatgrass-dominated sites, and spread from cheatgrass-dominated Wyoming big sagebrush sites into adjacent communities (fig. 10). In the Great Basin, 80% of multiday fires occurring from 2000 to 2009 that started in cheatgrass grasslands spread into adjacent communities, including Wyoming big sagebrush-basin big sagebrush steppes [22].

Figure 10—Fire spreading from a cheatgrass grassland (a site likely formerly dominated by Wyoming big sagebrush and perennial grasses) into a mountain big sagebrush community during the 2011 Constania Fire, Long Valley, California. Photo by Nolan Preece.

When conifers establish and spread into big sagebrush communities (see Woodland Expansion), fuel characteristics change. As communities succeed from sagebrush steppe to late-successional conifer woodland, cover of live big sagebrush and herbaceous plants decreases as tree cover increases (e.g., [29,403,490,505,601,840,846,847]. On sites where big sagebrush or similar large shrubs are dominant, shrubs are more likely than mature trees to carry fire, especially if trees are widely spaced. As big sagebrush and herbaceous species decline during succession, trees become more important in carrying fire [623]. Increases in the size of tree crowns and continuity of tree crown fuels and decreases in surface fuel abundance, density, and continuity increase the potential for crown fires burning under severe conditions (i.e., high wind, high atmospheric instability, low humidity, and high temperatures) [493,504]. Simulations suggest that high winds (>15 miles (25 km)/hour) are needed to carry fire through a singleleaf pinyon-California juniper woodland canopy that contains 4,800 pounds/acre (5,400 kg/ha) of canopy fuels, and that flame lengths in the woodlands exceed those in big sagebrush-rubber rabbitbrush shrublands [216].

Fuel loads and fire severity may be greater in late-successional woodlands than in sagebrush steppe communities. While no studies have been conducted on burn severity in Wyoming big sagebrush communities in particular, an analysis of a 46,680-acre (18,890-ha) July wildfire in southwestern Idaho showed that remotely-sensed burn severity in sagebrush steppe measured in postfire years 1 and 2 was negatively correlated with the amount of mountain big sagebrush and low sagebrush steppe and early-successional woodlands nearby (approximate range of r = -0.5 to -0.7) and positively correlated with the amount of late-successional western juniper woodlands nearby (approximate range of r = 0.5-0.7, $P <$ 0.05 for all correlations). Western juniper woodlands in mid- to late successional stages had higher fuel loads than intermingled sagebrush steppe [693].

Fire Regimes

Historical: Presettlement fires in the sagebrush biome were both lightning- and human-caused [18,296,300,660,744,817,820]. Peak fire season occurred from April to October and varied geographically [429]. Wildfires were stand replacing [20]. Fire frequency was influenced by site characteristics, and frequency estimates range from decades to centuries, depending on the applicable scales, methods used, and metrics calculated. Because Wyoming big sagebrush communities occur over a productivity gradient driven by soil temperature and moisture regimes, fire frequency likely changed across the gradient, with more frequent fire on more productive sites that supported more continuous fine fuels [142,493]. Because sites dominated by Wyoming big sagebrush are drier and tend to produce fewer fine fuels, they tended to burn less frequently than sites dominated by mountain big sagebrush [381,766,839]. Most fires were likely small (less than ~1,200 acres (500 ha)), and large fires (>24,000 acres (10,000 ha)) were infrequent [20,115,116]. Large fires were most likely after 1 or more cool, wet years that allowed fine fuels to accumulate and become more continuous [20,504].

Contemporary: Since European-American settlement, fuel and fire regime characteristics in many big sagebrush communities have shifted outside the range of historical variation. Settlement generally began in the late 1800s and caused changes in ignition patterns and fuel characteristics, although the timing and magnitude of these changes varied among locations [503]. Since then, fuels and fire regimes in many sagebrush ecosystems have changed due to a combination of interrelated factors, including fire exclusion; livestock grazing and associated land management; proliferation of nonnative invasive plants; woodland Expansion; climate changes; land alteration for agriculture and rangeland; and energy, urbanization, and infrastructure development [67,98,160,306,398,496,503,507,518,787].

For more detailed information about fire regimes in Wyoming big sagebrush communities, including information on fire ignition, season, type, frequency, severity, pattern, and size during presettlement and contemporary times, see the FEIS synthesis Fire regimes of Wyoming big sagebrush and basin big sagebrush communities. To find fire regime information for other plant communities in which Wyoming big sagebrush may occur, such as pinyon-juniper communities, enter "Wyoming big sagebrush" in the FEIS home page under "Find Fire Regimes".

FIRE MANAGEMENT CONSIDERATIONS:

Overview: Historically, prescribed fire and other treatments were commonly used to reduce big sagebrush cover and density [67,118,805]. Wyoming big sagebrush was frequently targeted and "may have received more treatments than any other sagebrush", due in part to its broad distribution [550]. From the 1930s through the 1970s, and to a lesser extent thereafter, land managers used fire, herbicides, and mechanical methods (e.g., plowing/disking, disk-chaining, root plowing, anchor chaining, railing, harrowing, and rotobeating) to reduce sagebrush and increase grass production for livestock [49,67,554,786]. Vale [743] reported that by 1974, about 10% to 12% of 99 million acres (40 million ha) of big sagebrush rangeland in North America had been managed to reduce big sagebrush cover and increase grass production. A 1987 review included the following objectives of prescribed burning in sagebrush-grassland communities in the northern Great Basin:

1. reduce sagebrush cover and density,
2. increase herbaceous plant productivity,
3. increase wildlife habitat diversity and edge,
4. reduce conifers,
5. alter herbivore distribution,
6. enhance palatability and nutritional value of vegetation, and
7. prepare for seeding desirable species [118].

Guidelines from 2013 for restoring and rehabilitating Wyoming big sagebrush shrub-steppe in eastern Washington included some of the same objectives:

1. reducing (but not removing) Wyoming big sagebrush cover and density where its abundance is high,
2. increasing Wyoming big sagebrush cover and density where its abundance is low,
3. increasing the abundance and diversity of native grasses and forbs, and
4. controlling nonnative invasive plants [223].

However, prescribed fire alone was never considered a treatment with a high likelihood of success for any of these objectives. It was only considered a high-likelihood treatment when used in combination with herbicides to control cheatgrass [223].

In 2017, I contacted several federal resource managers, and many reported that prescribed fire was still commonly used in Wyoming big sagebrush communities for many of the above purposes (e.g., [310,540,585,626,635,658,753]), although some managers have curtailed prescribed burning due to concern over widespread losses of big sagebrush communities from wildfire and other causes [540,679], including the spread of cheatgrass and other nonnative invasive species that can occur after fire [121,626,685].

Disagreement about the historical distribution and relative abundance of sagebrush communities and their historical fire regime characteristics occurs throughout the published literature and has led to opposing recommendations about the use of fire in big sagebrush communities [392,474,786]. Regardless of the disagreement, managing big sagebrush communities based on historical distribution and fire regime characteristics may not be realistic in landscapes impacted by human development, nonnative plant invasions, and climate change [190,201,496,745,806,855]. In a review, Davies et al. [201] stated that "while it may be tempting to mimic pre-European settlement conditions in an effort to bolster restoration success, practitioners should be cautious when inferring present-day restoration strategies based on the historical ecology of existing plant species. Historical disturbance regimes and climate patterns that shaped the environment in which perennial species evolved may or may not relate strongly to current disturbance regimes and environmental conditions, particularly in Wyoming big sagebrush communities at risk of exotic annual grass invasion". West [806] stated that resource managers should manage for a mix of desired plant communities in what remains of sagebrush steppes, noting that historical sagebrush steppes are unlikely to recover due in part to:

1. a warmer and drier climate in contemporary than presettlement times;
2. increased atmospheric carbon dioxide during the past ~100 years; and
3. the presence of nonnative invasive plants [806].

In addition, the large scale of the changes and limited financial and logistical resources make it unlikely that resource managers can return most big sagebrush communities to presettlement conditions [496].

In general, prescribed fire is not considered effective for maintaining or restoring Wyoming big sagebrush communities because fire reduces habitat quality for sage-grouse and other sagebrush obligates for potentially long periods and increases opportunities for postfire invasion by nonnative plants (especially cheatgrass) [19,71,207,301,442]. For example, Gruell [301] stated that "fire is not a good management choice" in many Wyoming big sagebrush communities because "too much fire occurs in the low-elevation Wyoming big sagebrush and nearby types that prehistorically burned infrequently", and Riegel et al. [614] stated “with little to gain and the potential to increase populations of exotic weeds, the use of fire as a tool to enhance sage-grouse habitat in these drier sagebrush communities is limited and very risky”. Because sagebrush is essential to maintain native plant communities and limit nonnative plant invasions, Beck et al. [47] stated that management activities in Wyoming big sagebrush communities "should be limited to those that do not eliminate or greatly reduce sagebrush".

However, some researchers advocate for the continued use of prescribed fire in Wyoming big sagebrush communities at sites where fire was relatively frequent historically, but only at sites not considered important to sage-grouse and unlikely to convert to cheatgrass grasslands [201,205,234,600,604]. For example, a 2011 review concluded that while severe disturbances should be minimized in all big sagebrush communities because they may eliminate native perennial plants and greatly increase the potential for cheatgrass invasion, less severe disturbances such as patchy prescribed fires or light to moderate livestock grazing that maintain or increase native perennial plants may help increase the resistance of big sagebrush communities to cheatgrass invasion in the long term [201] (see Preventing nonnative plant invasions). Thus, while prescribed fire use is limited, its use is likely to continue on some Wyoming big sagebrush sites [370]. Fuel and fire characteristics are important considerations when using prescribed fire in Wyoming big sagebrush communities. Techniques for using prescribed fire in sagebrush communities, including fireline construction, use of natural fuelbreaks, firing methods, fire weather, and safety are discussed by many authors (e.g., [67,118,740,814,840]) and are not detailed in this review.

Considerations for Wildlife Management:

- *General*
- *Birds*
- *Small mammals*
- *Wild ungulates*

General: In a review of the role of fire in sagebrush habitats, Knick et al. [399] stated that the use of prescribed fire to manipulate wildlife habitats is one of the most common yet contentious issues in managing big sagebrush ecosystems. Fire in big sagebrush communities impacts wildlife forage and cover [717]. Fires that create mosaics of diverse, productive forage near security and thermal cover are often considered beneficial to wildlife, including a broad range of ground, foliage, and aerial feeding birds [14,237,554,580,717], small mammals [470], and wild ungulates [717,845]. However, fire effects depend on the species of plants and wildlife [276] and the resultant ratio of forage to cover over time [148,298,474,717]. Maintaining big sagebrush and native herbaceous species and reducing opportunities for nonnative plant establishment and spread are important in managing big sagebrush communities for birds [224,314,344,554,627], small mammals [418,551,627], and wild ungulates [717,726,850]. Bukowski and Baker [116] suggested that due to the extensive fragmentation of contemporary sagebrush communities and the threat of the establishment and spread of nonnative annual grasses (see Other Management Considerations), management efforts for wildlife should focus on preserving or rehabilitating large landscapes composed of a mosaic of patches of dense and scattered sagebrush [116].

Management objectives for reducing big sagebrush often include increasing the abundance of native perennial grasses and forbs, particularly for sage-grouse (e.g., [161,172,257,317,843]) and wild ungulates (e.g., [164,322,834]). However, a 2011 literature review of the effects of prescribed burning in Wyoming big sagebrush communities that included seven studies on Wyoming big sagebrush in south-central Oregon, east-central and south-central Idaho, southwestern Montana, northeastern Utah, and northwestern Colorado [46,257,567,576,760,770,843] concluded that overall, prescribed burning is unlikely to result in increases in cover, frequency, relative abundance, or production of herbaceous species in the short term (≤10 years) or long term (>10 years). All studies reported short- and long-term decreases in Wyoming big sagebrush cover [48]. Wrobleski and Kaufmann [842,843] describe no short-term effects on density, frequency, and relative abundance of five of nine forbs important to greater sage-grouse diets after prescribed fires at Hart Mountain National Antelope Refuge. See the Research Project Summary for details and information on the fire prescriptions and fire behavior. Crawford et al. [172] suggested that fire is most likely to increase native perennial forbs and grasses where sagebrush is abundant, native forbs are present, and nonnative plants are limited. This most often applies to mountain big sagebrush communities where shrub cover is >35%, rather than Wyoming big sagebrush communities [172].

Most research on and management guidelines for sage-grouse (e.g., [38,46,47,161,261,319,320,609,643,766]) and wild ungulates [47,647] suggest avoiding prescribed burning and suppressing wildfires in Wyoming big sagebrush communities, particularly in critical wintering areas. In a 2012 review on the effects of treatments (e.g., prescribed fire, herbicides, and mechanical treatments) on Wyoming big sagebrush, Beck et al. [47] concluded that "given the overall lack of evidence documenting positive population responses of sage-grouse, pronghorn, mule deer, or elk to treatments in Wyoming big sagebrush, we urge land managers to refrain from these treatments until information is available that clearly documents appropriate treatments and the conditions, including appropriate temporal and spatial scales, under which those treatments are expected to impact these wildlife species."

On the other hand, fire can slow woodland succession in some Wyoming big sagebrush communities. Conifer establishment in big sagebrush communities is generally harmful to sagebrush obligates, but it may be beneficial to facultative wildlife species if tree density is low enough to support a healthy understory of shrubs and grasses. Low densities of western juniper tend to increase the abundance, diversity, and richness of bird and small mammal populations in shrub-steppe, and small, scattered stands of dense trees may provide thermal cover for wintering ungulates. However, as tree abundance increases, wildlife abundance, species richness, and diversity decline [490]. A review of the effects of reducing juniper and pinyon abundance on wildlife found that 69% of wildlife species demonstrated little response to tree reduction. Sagebrush obligates and shrubland-grassland associated wildlife species were more likely to have a positive response to tree reduction than woodland-shrubland and woodland-associated wildlife [78]. If using prescribed fire and other methods to reduce conifer establishment and dominance in big sagebrush communities, Holmes and Robinson [337] recommended that residual habitat be maintained at levels suitable to support shrub-dependent wildlife while treated areas recover.

The following discussion provides information on the importance of big sagebrush communities for food and cover and fire management considerations for wildlife. Many studies of the relationship between wildlife and their sagebrush habitats do not identify sagebrush taxa to species or subspecies, but for many wildlife species, the specific sagebrush taxon may be less important than its height, density, cover, and patchiness [554,823].

Birds: Numerous bird species use Wyoming big sagebrush and other big sagebrush for food and cover [787]. More than 90 bird species have a facultative relationship with big sagebrush ecosystems [785], while sage-grouse, sage sparrow, and sage thrasher are sagebrush obligates [355,785] that frequently use Wyoming big sagebrush communities [473,821]. For example, in Browns Park National Wildlife Refuge, Colorado, sage sparrow densities increased with increasing Wyoming big sagebrush cover [821].

Sage-grouse require sagebrush for food and cover year-round [99,160]. They use sagebrush communities with different heights and cover depending on the season and activity, ranging from 10 to 31 inches (25-80 cm) tall and 12% to 43% cover [160]. Due to its growth form, height, widespread distribution, and expansive areas covered, Wyoming big sagebrush is perhaps the most important plant for sage-grouse [172]. The thermal and security cover and food it provides are especially important during nesting (e.g., [206]) and wintering (e.g., [113,342]). Wyoming big sagebrush communities may be important sources of forage forbs during brood-rearing [206], although warm, dry Wyoming big sagebrush sites often have sparse forbs that do not provide high-quality brood-rearing habitat [243]. High cover of sagebrush may be especially important around sage-grouse nests to avoid predation, and nest success is highest in areas with relatively high cover and density of sagebrush or other shrubs, tall grasses, and other habitat features that provide visual obstruction (e.g., [162,295,303,315,332,373,390,391,586,621]). Because of the lack of adequate shrub cover, sage-grouse generally avoid nesting in young (<20 years old) burns (e.g., [131,318,387,536]). Nonnative annual grasses, such as cheatgrass, do not provide adequate cover for sage-grouse nests [172], so conversion of Wyoming big sagebrush to nonnative annual grasses is harmful to sage-grouse population productivity.

In general, fire is harmful to sage-grouse because it removes sagebrush plants that provide essential thermal and security cover and food year-round, especially during breeding, nesting, and wintering [131]. Dramatic declines in greater sage-grouse populations were correlated with habitat losses from a 2,000% increase in fire incidence in Idaho and subsequent conversion of Wyoming big sagebrush communities to cheatgrass communities (Crowley and Connelly 1996, cited in [399]). Because cheatgrass cover often increases after fire in Wyoming big sagebrush communities and cover of herbs and shrubs are often slow to recover, Beck et al. [46] recommend that managers avoid burning Wyoming big sagebrush communities and only implement treatments that maintain Wyoming big sagebrush cover. Large, homogenous fires are likely to harm sage-grouse populations more than small or patchy fires [47,237,366,564,656]. Sage-grouse avoid conifer communities during breeding, nesting, and brood-rearing [32,135,152,268,648], and their survival decreases with increased conifer cover [152,218,648] because they have less forage [268,497] and greater predation risk [32,135] than in big sagebrush communities. Thus, removal of conifers from big sagebrush communities using techniques that retain some sagebrush cover is likely to improve sage-grouse habitat [163,631].

Brewer's sparrows, sage sparrows, and sage thrashers are insectivorous or omnivorous sagebrush obligates that use Wyoming big sagebrush and other big sagebrush communities [473,554,821]. Brewer's sparrows are insectivores that glean insects mostly from the foliage and bark of big sagebrush and other shrubs or trees in big sagebrush communities. They also eat seeds, particularly in winter, and mainly from the ground [339]. Sage sparrows are omnivores that eat insects, seeds, fruits, and succulent vegetation mainly gleaned from the ground near or under big sagebrush and other shrubs in big sagebrush communities [340]. Sage thrashers are ground-foraging insectivores, with a small portion of their diet consisting of vegetation and fruits found in big sagebrush communities [126]. According to a review, sagebrush obligates prefer big sagebrush cover ranging from 20% to 36%, while nonobligate bird species do not require cover that dense [785,791]. Maintaining sufficient big sagebrush cover in unburned patches in burn perimeters is important to sagebrush obligates [73,237,333,471]. Studies in Oregon [333] and southeastern Idaho [580] suggest that abundance of these species may be relatively unaffected in the short term if sufficient unburned patches remain. However, in some cases a lack of a short-term response to burning may be attributable to site fidelity of breeding adults [399] or because prefire and postfire habitats are degraded [102].

In general, fire in big sagebrush communities reduces shrub-nesting bird populations until shrubs recover, and fire increases or has no effect on ground-nesting bird populations (e.g., [14,112,225,337,386,399,471,543,627,781]). For example, in south-central Wyoming, songbird species richness and relative abundance were highest on untreated Wyoming big sagebrush sites that had the highest shrub cover and lowest on a 9-year-old burn that had the lowest shrub cover. Species composition shifted to communities of predominantly shrub-nesting species in untreated areas (e.g., Brewer's sparrow and sage thrasher) and ground-nesting species in burns (e.g., horned lark). Generalist nesting species (e.g., vesper sparrow) were common in both areas [386]. Knick et al. [399] provide a summary table of available literature on the response of breeding birds to fire in sagebrush habitats.

Bird guilds shift as junipers and pinyons establish in big sagebrush communities. As tree cover and density increase, shrub and herb cover and density decrease, and shrub- and ground-nesting bird populations decline. On the other hand, woodland bird species (e.g., ash-throated flycatcher, pinyon jay, American robin, mountain bluebird, juniper titmouse, and western kingbird) colonize big sagebrush communities once they succeed to woodland (e.g., [77,78,179,335,399,542,603]). For example, in central Oregon, density of ground-nesting birds was highest in 5-year-old burns in grassland steppe, density of shrub-nesting birds was highest in early-successional mountain big sagebrush-Idaho fescue steppe, and density of tree- and cavity-nesting species was highest in old-growth western juniper/Idaho fescue woodland [603].

Small mammals: Many small mammals depend on big sagebrush communities for food and cover. Among these, pygmy rabbit and sagebrush vole have obligate relationships, and are therefore most likely to be affected by fires in Wyoming big sagebrush communities. In addition, nearly 80 species of small mammals, including black-tailed jackrabbits, ground squirrels, chipmunks, kangaroo rats, voles, shrews, and mice have facultative relationships. Some of these small mammals prefer early-successional Wyoming big sagebrush stands, while others prefer late-successional stands. For example, Townsend's ground squirrels prefer open and grassy Wyoming big sagebrush communities such as burns [388,455,741], while pygmy rabbits avoid open areas and prefer late-successional sagebrush stands [594,718,778,824]. Although small mammals use habitats with a range of big sagebrush cover (0%-68%), a review concluded that between 20% and 50% cover apparently supports the most small mammal species [785]. Mid- to late-successional stands are most likely to have Wyoming big sagebrush cover of >20% [59,243,845] (see Successional Status).

Because loss of big sagebrush reduces food and cover for pygmy rabbits, prescribed fires and other treatments that reduce sagebrush cover are harmful to them [281,824]. While all fires may be harmful, small, patchy fires are less so than large, homogenous fires [417,718]. Pygmy rabbits occur in dense stands of Wyoming big sagebrush, basin big sagebrush, mountain big sagebrush and other shrubs on deep loamy, alluvial, and other friable soils, which provide forage, escape cover, and conditions favoring burrow construction [418,778]. The primary food of pygmy rabbits is big sagebrush, which may comprise 99% of their winter diet. They also eat grasses and forbs in late spring, summer, and early fall [281,293,294,380]. Pygmy rabbits are colonial and tightly clumped in distribution, which makes them vulnerable to fires that remove shrubs at the colony site. A study in Nevada and California found that the likelihood of pygmy rabbit presence at Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush sites was high when sagebrush cover was high, understory stem density was low, and cheatgrass was absent [418]. Fragmentation of shrub communities may limit dispersal into favorable habitats [717,778], and pygmy rabbits may not disperse across large burns [418]. After fire, pygmy rabbits may be more vulnerable to predation. For example, after an August prescribed fire in a Wyoming big sagebrush-grassland community in Idaho, 6 of 12 radio-collared pygmy rabbits abandoned their home range; 2 of these established new home ranges and the other 4 were predated. Of the 6 that remained on the burned site, only 1 survived through winter, 4 were predated, and 1 was not located [281].

The effects of fire in big sagebrush communities on sagebrush vole populations are relatively unknown. Sagebrush voles were not captured on a burn up to 3 years after a severe September prescribed fire in a Wyoming big sagebrush-squirreltail community in Utah; however, they were captured on nearby unburned plots [87]. In south-central Washington, sagebrush voles were occasionally trapped on "old" burns dominated by bluebunch wheatgrass [546]. One study found no relationship between time-since-fire and sagebrush vole densities at two mountain big sagebrush sites on the Sheldon National Wildlife Refuge [334,338]. Sagebrush voles occur in steppes with 0% to 27% big sagebrush cover and generally require an understory of dense herbaceous vegetation. Grass cover, not big sagebrush cover, appears most limiting for sagebrush vole populations [155,450,454,546,547]. A conservation assessment indicated that patchy, infrequent fires in big sagebrush communities that do not kill the understory herbaceous vegetation probably have little effect on sagebrush vole populations, except where nonnative plants replace native grasses. However, sagebrush vole populations may decline during the year of the fire due to reduced grass cover, which is required for forage and hiding cover. Additionally, complete kill of shrubs removes the vertical stand structure sagebrush voles prefer [155]. Vole populations are cyclic, but their population cycles are difficult to predict. A better understanding of both the effects of fire and the factors that trigger eruptions in vole populations would be valuable for big sagebrush management [14].

Black-tailed jackrabbits eat most plant species in sagebrush communities, and big sagebrush is a primary forage [7]. Big sagebrush is eaten year-round [7,246], especially in fall and winter. Grasses and forbs are mostly eaten in spring and summer [7,246,455]. Patchy fire in big sagebrush and other shrub types may benefit black-tailed jackrabbits by increasing grasses and forbs adjacent to shrub cover. Reducing shrub cover over large areas, however, can increase mortality from predation by golden eagles and other predators [281,717,741]. Black-tailed jackrabbits do not burrow, so they require tall shrubs such as big sagebrush for cover [545]. In Idaho, black-tailed jackrabbit density was higher in big sagebrush plots burned under prescription than in unburned plots in two of four surveys ($P < 0.01$), but density was similar on burned and unburned plots in the other two surveys [281]. In contrast, the loss of sagebrush habitat and increase in nonnative annual grasslands due to extensive fire was associated with a decline in black-tailed jackrabbit densities during three jackrabbit population cycles from 1971 to 1992 at the Morley Nelson Snake River Birds of Prey National Conservation Area [741].

Wyoming big sagebrush may be slow to recover on sites with black-tailed prairie dog colonies [157,369], and black-tailed prairie dogs may potentially exacerbate the effects of fire on Wyoming big sagebrush habitat by lengthening Wyoming big sagebrush recovery time (see Wildlife browsing: Small mammals).

In a study of prescribed fire effects on small mammals, McGee [470] concluded that "ideal" sagebrush management should create a mosaic of various successional stages, so that "no small mammal species, or group of similar species, would be significantly displaced in space and time". Species that tolerate openings—such as Great Basin pocket mouse, North American deermouse, and Uinta ground squirrel—often increase soon after fire, while species requiring cover—such as western jumping mice and vagrant shrew—decline until cover returns [267,334,338,470]. Welch [785] provides a summary table listing the effects of big sagebrush reduction or removal by fire or mechanical methods on individual species of small mammals. Overall, these treatments reduced the overall abundance of small mammals [785].

Conversion of Wyoming big sagebrush to nonnative annual grasslands is likely harmful to small mammal populations. In Tooele County, Utah, the number of rodent species was greater in Wyoming big sagebrush sites (n = 9 species) than in cheatgrass sites (n = 5 species); all species trapped in cheatgrass sites were also trapped in Wyoming big sagebrush sites. The mean number of individuals captured was also greater in Wyoming big sagebrush sites ($P \leq 0.05$ for 4 of 5 comparisons), and total rodent abundance was >6 times greater in Wyoming big sagebrush sites than in cheatgrass sites [551].

The effects of conifer establishment in Wyoming big sagebrush communities are likely to vary among small mammal populations. Many small mammals—including North American deermice, yellow-pine chipmunks, golden-mantled ground squirrels, dusky-footed woodrats, mountain cottontails, and black-tailed jackrabbits—use western juniper foliage and/or female cones for food during part of the year [449,646]; however, increased cover of western juniper also decreases understory plant cover, which would likely have a negative impact on many small mammal populations [490]. A review of the effects of reducing juniper and pinyon abundance on small mammals found that small mammal responses to woodland reduction varied considerably by wildlife species and treatment type. Treatments that completely removed overstory cover were likely to increase the number of grassland-associated small mammals in the short term. Thinning often increased, or did not adversely affect, the abundance of woodland-associated and generalist small mammal species [78].

Wild ungulates: Big sagebrush habitats provide important food and cover for ungulates, including pronghorn, mule deer, elk, and bighorn sheep, during all seasons [762,782,785,834]. Paige [554] considered pronghorn a big sagebrush obligate in the Great Basin. Wyoming big sagebrush is highly palatable and nutritious browse for these ungulates [655,763,785], especially during winter when other forage is less nutritious or unavailable [762,782]. While all sagebrush taxa are potentially valuable forage for wild ungulates [763,783], among the three major big sagebrush subspecies, pronghorn apparently prefer Wyoming big sagebrush [76,671]. Mule deer and elk often have the highest preference for mountain big sagebrush and moderate to low preference for Wyoming big sagebrush and basin big sagebrush (e.g., [100,577,641,654,655,761,763,769,796,797]).

Conifer expansion in big sagebrush habitats has varied effects on wild ungulates. Pronghorn generally avoid wooded areas [647,730] and may benefit from fires that reduce conifers and increase long-range visibility [851], while elk and mule deer are year-round residents in pinyon-juniper habitats [439,565] and may not benefit from fire and other disturbances that remove trees. A review of the effects of reducing juniper and pinyon abundance on wildlife found that mule deer and elk responded positively to mechanical removal or thinning in only 10% and 20% of the studies conducted, respectively [78]. Bighorn sheep occur in a variety of plant communities, including pinyon-juniper woodlands, but avoid dense forests [405].

Figure 11—Pronghorn in sagebrush habitat in Yellowstone National Park. Photo courtesy of Jim Peaco, National Park Service, U.S. Department of the Interior.

Sagebrush-grasslands with Wyoming big sagebrush are important pronghorn habitats [281,541]. Large fires in sagebrush habitats are harmful to pronghorn because they rely on sagebrush for food [67,281,448,541,671,785] and cover [1,281,330,389,394,853] year-round, especially during winter and spring, and shrubs such as big sagebrush may be particularly important protective cover during fawning [16,853]. However, fires that create openings in dense sagebrush habitats generally benefit pronghorn [322,389,851,853], because pronghorn require open cover that provides long-range visibility to escape predation [587,853]. Pronghorn may not use areas with dense, tall sagebrush (e.g., >50% cover, >23 inches (58 cm) tall), but may use these areas after fire [213,850,851]. While Scott and Geisser [647] acknowledged that pronghorn may benefit from small burns that "open up" forested areas in Yellowstone National Park, they recommended suppressing fires in large stands of Wyoming big sagebrush to conserve critical winter forage for pronghorn. In the Great Basin, pronghorn prefer sagebrush steppe habitats where total vegetation cover averages ~50%—with about equal proportions of grasses, forbs, and shrubs—and trees are sparse [389,852]. Yoakum [849,852] recommended that prescribed fires in pronghorn habitat be <1,000 acres (400 ha) and leave 5% to 10% shrub cover remaining in fire perimeters. Pronghorn used a 1,000-acre (400-ha) burn in Wyoming big sagebrush in southeastern Idaho year-round, but use was highest during winter and spring. Among three winters, use was lowest during a winter with deep snow. The author concluded that while pronghorn rely on sagebrush for food and cover during winter and could be negatively impacted by burns where sagebrush cover is limited, the prescribed fire did not appear to have a negative impact on the pronghorn population due to the small size of the burn relative to other available habitat [281]. Repeated fires that prevent big sagebrush reestablishment in sagebrush-grasslands are likely harmful to pronghorn populations [853].

Wyoming big sagebrush communities are critical winter range for mule deer in some areas [671,720], and Wyoming big sagebrush is highly palatable to [286,671,762] and often heavily browsed by mule deer, especially in late fall and winter [541,671]. Mule deer may eat Wyoming big sagebrush year-round, but in general, they prefer forbs and grasses when green and succulent and switch to sagebrush and other browse when forbs and grasses are dry [65,408,440,548,758]. Many authors recommend creating or maintaining a mosaic of burned and unburned habitats to benefit mule deer (e.g., [114,148,164,322,657,834]). Stevens [687] stated that diversity of cover and food over short distances is key to enhancing mule deer populations in big sagebrush areas. Fires that result in large expanses of homogeneous vegetation are harmful to mule deer [322,436,651,733]. Fire may also enable unpalatable or nonnative invasive plants to establish, which can reduce mule deer forage [834].

Because snow is relatively shallow in Wyoming big sagebrush communities, they are often important as winter ranges for mule deer [671]. Fire is likely harmful on winter ranges because it removes Wyoming big sagebrush cover and browse [47]. For example, mule deer numbers declined 66% during 33 years on the northern Yellowstone winter range, possibly because Wyoming big sagebrush density declined 43% and cover declined 29% during that time [671]. Because fire reduces cover, several authors cautioned against using prescribed fire in mule deer habitats where cover is limiting, particularly on winter ranges [57,247,322,649,651,700]. Klebenow [394] noted that mule deer avoided large burns on sagebrush-grassland winter range until shrubs recovered. Regardless of habitat, small burns are often considered better for mule deer because they may not use portions of large burns [8,57,65,651,721]. However, small burns may be heavily browsed, which may reduce or eliminate preferred sprouting trees and shrubs [651].

Elk are generally associated with a mosaic of open areas for foraging and forested areas for cover [674], and fire tends to maintain this mosaic [111,322,435]. When preferred forest cover is not available, elk seek habitat that provides a combination of variable topography, areas with little human disturbance, and shrubs, including big sagebrush [467,633]. Wyoming big sagebrush and other big sagebrush taxa provide important cover for elk during bedding [467,695] and calving [365]. Elk most likely benefit from patchy fires that create early-successional habitats that provide forage while leaving interspersed patches of forests and shrublands that provide cover. Elk are not likely to benefit from fires that result in large expanses of homogeneous vegetation [226,322,435,670,709,747,754]. Fire reduces big sagebrush forage, which elk browse in fall and winter [33,407,566]; however, elk eat a variety of plant species and prefer grasses and forbs over browse when available [212]. Elk use of sagebrush communities may increase after fire, when palatable grasses and forbs increase and less palatable shrubs decrease [747]. Fire may also enable unpalatable or invasive plants to establish, which can reduce elk forage availability and thus, elk use [726,727,729]. After fire, the "optimum" postfire successional stage is when herbaceous plant cover has built up and tree and shrub canopies are open [674,703]. However, elk use of burned areas varies widely among locations, plant communities, and seasons due to variation in postfire vegetation growth rates, adjacent habitat, and prefire elk density and movements [560,728,746,747]. Having a variety of sizes of burned areas in a landscape may be most beneficial to elk [432,433]. However, small burns may be especially vulnerable to overbrowsing by elk, especially in areas with large elk populations, such as elk winter ranges [111].

Bighorn sheep prefer habitats generally free of visual obstruction, including mountain grasslands, big sagebrush steppe, and pinyon-juniper woodlands [382,567,677,717,748] that are near escape terrain (e.g., cliffs, rock rims, rock outcroppings, and bluffs with sparse cover of trees or shrubs) [146,307,717,748]. In general, fires that reduce visual obstruction in foraging areas near escape terrain benefit bighorn sheep by improving visibility and potentially increasing forage [146,568,676,677,717,756,835]. Bighorn sheep primarily graze grasses and forbs, but browse woody plants when herbs are unavailable [146], and big sagebrush can be an important part of their winter diet [379,382,448,785]. Bighorn sheep use Wyoming big sagebrush communities as winter ranges after fires that increase herbaceous forage availability [567]. Fires in mature conifer stands adjacent to escape terrain may maintain or establish bighorn sheep winter range. Fall and early spring fires, particularly on southern and southwestern aspects, may provide more spring forage than would otherwise be available to bighorn sheep [676,756,835]. Burning young forests and shrublands adjacent to bighorn sheep winter range could provide migration corridors between winter and summer ranges [696]. While fire may help maintain grasslands and improve production and palatability of important forage species for bighorn sheep [567], it reduces habitat quality when rangeland condition is poor, nonsprouting forage species are eliminated, or too much area is burned and forage is inadequate [568].

Follow links in table A2 to FEIS Species Reviews for fire effects information on wildlife species mentioned in this section.

Considerations for Nonnative Invasive Plants:

- *Consequences of annual grass invasion*
- *Preventing nonnative plant invasions*

Figure 12—Wyoming big sagebrush steppe west of Vernal, Utah, with a dense cheatgrass understory. Photo by Matt Lavin, courtesy of Wikimedia Commons.

Consequences of annual grass invasion: Of the nonnative plant species present in Wyoming big sagebrush ecosystems, annual grasses pose the biggest threat because they alter fuel characteristics and have the potential to lengthen the fire season and increase the frequency, size, spread rate, and duration of wildfires [9,22,204,397,428,496,559], such that Wyoming big sagebrush cannot reestablish [742], a grass/fire cycle establishes, and Wyoming big sagebrush communities are converted to annual grasslands [22,108,180,400,702]. Nonnative invasive annual grasses of concern in big sagebrush ecosystems include cheatgrass, medusahead, and ventenata [172,627]; among these, cheatgrass has been the most harmful to date [663], and large areas of big sagebrush ecosystems have been converted to cheatgrass monocultures [22,180,400,702]. Wyoming big sagebrush communities are highly susceptible to cheatgrass invasions [142,491,492] (table 6). In the early 2010s, the U.S. Fish and Wildlife Service [742] considered wildfire "the most significant threat to landscape scale losses of sagebrush habitat", especially because of the grass/fire cycle.

Cheatgrass-invaded Wyoming big sagebrush communities have more abundant fine fuels, greater fuel continuity, and lower fuel moisture content than noninvaded communities, increasing the potential for frequent, large-scale, fast-spreading wildfires [204]. Increased fire activity following cheatgrass invasion was documented by several researchers (e.g., [64,578,813]) and quantified by others (e.g., [22,397,428,475]). For example, analyses of burned area data using three datasets from 1980 to 2009 found that cheatgrass grasslands consistently had more frequent, faster spreading, and longer duration fires and the largest proportional area burned compared to four native cover classes. Fire intervals for cheatgrass-dominated grasslands in 251,000 miles² (650,000 km²) of the Great Basin averaged 78 years from 2000 to 2009, which was 2.5 times more frequent than fire intervals in the Wyoming big sagebrush-basin big sagebrush steppe cover class [22]. The likelihood of ignition was greater in cheatgrass grasslands [22], and fire spread increased with increasing cheatgrass cover [428]. The number ($R^2 = 0.22$) and size ($R^2 = 0.27$) of cheatgrass fires were positively correlated with precipitation during the preceding calendar year. Multiday fires from 2000 to 2009 were more likely to start in cheatgrass grasslands than in other cover classes; however, 80% of these fires burned multiple cover classes [22].

Preventing nonnative plant invasions: Preventing invasive plants from establishing and spreading into new areas is the most effective and least costly management approach (Box 1). In addition to invasive annual grasses, nonnative forbs are becoming increasingly detrimental to sagebrush communities (see Other Management Considerations: Nonnative invasive plants).

Box 1—Preventing the establishment of invasive plants in burned areas can be accomplished through early detection and eradication, careful monitoring and follow-up, and limiting dispersal of invasive plant seed. Specific recommendations from these sources [13,107,291,736] include:

- Incorporate the cost of invasive plant prevention and management into fire rehabilitation plans.
- Acquire restoration funding.
- Include prevention education in fire training.
- Minimize soil disturbance and vegetation removal during fire suppression and rehabilitation activities.
- Minimize the use of retardants containing nitrogen and phosphorus.
- Avoid areas dominated by high priority invasive plants when locating firelines, fire camps, staging areas, and helibases.
- Clean equipment and vehicles prior to entering burned areas.
- Regulate or prevent human and livestock entry into burned areas until desirable vegetation has recovered sufficiently to resist invasion by undesirable vegetation.
- Monitor burned areas and areas of significant disturbance or traffic from management activity.
- Detect invasive plants early and control before vegetative spread and/or seed dispersal.
- Eradicate small patches and contain or control large infestations in or adjacent to burned areas.
- Reestablish native vegetation as soon as possible.
- Avoid use of fertilizers in postfire restoration and rehabilitation.
- Use only certified weed-free seed mixes when revegetation is necessary.

Warm, dry sagebrush sites are at greatest risk of cheatgrass establishment and spread, while cool and cold, relatively moist sites have the least risk [30,141,156,496,702,712,831] (table 6, fig. 2). In 2005, >70% of the area occupied by Wyoming big sagebrush-basin big sagebrush communities in the Great Basin region of Nevada, Utah, and California was considered to have moderate to high risk of displacement by cheatgrass. Warm, dry sites at low elevations and on south- and west-facing slopes were at the highest risk. Sites at high elevations and on north- and east-facing slopes were at low risk [702]. Predicted climate changes are likely to favor the establishment and spread of cheatgrass [91,479,496,629]. Consequently, low-elevation Wyoming big sagebrush-basin big sagebrush sites will likely become more vulnerable to drought-related sagebrush mortality and less resistant to cheatgrass invasion following fire [555].

Because fire initially reduces perennial herb and biological soil crust cover and reduces the resistance of Wyoming big sagebrush communities to cheatgrass invasion, prescribed fire is not recommended in areas where cheatgrass or other nonnative plants are present and likely to spread or become dominant after fire [282,399,444]. In Wyoming big sagebrush communities, ~20% or more cover of native perennial herb cover [141] and <15% cover of cheatgrass [704] appear necessary to prevent cheatgrass invasion in burns. A study in Wyoming big sagebrush communities in north-central Nevada and northeastern California found that while postfire site dominance could be of either native or nonnative plants where cheatgrass cover on adjacent unburned sites was less than ~15%, native species never dominated or increased in dominance where cheatgrass cover on adjacent unburned sites was >15% [704]. However, cheatgrass can quickly become dominant after fire, even if it was a minor component of the prefire community. In a Wyoming big sagebrush/bluebunch wheatgrass community in central Utah, cheatgrass cover on burned plots (36%) was >3 times that on unburned plots (11%) 1 year after a midsummer, 27,000-acre (11,000-ha) wildfire. In postfire year 2, cheatgrass cover on burned plots (50%) was about twice that on unburned plots (24%), despite a high density of native perennial bunchgrasses present before the fire. Total precipitation was higher than average during both years [807]. Relatively wet and warm weather, especially in fall and spring, favors cheatgrass establishment and growth [94,143,349,350,442,807]. Overgrazing by livestock and infilling of junipers and pinyons are likely to decrease cover of native perennial grasses, decreasing resistance to the establishment and spread of nonnative annual grasses [106] (see Vegetation and site characteristics).

Biological soil crusts help prevent the establishment and spread of nonnative annual grasses [109,142,605,739], so maintaining and restoring biological soil crusts in Wyoming big sagebrush communities is important in preventing nonnative plant invasions [223,625]. A rehabilitation study of nineteen 1- to 9-year-old burns in Wyoming big sagebrush and twoneedle pinyon-Utah juniper communities in western Colorado found that cheatgrass cover is more likely to increase after fire where biological soil crust cover is low than where it is high [661]. Grazing too soon after fire can promote the spread of nonnative annual grasses by disturbing biological soil crusts and reducing native perennial plants [49,172,201,421,605,739] (see Managing Postfire Livestock Grazing).

While protection from disturbance (i.e., suppression of wildfires and exclusion of livestock grazing) may help maintain native perennial plants in "intact" Wyoming big sagebrush communities [139], some researchers advocate using prescribed fire and livestock grazing in Wyoming big sagebrush communities where risk of cheatgrass invasion is low [190,201,205,234,604]. For example, Davies et al. [205] stated that because Wyoming big sagebrush communities evolved with fire, fire is important in maintaining these ecosystems. They hypothesized that prescribed fire might increase the resistance of Wyoming big sagebrush communities to cheatgrass invasion by increasing herbaceous vegetation cover, reducing bare ground, and reducing soil inorganic nitrogen. They seeded cheatgrass in unburned and unburned sites 3 years after fall prescribed fires in Wyoming big sagebrush-bunchgrass plots at the Northern Great Basin Experimental Range, Oregon, where annual precipitation averaged 12 inches (300 mm). The fires killed all the Wyoming big sagebrush but was of low severity to the understory vegetation. In postfire year 4, total herbaceous plant cover, density, and production were greater in burned than unburned sites, while cheatgrass cover and density, bare ground, and soil inorganic nitrogen concentrations were lower ($P < 0.10$ for all comparisons), suggesting that resistance to cheatgrass invasion may have been higher on burned than unburned sites. Many factors may have contributed to the lower postfire cheatgrass cover and density on the burned sites: Before the fires, burned sites had an intact native herbaceous understory and 9% to 15% Wyoming big sagebrush cover, lacked cheatgrass and other nonnative invasive plants, and were not grazed for 5 years. In addition, the fires resulted in low herbaceous plant mortality, cheatgrass seeds were introduced after a 3-year recovery period, and precipitation was 117% of average during the year of cheatgrass seed introduction. The authors acknowledged that results would likely have been different if native herbaceous plants had been depleted and cheatgrass was already present prior to burning [205].

In areas where native perennial plant cover is depleted, seeding after fire may help stabilize soils, speed recovery of sagebrush and other shrubs, and prevent establishment and spread of nonnative species [63,171,187,231,492,620,669,713,719,860]. However, seeding sagebrush communities after fire has had low success rates, particularly on warm, dry sites [11,201,592,632]. For example, analyses of 101 postfire seeding sites in Oregon, Idaho, Nevada, and Utah from 1990 to 2003 indicated that postfire seeding success was least likely on warm, dry Wyoming big sagebrush sites. Seeding was most successful on sites with relatively low annual temperatures (especially cool springs and falls) and relatively high total and spring precipitation, such as mountain big sagebrush sites [11]. Seeding may not be needed if native plant species can recover naturally after fire [288]. In Utah, natural revegetation (no seeding) after fire was least successful on dry, low-elevation (<6,000 feet (1,820 m)) sagebrush sites because cheatgrass "readily invaded the burned areas" and was most successful on moist, high-elevation sagebrush sites, especially on northern and eastern aspects. Favorable weather (above normal precipitation and above average winter temperatures) followed burning [438]. Controlling cheatgrass established on burned Wyoming big sagebrush sites may aid in establishing desired seeded plant species [690]. Miller et al. [492] provide guidelines for determining when and where to seed sagebrush stands (fig. 13). For more information, see Value for Restoration of Disturbed Sites and Field guides and handbooks.

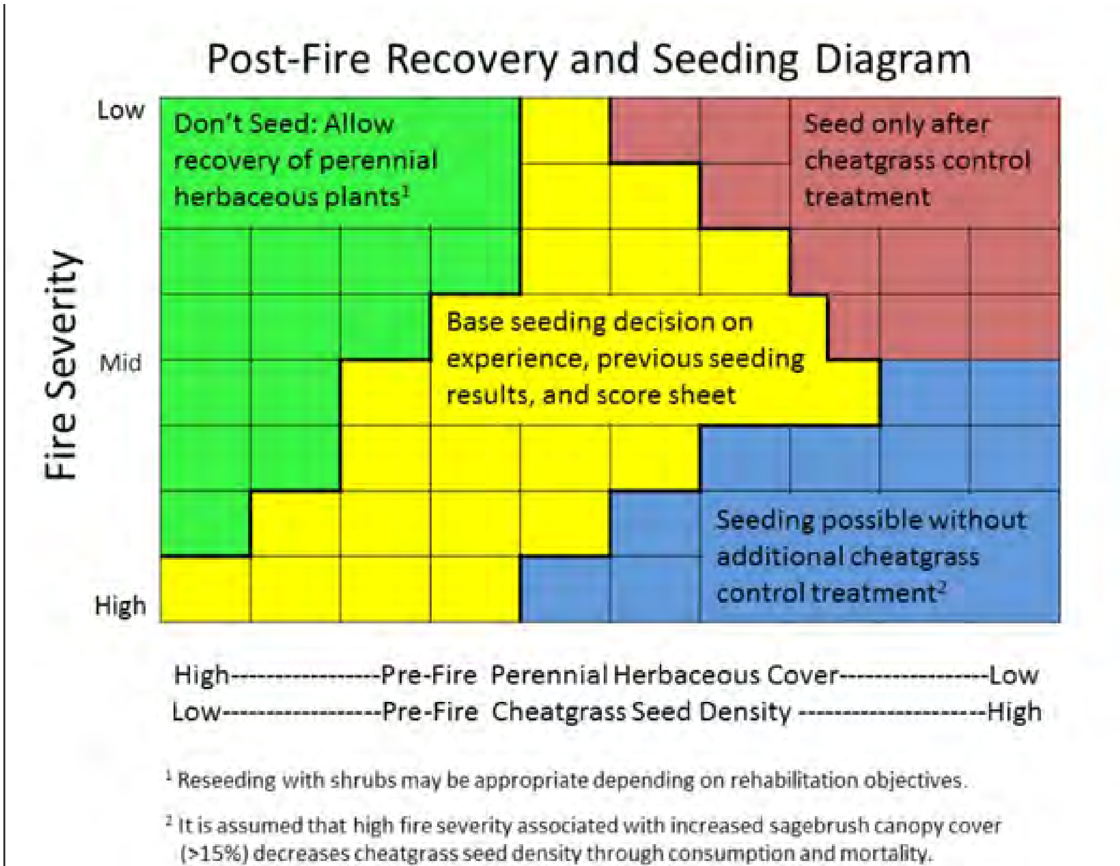


Figure 13—Considerations for postfire seeding in sagebrush communities based on relationships among prefire perennial herbaceous cover, prefire cheatgrass seed density, and severity of the wildfire to perennial herbs and cheatgrass. The red blocks represent areas where cheatgrass seed mortality was limited as a result of low to moderate fire severity, and successful postfire seeding requires cheatgrass control. The blue blocks represent areas where postfire cheatgrass seed density is low as a result of high fire severity, and a 1-year window for seeding with minimal competition from cheatgrass typically occurs. The yellow blocks represent areas where vegetation response is less predictable and information on past seeding results, local experience, and use of a score sheet are needed to evaluate resilience to disturbance and resistance to nonnative annual grasses. The green blocks represent areas where prefire perennial herbaceous cover was high and prefire cheatgrass seed density was low or postfire cheatgrass seed density is low as a result of high fire severity, and seeding is not needed for perennial herbaceous plant recovery [492].

Crested wheatgrass, a nonnative perennial bunchgrass, has been seeded extensively in sagebrush communities by land management agencies [832]. Crested wheatgrass is commonly planted after fire on warm, dry Wyoming big sagebrush sites—where revegetation success is relatively low and the threat of cheatgrass invasion is high—to preclude the development of cheatgrass stands and to meet other management objectives [12,236,239,302,513]. Some researchers consider stands of crested wheatgrass a preferred alternative to cheatgrass (e.g., [12,171,201,628]) because crested wheatgrass is "fire resistant" and its caespitose growth form helps disrupt fuel continuity and slow wildfire spread [512,569,570,571].

A rehabilitation process of "assisted succession" whereby cheatgrass stands are first revegetated with crested wheatgrass and then revegetated with Wyoming big sagebrush and other native species can be successful (e.g., [171]). However, Wyoming big sagebrush may be slow to reestablish on sites seeded with crested wheatgrass [302,481], and crested wheatgrass may limit diversity of native grasses and forbs [201,518]. While big sagebrush may naturally reestablish in crested wheatgrass stands over time [302,532], recruitment is variable, depending on site characteristics, grazing practices, presence of seed sources, and climate [201,514]. Recruitment is most likely if big sagebrush seedlings establish soon after seeding, while recruitment in established crested wheatgrass stands is often sparse. Recruitment appears most likely on sites receiving >12 to 14 inches (304-356 mm) of average annual precipitation [514]. Establishment of Wyoming big sagebrush in established crested wheatgrass stands may be improved by reducing crested wheatgrass cover prior to seeding or planting Wyoming big sagebrush [171]. Steps that may be required to increase Wyoming big sagebrush on sites dominated by crested wheatgrass include: 1) fire exclusion, 2) control of crested wheatgrass, 3) planting or seeding Wyoming big sagebrush, and 4) posttreatment livestock grazing management [532]. Using prescribed fire to reduce crested wheatgrass is not recommended because it recovers from fire more quickly than Wyoming big sagebrush [302]. Managed livestock grazing [239,302,347,532] and herbicides [202] may help reduce crested wheatgrass cover and increase Wyoming big sagebrush cover.

In areas where cheatgrass is already abundant, special measures may be necessary to prevent recurrent fires [67] that prevent sagebrush from reestablishing [742]. Greenstripping and grazing management to reduce fuel loads are two methods employed to prevent large, recurrent fires in areas dominated by cheatgrass [570,707]. Nonnatives crested wheatgrass and forage kochia have been the most successful species in greenstrips [438,513,525,570]. Greenstripping is only recommended on high-value sagebrush sites threatened by annual grass invasion, because it fragments sagebrush habitat and may result in greater abundance of nonnative plants if the seeding is unsuccessful [554]. Fire behavior models suggest that managed livestock grazing may reduce fuel loads and flame lengths in greenstrips seeded with cool-season perennial grasses, making fires easier to manage by hand crews under most fire weather conditions [864]. Herbicides may also help to maintain greenstrips [208]. Greenstrip establishment alone may not be sufficient to alter fire behavior in cheatgrass grasslands [864].

Managing Conifers: Removal of junipers and pinyons to increase forage for livestock or improve wildlife habitat has historically been a primary objective of prescribed burning in big sagebrush communities; however, this is not always appropriate [10,282,490,623] (see Considerations for Wildlife Management). Authors generally only advocate for conifer removal in areas where trees were historically sparse or absent and the density of trees has increased since presettlement times [116,201,259,490,493,623].

Several authors recommended that priority for conifer removal on sagebrush sites be given to sites in the early stages of woodland succession, before trees become dominant, because these sites are likely more resilient to nonnative annual grass invasion, and restoration to sagebrush dominance is more likely on sites in early stages of woodland succession [40,44,141,493,504] (see State-and-transition models).

Prescribed fire, mechanical treatments, and hand thinning of conifers have been recommended and implemented in big sagebrush communities to slow conifer expansion and reduce the risk of high-intensity crown fires [42]. Many of these methods have been used by federal land managers to reduce conifers in Wyoming big sagebrush communities (e.g., [310,635]). Gentilcore [282] and Miller et al. [491] review the advantages and disadvantages of conifer removal methods. Prescribed fire can remove nearly all vegetation and easily covers large areas. However, it can also be unpredictable, hard to control, may burn nontarget species, and often results in greater risk of cheatgrass establishment and spread after treatment. Mechanical methods of conifer removal may be more appropriate than prescribed fire [141,392]. Seeding of site-adapted big sagebrush taxa my help speed the recovery of big sagebrush after reducing conifers [193]. See table A1 for links to FEIS reviews available for conifer species of interest.

Managing Postfire Livestock Grazing: Livestock tend to concentrate on revegetating burns in sagebrush communities [147,262,277], including recent burns in Wyoming big sagebrush communities [277]. For example, in central Oregon, cattle selected burns the first growing season after fall prescribed fires in Wyoming big sagebrush, mountain big sagebrush, and low sagebrush communities, while they generally avoided these areas before the fires [277].

Many authors recommend excluding livestock from recent burns in big sagebrush communities for at least the first 1 or 2 years to protect regenerating herbs (e.g., [60,67,118,492,563,740,749,814,840]) because grazing during the first growing season after fire may accelerate sagebrush reestablishment at the expense of native perennials [563]. Different recommendations include a nongrazing period of 2 to 3 years after fire [60], periodic growing-season rest from grazing for up to 25 years after fire [181], and excluding livestock from burned areas until perennial grasses have recovered and are producing viable seeds at a rate equal to that of prefire or unburned areas [134,749]. Stevens [688] recommended a minimum of 3 growing seasons with no livestock grazing following seeding for burned and other disturbed Wyoming big sagebrush sites with >12 inches (300 mm) average annual precipitation. He recommended 4 growing seasons with no livestock grazing following seeding for sites with <12 inches average annual precipitation [688]. According to Miller et al. [492,493], the length of time to defer livestock grazing depends on prefire vegetation, site characteristics, fire severity, weather, and whether the burned area was reseeded.

Excluding livestock from recent burns in sagebrush communities *for the first* 2 years is probably adequate where:

- fire severity to understory vegetation was low to moderate;

- postfire erosion is minimal;
- resilience to fire and resistance to invasive annual grasses are high;
- prefire herbaceous vegetation was dominated by native species, and invasive annual grasses were only a minor component; and
- postfire monitoring indicates adequate recovery of shrubs, perennial grasses, and forbs or that seeding objectives have been met [492].

Excluding livestock from recent burns for *more than* 2 years may be needed where:

- fire severity was high, resulting in high mortality of deep-rooted perennial grasses;
- resilience to fire and resistance to invasive annual grasses are moderate to low;
- invasive annual grasses were codominant or dominant prior to the fire; and
- postfire monitoring indicates slow recovery of perennial grasses and forbs or that seeding objectives have not been met [492].

Grazing too soon after fire can promote the spread of nonnative annual grasses by reducing native perennial plants and disturbing biological soil crusts [49,172,201,421,605,739]. Once cheatgrass is established, complete protection from grazing or other disturbances will not usually reduce cheatgrass persistence [170,511,808]. Sixteen 4.0-acre (1.6-ha) livestock exclosures were constructed in sagebrush (Wyoming big sagebrush, basin big sagebrush, black sagebrush, low sagebrush, and Lahontan sagebrush), black greasewood, and winterfat communities in 1937 following the passage of the Taylor Grazing Act. Sixty-five years later, cheatgrass cover was similar inside and outside exclosures, indicating that excluding livestock had not prevented cheatgrass establishment and spread or reduced its cover [170]. Preventing grazing for long periods may allow fine fuels to accumulate, which could lead to greater mortality of native perennial plants and increases in cheatgrass abundance after fire [190].

In addition to delaying grazing after fire, authors recommend reducing livestock impacts on prescribed burns by spreading use throughout numerous small, well-distributed burns. Small burns tend to be disproportionately trampled by livestock, and burns >0.5 mile (0.8 km) from water have less chance of being "camped on" by livestock [444]. Miller et al. [492] suggested that managers also consider impacts by wildlife, which can be heavy, when considering how to manage livestock grazing in burns (see Wildlife browsing).

Decision Tools: There is a growing body of literature and tools to help managers manage, restore, or rehabilitate Wyoming big sagebrush and other sagebrush communities. These include the following:

- *Management guidelines*
- *Field guides and handbooks*
- *Web-based tools*
- *State-and-transition models*

Management guidelines:

- Science Framework for conservation and restoration of the sagebrush biome: linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions: Part 2 (2019) [177]
- Science Framework for conservation and restoration of the sagebrush biome: linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions: Part 1 (2017) [138]
- Wyoming guidelines for managing sagebrush communities with an emphasis on fire management (2002) [845]
- Guidelines to manage sage grouse populations and their habitats (2000) [161]
- Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin (1987) [118]

Field guides and handbooks:

- Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 3. Site level restoration decisions (2017) [588]
- Guide for quantifying shrub cover and herbaceous fuel load in the sagebrush steppe in the thesis titled "Targeted grazing applied to reduce fire behavior metrics and wildfire spread" (2016) [634]
- A field guide for rapid assessment of post-wildfire recovery potential in sagebrush and piñon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses and predicting

vegetation response (2015) [492]

- Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 1. Concepts for understanding and applying restoration (2015) [590]
- Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 2. Landscape level restoration decisions (2015) [589]
- A field guide for selecting the most appropriate treatment in sagebrush and piñon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses, and predicting vegetation response (2014) [491]
- Guide for quantifying post-treatment fuels in the sagebrush steppe and juniper woodlands of the Great Basin (2011) [86]
- Guide for quantifying fuels in the sagebrush steppe and juniper woodlands of the Great Basin (2009) [684]
- Piñon and juniper field guide: Asking the right questions to select appropriate management actions (2009) [710]
- Western juniper field guide: Asking the right questions to select appropriate management actions (2007) [487]

Web-based tools:

- Data Basin Mapping Tools is an online mapping and analysis platform centered on Great Basin ecosystems.
- The Fire and Invasive Annual Grass Assessment Tool (FIAT) is an assessment tool used to determine priority landscapes most at risk of fire and invasive species.
- The Fire Effects Information System (FEIS), of which this review is a part, is an online collection of scientific literature reviews about fire effects on plants and animals and about fire regimes of plant communities in the United States.
- The Fuels Database for Intact and Invaded Big Sagebrush (Artemisia tridentata) Ecological Sites is an online tool designed to assist land managers in estimating fuel loads in big sagebrush communities.
- The Sagebrush Steppe Treatment Evaluation Project (SageSTEP) is a long-term multidisciplinary experiment evaluating methods of sagebrush steppe restoration in the Great Basin.
- SAGEMAP is a geographic information system database for sage-grouse and sagebrush steppe management in the Intermountain West.
- The Sage Grouse Initiative Interactive Web Application is an online map application that visualizes, distributes, and interactively analyzes spatial data from sagebrush steppe ecosystems.
- The Wildland Fire Decision Support System (WFDSS) is a web-based application used to evaluate wildfire risks and document decisions.

State-and-transition models: Managers use state-and-transition models to determine recovery potentials and management alternatives for sagebrush communities [176,472] and to explore how management alternatives may interact with natural disturbances and affect the potential long-term trajectory of the community [242]. Many state-and-transition models are available that describe Wyoming big sagebrush 'ecological states' and model transitions between states resulting from natural and human-caused disturbances (e.g., [142,176,223,242,336,714,716,722,803,833]), including some models that incorporate information on resilience to disturbance and resistance to nonnative annual grasses (e.g., [140,141]). Changes in disturbance regimes and the establishment and spread of nonnative species can cause a transition to a new state that differs in plant composition, structure, and function. Returning to the former state is often difficult (and expensive) because of altered species composition and site attributes [419,714]. Restoration is more likely in healthier than in degraded states [141]. Wildfire can either help to maintain ecosystem function within a desirable ecological state, or move the ecosystem to a less desirable ecological state, such as one dominated by nonnative annual grasses [714]. Careful assessment of site condition is necessary to determine the relevance of a particular state-and-transition model, the suitability of a site for management, and the most appropriate treatment(s) for the site [141].

Several authors [714,803] developed a state-and-transition model for the Great Basin that describes Wyoming big sagebrush ecological states and shows how management affects those states (fig. 14). The "healthy sagebrush" state (WSS-1) is dominated by Wyoming big sagebrush, native grasses, and forbs, and nonnative annual grasses are present but sparse. Wildfire occurring at 107-year intervals maintains this state. Without fire for extended periods, this state may shift to the "overgrown sagebrush" state (WSS-2). In WSS-2, Wyoming big sagebrush and possibly rubber rabbitbrush are dominant with an understory of Sandberg bluegrass and increasing abundance of nonnative annual grasses. Junipers may be present or increasing in abundance. In WSS-1, the success of treatments that maintain that state (i.e., prescribed fire, mechanical treatments, herbicides, and seeding of desired species) is 100% and treatment costs are low. In WSS-2, the success of treatments intended to transition the state back to WSS-1 is 50% and treatment costs are high. If treatments are not successful, WSS-2 succeeds to the nonnative "annual grass dominated" state (WSS-3). Once in WSS-

3, returning to WSS-1 is unlikely, with only a 2.5% treatment success rate, and treatment costs are high. Fire occurring in WSS-3 tends to maintain this state. Thus, the probability of treatment success is strongly influenced by the relative abundance of native perennial grasses and nonnative annual grasses [714,803].

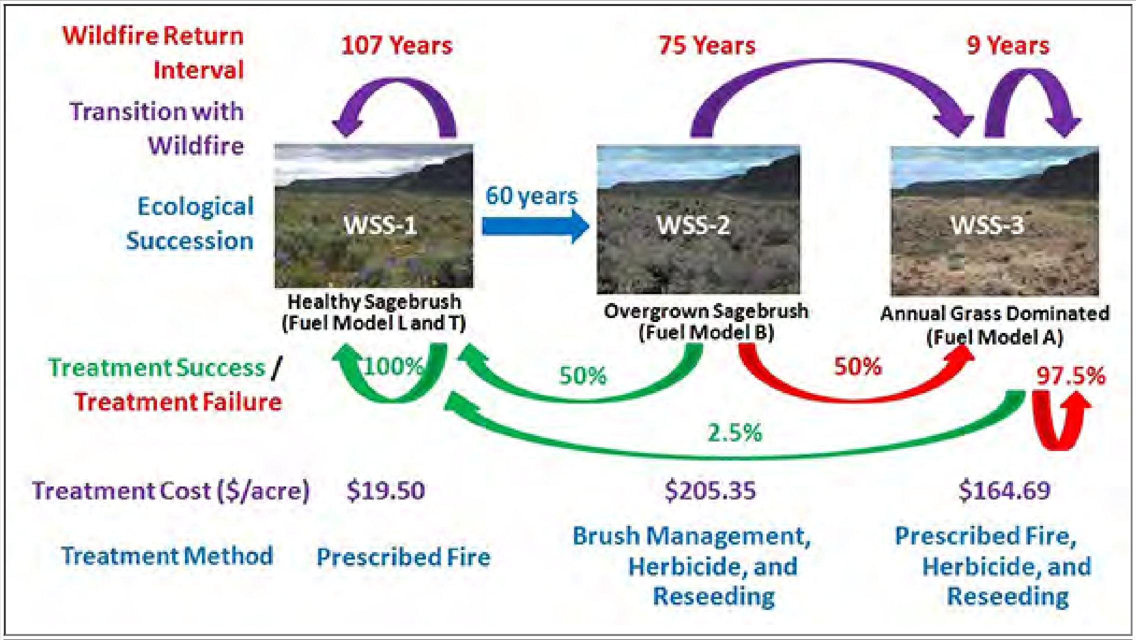


Figure 14—Economic cost of management for alternative states in a warm, dry Wyoming big sagebrush plant community [803]. Image used with permission.

Analyses of state-and-transition models for warm and dry Wyoming big sagebrush, warm and moist Wyoming big sagebrush, and cool and moist mountain big sagebrush communities in California, Idaho, Nevada, Oregon, Utah, and Washington found differences in resilience to fire and mechanical treatments among sites differing in soil temperature and moisture regimes [141]. Resilience to disturbance and resistance to nonnative annual plants tended to increase from warm and dry, to warm and moist, to cool and moist sites. On warm and dry sites, prescribed fire and mowing treatments had similar effects. Both treatments tended to increase nonnative annual plant cover, while having no effect on native perennial grass and forb cover and shrub recruitment. On warm and moist sites with juniper and pinyon expansion, prescribed fire and cut-and-leave treatments tended to increase native perennial grass and forb cover and shrub recruitment, but large increases in nonnative annual plant cover occurred on some sites. Cut-and-leave treatments were more likely to aid recovery to a desirable state than prescribed fire. On cool and moist sites with juniper and pinyon expansion, prescribed fire and cut-and-leave treatments in early- to midsuccessional stages of woodland succession aided recovery to a desirable state and tended to increase native perennial grass and forb cover and shrub recruitment. Native perennial grass and forb cover of ~20% or more prior to treatments appeared necessary to prevent substantial increases in cheatgrass and other nonnative annual plants after treatments on all sites [141]. Detailed state-and-transition models applicable to big sagebrush communities in Sage-grouse Management Zones III, IV, V, and VI are provided by Chambers et al. [142]. See fig. 2 for a map of these management zones.

While state-and-transition models developed for Wyoming big sagebrush and other sagebrush communities can be informative tools for resource managers, they may "overemphasize (or be misinterpreted as to) the need for treatments while minimizing the relatively stable essence of many sagebrush communities" [812] (see Successional Status).

Considerations for Fuels:

Overview: Warm, dry Wyoming big sagebrush communities often have sparse fuels [118,830] that make prescribed burning difficult [127,149,404,770], while moister Wyoming big sagebrush stands may have enough fuels to carry fire [67,127]. Because cover of Wyoming big sagebrush and herbaceous fuels is variable and often patchy [149,325], burns often form a patchy mosaic of burned and unburned areas [149,856]. Britton and Clark [104] considered Wyoming big sagebrush sites the most difficult to burn under prescription, basin big sagebrush intermediate, and mountain big sagebrush sites the easiest based on the amount of herbaceous fuels (see Fuels).

Prescribed fire may be used to create fire breaks and potentially reduce spread rate, flame lengths, and intensity of future wildfires in midsuccessional Wyoming big sagebrush communities where postfire cheatgrass invasion is unlikely [604]. Seventeen years after prescribed fire in a Wyoming big sagebrush site with low pre- and postfire cover of cheatgrass

(<8.4%) at Hart Mountain National Antelope Refuge, total fuel loads were 7 times greater in unburned plots (5,366 pounds/acre (6,015 kg/ha)) than burned plots (741 pounds/acre (831 kg/ha)). Shrub fuel was nearly 10 times greater in unburned than burned plots, and litter under shrubs was nearly 4 times greater in unburned than burned plots. Herbaceous fuels were 5 times lower in unburned than burned plots ($P < 0.01$ for all comparisons). These fuels data were used to model fire behavior in unburned and burned plots under four scenarios of fuels drying. The model estimated that rate of spread, flame lengths, and fireline intensity were lower in burned than unburned plots across all scenarios [604]. Historically, sparse fuels on burned sagebrush areas may have acted as fire breaks [578].

Field sampling methods to estimate fuel characteristics of Wyoming big sagebrush were developed in the 1980s [110,211], and more recently, photo series guides were developed to estimate fuels in Wyoming big sagebrush communities (e.g., [86,553,634,684,737,838]). Wyoming big sagebrush fine fuel (twig) and foliage biomass can be estimated using crown area and height [211]. The strong correlation between these variables ($R^2 = 0.71$) makes crown area and height suitable for modeling fuel characteristics of Wyoming big sagebrush and mountain big sagebrush [110]. Reiner et al. [602] developed regression equations to predict foliage biomass, live biomass, and total biomass for Wyoming big sagebrush and mountain big sagebrush in central Nevada. Photo guides that quantify fuels in all strata (e.g., [86,684]) can be used to predict vegetation and fuel response to various treatments, assess target conditions, set management objectives, help choose management activities to meet objectives, and determine treatment effectiveness [86].

Several models describe fuel and weather conditions necessary to enable fire spread in big sagebrush ecosystems (e.g., [45,67,105,110,264,563,740,836,840]). For example, Brown [110] developed a fire behavior model in Wyoming big sagebrush and mountain big sagebrush ecosystems based on fuels sampled in Montana and Idaho and estimated how rate of spread and fireline intensity vary with big sagebrush height, percent cover, foliage moisture, and fraction of dead stemwood. Wright [836] developed models for predicting fuel consumption and proportion of area burned during spring and fall prescribed fires in big sagebrush communities, which included Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush communities. Frandsen [264] developed a model estimating fuel load of Wyoming big sagebrush and basin big sagebrush for fire behavior predictions. Britton et al. [105] provide a big sagebrush cover-herbaceous fuel load curve representing proportions of big sagebrush cover and herbaceous fuels needed to produce a successful burn. They conclude that at least 20% big sagebrush cover and 200 to 300 pounds/acre (224-336 kg/ha) of herbaceous fuel are needed to ensure a prescribed burn that reduces big sagebrush density. Wyoming big sagebrush cover is typically <25% [285,495] (see Stand structure), and this may contribute to the difficulty in getting a fire to carry through many Wyoming big sagebrush communities [118]. Fuel characteristics and subsequent fire behavior change when Wyoming big sagebrush and other warm to cool and moist sagebrush communities succeed to woodlands [846] (see Fuels) and when these communities are invaded by nonnative annual grasses [813] (see Considerations for Nonnative Invasive Plants).

Grazing management to reduce fuel loads: While impacts of livestock grazing on big sagebrush communities vary (see Livestock grazing), strategic livestock grazing can be used under some conditions to reduce fine fuel biomass and continuity and thereby decrease the risk, size, and severity of wildfires and possibly increase effectiveness of fire suppression [189,197,198,199,200,201,203,526,634]. This is particularly important in areas with cheatgrass-dominated understories [215,235,526,569], where seasonally targeted grazing may help break the grass/fire cycle [201]. Ungrazed Wyoming big sagebrush, mountain big sagebrush, and low sagebrush plots in southeastern Oregon had ~2 times more perennial bunchgrass cover, 1.5 times more total herbaceous cover, ~3 times more standing fine fuel biomass, ~2 times more total fine fuel biomass (standing biomass plus litter), more perennial grass cover without fuel gaps, and smaller fuel gaps than grazed plots ($P \leq 0.03$ for all comparisons) [197]. Fall and spring grazing in Wyoming big sagebrush steppe in east-central Oregon reduced fine fuel biomass, cover, and height, and increased fuel moisture, thereby decreasing ignition and initial spread potential compared with the ungrazed treatment. Grazing effects on predicted fire behavior differed between fall and spring grazing. In the August that followed grazing treatments, the probability of initial fire spread was 6-fold greater in the fall-grazed compared with the spring-grazed treatment. This suggests that spring grazing may reduce fuels more than fall grazing [203]. In Wyoming big sagebrush and mountain big sagebrush communities in Owyhee County, Idaho, cattle grazing was an effective tool for reducing flame height and rate of fire spread during a late September prescribed fire. Shrub cover was low (<25%-30%); at higher shrub cover (31%-78%), fire may have carried though the shrub canopy. The authors concluded that for cattle grazing to reduce fuels, and thus create or maintain fire breaks, shrub cover must be maintained at low levels [634]. Diamond et al. [215] suggest that strategic grazing in nonnative annual grasslands could reduce fuel loads and continuity enough to prevent a flame front from carrying across treated areas even under "peak fire conditions" (i.e., July-August). Davison [209] provides detailed information on using livestock grazing to reduce fuel loads in cheatgrass-dominated rangelands.

Considerations for Fire Characteristics:

- *Fire frequency*
- *Fire size and pattern*
- *Fire season*

Fire frequency: Miller et al. [496] stated that fires in sagebrush communities should not be more frequent than the amount of time required for sagebrush cover and density to fully recover. My analyses of Wyoming big sagebrush postfire recovery data showed slow postfire recovery of Wyoming big sagebrush cover on most sites, even at 66 years since fire (fig. 7B) (see Analysis of postfire recovery studies). On the other hand, some authors recommended that fires in cool to warm, moist sites be frequent enough to prevent conifer establishment and succession to woodland (e.g., [393]) (see Woodland Expansion).

Estimates of historical fire frequency in Wyoming big sagebrush communities can be used as an assessment tool for comparison with current fire regimes and trends and to provide general guidelines for ecological restoration [745]. For more information about historical and contemporary fire frequency in Wyoming big sagebrush communities, see the FEIS synthesis Fire regimes of Wyoming big sagebrush and basin big sagebrush communities.

Fire size and pattern: While fire suppression efforts reduce fire sizes overall [132], wildfires in sagebrush communities that occur during hot, windy weather can become large despite aggressive fire suppression responses [244,717]. The 1994 Butte City Fire near Idaho Falls, Idaho burned >20,500 acres (8,300 ha) of Wyoming big sagebrush communities in <6.5 hours with spread rates as fast as 490 feet (150 m)/minute and flame lengths >40 feet (12 m). The fire was driven by high winds. The authors of a case study on the fire reported that "during the majority of its run, the fire was moving so fast that firefighters were never able to safely catch and attack the fire's head" [130]. Bunting [120] noted that fire suppression can be difficult in many Wyoming big sagebrush communities because they are often surrounded by stands of nonnative annual grasses, which are prone to fire.

Postfire recovery of Wyoming big sagebrush is likely faster if fires are small or have seed sources in burn perimeters [20,567] (see Fire characteristics). If burning under prescription, guidelines recommend burning only small areas [690]. However, small burns tend to be disproportionately trampled by livestock [444] and may be heavily browsed by wild ungulates [111,651]. Ypsilantis [865] recommended protecting small burned areas from overgrazing by livestock and wild ungulates or using a mosaic burn pattern to distribute animals over a larger burned area.

Guidelines from Wyoming in 2002 suggest that prescribed fires be used in Wyoming big sagebrush communities to a create a mixture of successional stages on the landscape, with ~13% of the area in early-successional stages with 0% to 5% Wyoming big sagebrush cover; ~33% in midsuccessional stages with 5% to 15% Wyoming big sagebrush cover; and ~53% in late-successional stages with >15% Wyoming big sagebrush cover. These guidelines also suggest adjusting for local conditions and managing for specific wildlife habitat needs. Caution is urged when treating dry Wyoming big sagebrush sites because postfire recovery can take longer than on moist sites [845]. Baker and Bukowski [20,115] asserted that most contemporary sagebrush landscapes with Wyoming big sagebrush, mountain big sagebrush, and other sagebrush taxa are highly heterogeneous due to fragmentation from land uses and natural disturbances, and that rest, recovery, and preservation are more appropriate management objectives than further increasing heterogeneity.

Fire season: To produce a patchy burn that reduces big sagebrush and increases herbaceous plant production, authors recommend burning when plants are dormant, either in early spring or fall [45,67,118,786]. For example, Beardall and Sylvester [45] recommended prescribed burning mountain big sagebrush and basin big sagebrush before or just after plants have broken dormancy in spring but before new grass growth reaches 2 inches (5 cm) tall. Burning big sagebrush when soils are wet in spring can result in a patchy burn that allows some big sagebrush plants to survive [45,364,786]. However, the short time between snowmelt and green-up makes it difficult to burn when plants are dormant [118,310]. The Cody Field Office, Bureau of Land Management, conducted prescribed fires in Wyoming big sagebrush communities in fall because relatively cool temperatures and relatively high fuel moisture make spring fires infeasible. In addition, fall fires harm cheatgrass and favor native, cool-season perennial grasses such as bluebunch wheatgrass more than spring fires because cool-season perennials are dormant in fall, while cheatgrass is not [310,786,862] (see FEIS Species Review about cheatgrass).

Considerations for Climate Change: Places where conditions are becoming less suitable for big sagebrush may benefit from management actions that promote sagebrush establishment, including fire exclusion, managing postfire livestock grazing, reducing conifers, and preventing nonnative plant invasions [243,638]. A review by Finch et al. [255]

suggests that managers could facilitate adaptation to climate change by maintaining landscape connectivity to ensure that species can disperse from unsuitable sites to colonize more suitable sites. Long-term strategies for dealing with climate change impacts on big sagebrush ecosystems include identifying areas that can maintain sagebrush communities in the future, limiting anthropogenic development in these areas, and promoting sagebrush expansion into other communities at the leading edge of climate-driven shifts in big sagebrush distribution [255].

MANAGEMENT CONSIDERATIONS

SPECIES: Artemisia tridentata subsp. wyomingensis

Figure 15—Pygmy rabbit tracks through a Wyoming big sagebrush stand at the Seedskadee National Wildlife Refuge, Wyoming. Photo courtesy of U.S. Fish and Wildlife Service.

FEDERAL LEGAL STATUS:
None

OTHER LEGAL STATUS:
None. Information on state- and province-level protection status of plants in the United States and Canada is available at NatureServe.

IMPORTANCE TO WILDLIFE AND LIVESTOCK:

Overview: Sagebrush are keystone plants [47,844]. Many wildlife species depend on big sagebrush communities for food and cover, including birds, small and large mammals, reptiles, amphibians, and insects [67,687,791,855]. Of these, several are sagebrush obligates, including sage-grouse, sage thrasher, sage sparrow, Brewer's sparrow, pygmy rabbit, and sagebrush vole [785]. Paige [554] also consider pronghorn and sagebrush lizards to be obligates in sagebrush ecosystems of the Great Basin. About 60 reptile and amphibian species, including Great Basin spadefoot, live in big sagebrush ecosystems as do about 90 bird species, 80 small mammal species, and several large mammal species [785]. Important predators in sagebrush communities include red fox, coyote, bobcat, American badger, weasels, and birds of prey such as great horned owl, red-tailed hawk, golden eagle, and ferruginous hawk (e.g., [61,74,159,174,804]. Numerous insects and other arthropods, including aphids, beetles, moths, crickets, grasshoppers, katydids, cicadas, thrips, ants, and spiders occur in big sagebrush ecosystems [723,788].

Wyoming big sagebrush is a crucial food item of sage-grouse, and Wyoming big sagebrush communities are critical habitat for them (e.g., [149,257,606,732,800]). Wyoming big sagebrush is commonly browsed by mammals, especially black-tailed jackrabbits, pygmy rabbits [844], mule deer, and pronghorn (e.g., [100,567,671,796]). Wyoming big sagebrush communities are important ungulate winter ranges (e.g., [325,671,732,762,772]). On the northern Yellowstone winter range, big sagebrush comprised 49%, 23%, and 4% of pronghorn, mule deer, and elk diets, respectively. Pronghorn and mule deer occurred most commonly on low-elevation Wyoming big sagebrush sites, while elk were equally common on low-elevation Wyoming big sagebrush sites and high-elevation mountain big sagebrush sites [671]. Cover and food value of Wyoming big sagebrush for several classes and species of wildlife are discussed in Considerations for Wildlife Management.

Cattle, domestic sheep, domestic goats, and feral horses and burros use big sagebrush communities [785,855]. Some Wyoming big sagebrush communities, such as Wyoming big sagebrush/Sandburg bluegrass communities in Idaho in the 8-inch (200-mm) precipitation zone, have only limited use for livestock grazing due to low forage productivity and inability to support deep-rooted perennial bunchgrasses. Wyoming big sagebrush communities receiving greater annual precipitation, such as Wyoming big sagebrush/bluebunch wheatgrass communities in the 7- to 12-inch (180- to 300-mm) precipitation zone, may be important spring-fall range for livestock and winter range for wild ungulates [325].

Because of its importance as forage and cover for wildlife, several researchers developed methods for estimating Wyoming big sagebrush forage (and fuel) production using plant crown measurements [211,618,673,759]. For example, Wambolt et al. [759] modeled annual winter forage production of Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush in areas of high and low ungulate use in southwestern Montana.

See table A2 for links to available FEIS Species Reviews on animals mentioned in this section.

Palatability: The palatability of big sagebrush depends on the animal species and varies by season, big sagebrush infrataxa, and local big sagebrush populations and individuals [789]. Various wildlife species consume all parts of big sagebrush, including the leaves, stems, pollen, seeds, and roots [791]. Wyoming big sagebrush is considered palatable to most wildlife browsers [625]. Its palatability to livestock varies by species. Domestic sheep may eat big sagebrush extensively, especially in winter and during drought [304]. Wyoming big sagebrush generally has low palatability for cattle [541,785], although cattle may learn to eat it, and it can become a substantial part of their fall diet [579]. Domestic goats browsed Wyoming big sagebrush very little on a Utah summer range [615], and results of a summer study at the Northern Great Basin Experimental Range suggested that domestic goats had little potential for controlling of Wyoming big sagebrush because they ate very little of it [248].

The characteristic aroma of big sagebrush is from volatile oils in the leaves (e.g., terpenoids and coumarins) that serve as a chemical-defense mechanism to limit herbivory [844] and protect against rapid temperature changes and water loss (Adams and Billinghurst 1927, cited in [655]). Sagebrush taxa differ in their concentrations of these compounds. For example, in Gardiner, Montana, crude terpenoid concentrations were lowest in mountain big sagebrush, intermediate in Wyoming big sagebrush and black sagebrush, and greatest in basin big sagebrush [694]. Total monoterpenoids of plants collected from 20 locations and grown in common gardens varied from 0.93% to 1.41% dry-matter content for Wyoming big sagebrush, 0.95% to 1.91% for basin big sagebrush, and 1.02% to 2.95% for mountain big sagebrush plants [793].

The role of terpenoids in determining palatability among sagebrush taxa or local populations of the same taxon is unclear [797]. Some studies concluded that these compounds determine browse preferences (e.g., [533,577,655]), while others concluded they are unimportant or less important than other factors (e.g., [151,641,796,816]). For a review of studies on big sagebrush plant chemistry, see Welch [783]. For a review of studies on big sagebrush plant chemistry on the northern Yellowstone winter range, see Wambolt [762].

Palatability of sagebrush species to sage-grouse varies within and among taxa, with Wyoming big sagebrush among the most palatable [625]. In south-central Idaho, greater sage-grouse selected black sagebrush communities over Wyoming big sagebrush communities, likely because black sagebrush had lower plant secondary metabolite concentrations [275]. In a common garden study in Utah, Welch et al. [800] found that greater sage-grouse preferred mountain big sagebrush over both Wyoming big sagebrush and basin big sagebrush, but the birds shifted to the less preferred subspecies when leaves and buds of mountain big sagebrush became limited. In contrast, in North Park, Colorado, greater sage-grouse feeding sites contained more Wyoming big sagebrush and less mountain big sagebrush than random sites ($P < 0.05$ for both comparisons). Wyoming big sagebrush leaves contained more crude protein and lower levels of monoterpenes than mountain big sagebrush plants [606].

All sagebrush taxa are potentially valuable forage; however, wild ungulates often show a preference among taxa [763,783]. Among the three major big sagebrush subspecies, mule deer and elk often have the highest preference for mountain big sagebrush and moderate to low preference for Wyoming big sagebrush and basin big sagebrush (e.g., [100,577,641,654,655,761,763,769,796,797]), while pronghorn prefer Wyoming big sagebrush [281,671]. Ungulate preference varies among Wyoming big sagebrush populations and years [763,796]. For example, preference by mule deer differed between two sites in Beaverhead County, Montana, over 10 years. At one site, mule deer preferred gray low sagebrush (an average of 36% of leaders were consumed each year) and mountain big sagebrush (34%) over Wyoming big sagebrush (11%) and basin big sagebrush (7%), but at another site mule deer preference was similar among mountain big sagebrush (32%), tall threetip sagebrush (32%), and Wyoming big sagebrush (29%). Utilization of Wyoming big sagebrush leaders ranged from 3% to 26% at the first site and 10% to 52% at the second site during the 10 years [763]. Welch [783] provides additional information about ungulate preferences among sagebrush taxa.

Sage-grouse, voles, and ungulates browse Wyoming big sagebrush primarily in winter, when it is more palatable than most other available vegetation [172,232,723,785]. Wyoming big sagebrush may be more available than mountain big sagebrush in winter due to shallower snowpack on Wyoming big sagebrush sites [181,286,671,762] (see Climate). For this reason, Wyoming big sagebrush is often severely browsed [671]. For example, elk, mule deer, and pronghorn on the northern Yellowstone winter range browsed in Wyoming big sagebrush sites at low elevation (an average of 87% of leaders browsed) 8 times more than in mountain big sagebrush sites at high elevation (11%); in part because Wyoming big sagebrush plants were more available above the snow at low-elevation sites [671]. Wambolt and Sherwood [772] stated that low-elevation Wyoming big sagebrush sites on the northern Yellowstone winter range "offer the best winter foraging opportunities for ungulates" because of shallow snow.

Figure 16—Wyoming big sagebrush stems emerges above the snow at the Seedskadee National Wildlife Refuge. Photo by Tom Koerner, U.S. Fish and Wildlife Service.

Nutritional Value: Big sagebrush is nutritious forage for many wildlife species, although nutritional content changes seasonally [783] and may vary among subspecies (e.g., [764,799]) and local populations (e.g., [799]). Nutritional value generally does not decline substantially as plants age [194,385,583]. While Wambolt [764] found no difference between young and old mountain big sagebrush and basin big sagebrush plants, young Wyoming big sagebrush plants contained more crude protein (12.45%) than old plants (11.25%). The authors concluded, however, that there was "no meaningful difference for herbivores" between young and old Wyoming big sagebrush plants [764].

Big sagebrush protein content and digestibility are typically higher than other available plants in winter. They are lower than most associated plants in spring, when big sagebrush is not browsed as much [762,782]. A review of studies on the chemistry of Wyoming big sagebrush, mountain big sagebrush, and basin big sagebrush provides data on seasonal variation in crude protein and in vitro digestibility and suggests that big sagebrush in general contains enough protein to meet the maintenance, gestation, growth, and lactation requirements of domestic sheep and cattle year-round; maintenance and gestation of horses; maintenance, gestation, and lactation of mule deer; and maintenance of birds. Winter crude protein content levels of big sagebrush seeds may meet the breeding and growing requirements of birds. In vitro digestibility of big sagebrush ranges from 54% in winter to 59% in summer and fall. All are above the maintenance and gestation requirements of most animals, but do not meet lactation needs [782]. For more information on big sagebrush nutrition, see Welch [782].

Big sagebrush subspecies may differ in nutritional value [764,783,799]. For example, on the Gallatin National Forest, Montana, midwinter crude protein of Wyoming big sagebrush (11.25%) and basin big sagebrush (11.29%) were more than that of mountain big sagebrush (8.34%) ($P < 0.05$) [764]. All were above the maintenance requirements of mule deer (7.5%) [779,782]. In a common garden, digestible dry matter was greater in basin big sagebrush (62.1%) than both Wyoming big sagebrush (51.4%) and mountain big sagebrush (53.2%) [799].

Cover Value: Some Wyoming big sagebrush stands provide good cover for many wildlife species, although stands with small, scattered Wyoming big sagebrush plants may provide little cover, especially for large animals [210]. Many sagebrush obligate birds, such as sage-grouse [99,496], sage sparrow [473], and sage thrasher [473], use Wyoming big sagebrush communities for cover. Wyoming big sagebrush communities provide important cover for many small mammals, including mice, shrews, voles, kangaroo rats, chipmunks, ground squirrels, rabbits, and hares [388,778,785]. Wyoming big sagebrush cover is reduced by burning [497] (see Plant Response to Fire). Cover and food value of big sagebrush for wildlife are discussed in further detail in Considerations for Wildlife Management.

Herbivory: Wyoming big sagebrush has low tolerance to browsing [274]. Singer and Renkin [671] stated that the ability of Wyoming big sagebrush to recover from herbivory is less than that of mountain big sagebrush and basin big sagebrush because Wyoming big sagebrush tends to be shorter, have slower seedling growth rates, and accumulate less annual growth.

Heavy browsing of big sagebrush can reduce density, cover, height, seed production, and recruitment (e.g., [272,328,474,671,768,787]) and even kill big sagebrush plants [723,762]), especially where big sagebrush densities are low (<1.5 plants/100 feet²) [272]. The percent of dead crown in live Wyoming big sagebrush, basin big sagebrush, and mountain big plants increases in proportion to the overall amount of browsing received. For example, at two study sites near Gardiner, Montana, the percent of dead crown on live plants of Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush following heavy elk and mule deer browsing from 1982 to 1992 was 45%, 30%, and 59%, respectively [761]. Dead stemwood is common in old plants [110] (see Botanical Description).

- *Wildlife browsing*
    - *Small mammals*
    - *Wild ungulates*
    - *Insects*
- *Livestock grazing*

Wildlife browsing
Small mammals: In winter, long-tailed voles, mountain voles, and meadow voles eat the cambium layer of big sagebrush stems buried in the snow [14,271,783]. When vole populations are large, browsing can kill or cause extensive damage to big sagebrush plants [271,528,783], especially where snow is deep [271,528]. Although extensive damage to sagebrush by voles is probably most common in mountain big sagebrush communities that accumulate deep snow [243], it may also occur in Wyoming big sagebrush communities [6]. While Evers [243] did not include vole damage in the modeled successional rate for warm, dry Wyoming big sagebrush communities where shallow snow is typical, she included it in the modeled successional rate for cool, moist mountain big sagebrush communities where deep and persistent snow is frequent. An assumed 4- to 5-year population outbreak cycle meant that during 100 years, 23% of the years would have vole populations large enough to thin mountain big sagebrush stands [243].

Because black-tailed jackrabbits eat the seedlings of most plant species in sagebrush communities, Barbour et al. [25] hypothesized that when black-tailed jackrabbit population density is high, seedling recruitment of big sagebrush and other plant species could be eliminated (e.g., [455]). In southeastern Idaho, years with high black-tailed jackrabbit populations often corresponded with years of low big sagebrush establishment [153].

Black-tailed prairie dogs may reduce Wyoming big sagebrush biomass and cover at colonized sites [369]. In eastern Montana, sites colonized by black-tailed prairie dogs averaged less aboveground biomass of Wyoming big sagebrush (0.9 pound/acre (1 kg/ha)) than uncolonized sites (187 pounds/acre (210 kg/ha); $P < 0.001$) during 2 years, and average Wyoming big sagebrush cover on colonized sites (0.1%) was less than that on uncolonized sites (7%; $P < 0.001$). Wyoming big sagebrush had not recovered on a site 50 years after a black-tailed prairie dog colony was poisoned, suggesting a long recovery period following Wyoming big sagebrush removal by black-tailed prairie dogs [369].

Wild ungulates: Heavy wild ungulate browsing decreases Wyoming big sagebrush cover, density, and production [289,474,671,672,761,772,787]. Declines in Wyoming big sagebrush cover associated with heavy, long-term mule deer, elk, and pronghorn browsing on the northern Yellowstone winter range are described by many researchers (e.g., [328,474,671,762,767,772]) (see Postfire herbivory). Wyoming big sagebrush decline (i.e., slow growth, low seed production, shoot dieback, and occasional death) on Taylor Flat in Daggett County, Utah, was attributed to overbrowsing by mule deer [537]. In addition to directly eliminating sagebrush, fire concentrates ungulate browsing on burns [762] (see Considerations for Wildlife Management).

Insects: Insects such as *Aroga* moths (e.g., [280,785]), grasshoppers [4,292,311], a leaf-feeding beetle (*Trirhabda pilosa*) [708], and sagebrush webworm [678] damage and kill big sagebrush plants, and insect herbivory reduces Wyoming big sagebrush flower and seed production [708]. Outbreaks of *Aroga* moths may cause high mortality of big sagebrush plants. For example, they caused nearly 100% mortality of mountain big sagebrush plants in a stand in the Great Basin [491]. However, *Aroga* moth populations are heavily parasitized during peak periods and usually decline abruptly after 1 or 2 years at peak level. The sagebrush stands then gradually recover [785]. In 2013, Evers et al. [242] stated that very little information was available on *Aroga* moth outbreak frequency, size, and severity. Their models of Wyoming big sagebrush postfire successional rates in southeastern Oregon suggested that *Aroga* moth outbreaks may have played a much greater role than fire and drought in Wyoming big sagebrush dynamics prior to 1850 by either affecting larger areas or by occurring more frequently. However, pronghorn browsing appeared to play an even bigger role than *Aroga* moth outbreaks [243].

Many species of grasshoppers consume large quantities of big sagebrush and may kill Wyoming big sagebrush plants [311,788]. For example, in field plantings in eastern Montana, grasshoppers caused "considerable" mortality of Wyoming big sagebrush seedlings [311]. Welch [788] listed 12 species of grasshoppers that eat big sagebrush plants. Some species prefer big sagebrush, while others are generalists [788]. Decreased sagebrush cover and increased annual grass cover resulting from wildfires or other causes may lead to greater grasshopper densities, lower grasshopper diversity, and a greater proportion of grasshoppers with a generalist diet [252,253,788]. In sagebrush-bunchgrass types (Wyoming big sagebrush, basin big sagebrush, mountain big sagebrush, low sagebrush, alkali sagebrush, and threetip sagebrush) in southern Idaho, areas severely disturbed by wildfires and nonnative annual grasses had greater grasshopper densities for 3 years than less severely disturbed areas that retained some sagebrush cover [252]. For further information on insect use of big sagebrush, see Welch [788].

Livestock grazing: Impacts of livestock grazing on big sagebrush stands can be positive, negative, or neutral to big sagebrush communities, depending on livestock class, timing, severity, duration of grazing, and vegetation composition of the community [49,67,172,723,789,791]. Wyoming big sagebrush communities have a lower capacity to support livestock grazing because they have lower production, ground cover, shrub cover, and diversity in species and structure than the other major big sagebrush subspecies [288]. Many reviews of the effects of livestock grazing on big sagebrush communities are available (e.g., [49,67,172,723]).

When big sagebrush communities are heavily grazed by livestock, herbaceous plant abundance tends to decrease and big sagebrush density and cover tend to increase because most of the herbaceous species are more palatable to livestock than big sagebrush, especially during the growing season [49,172,232,643,723]. While Wyoming big sagebrush sites that have been heavily grazed may become relatively dense (>20% Wyoming big sagebrush cover) and have depleted understories [495,827], the response of Wyoming big sagebrush to the exclusion of livestock following periods of heavy livestock grazing varies. Some studies show increases in Wyoming big sagebrush cover after grazing exclusion (e.g., [5,97,640]), while others show decreases (e.g., [770]) or no change (e.g., [186,848]).

Overgrazing by livestock during the late 1800s and early 1900s, coupled with severe drought triggered a rapid change in sagebrush plant communities, resulted in reduced cover and density of native herbaceous plants. However, overgrazing alone is not sufficient to explain vegetation changes throughout the sagebrush region since that time [496,503].

Beginning in the 1930s and peaking in the 1950s and 1960s, land management agencies reduced sagebrush cover over large areas. Prescribed fire, herbicides, mechanical methods, and grass plantings were used to convert sagebrush types to grasslands for seasonal grazing by livestock [133,453,518]. Planting efforts included seeding with nonnative grasses, primarily crested wheatgrass, which affected approximately 6.4 million acres (2.6 million ha) of sagebrush lands by the 1970s [398]. As of 2017, federal resource managers in some regions continued to use prescribed fire and other methods to reduce big sagebrush cover and increase herbaceous plant production for livestock and wildlife (e.g., [310,585,658,753]). However, prescribed burning on some federal lands had been curtailed due to concern over additional widespread losses of big sagebrush communities from wildfire, nonnative plant proliferation, and other causes [121,540,679,685]. Past management has had legacy effects on the composition and diversity of sagebrush steppe plant communities, and many sites have not recovered [532,616]. Livestock grazing and associated habitat alterations have had the most widespread impact on sagebrush rangelands of any land use [398].

Livestock grazing often exacerbates impacts from invasive annual grasses such as cheatgrass [833]; however, cheatgrass abundance may also be reduced by uniformly heavy spring grazing. It is highly palatable to cattle in spring, and appropriately timed grazing reduces seed production [351,854]. In some cases, light to moderate grazing may indirectly prevent cheatgrass invasion of Wyoming big sagebrush sites by reducing litter accumulation and associated fire risk, which could kill desirable vegetation from fire [190], while intensive grazing can reduce the abundance and continuity of cheatgrass fine fuels [201] (see Considerations for Fuels). However, heavy spring grazing may increase cheatgrass abundance by weakening native cool-season perennial grasses [854]. For more information, see the FEIS Species Review of cheatgrass.

Biological soil crusts are an important component of the nutrient cycle in sagebrush ecosystems because they include nitrogen-fixing microbiota, sequester many nutrients—including phosphorus and potassium—and increase soil carbon storage. Livestock grazing disturbs biological soil crusts [55]. For example, in a Wyoming big sagebrush community in east-central Idaho, biological soil crust cover inside an 8-year-old exclosure was about twice that outside the exclosure [374]; however, biological soil crust cover was greater inside only one of nine 30- to 45-year old exclosures in Wyoming big sagebrush communities in Wyoming. These results were attributed to low Wyoming big sagebrush cover in most exclosures at the time of their construction and to varied grazing use outside of exclosures since [531]. Once disturbed, soil crust recovery rates are slow [55]. As a result, contemporary nutrient cycling in sagebrush systems is probably substantially different from that historically, with greater leaching of nutrients from current systems [739]. Where crust communities are well established in sagebrush ecosystems, they help prevent the establishment and spread of nonnative annual grasses [109,142,605,739]; consequently, they reduce the likelihood and slow the spread of wildfire [56].

The introduction of livestock grazing during the late 1800s may also have contributed to woodland expansion in big sagebrush communities. However, a direct relationship between livestock grazing and woodland expansion is difficult to substantiate because the role of fire must also be accounted for, and fire characteristics prior to livestock introduction are poorly understood. Patterns of woodland expansion into sagebrush steppe are not apparently related to grazed/ungrazed fenceline contrasts or distance to water, which are often observed with livestock grazing [496].

VALUE FOR RESTORATION OF DISTURBED SITES:

Wyoming big sagebrush is used for stabilizing slopes and gullies and for restoring degraded wildlife habitat, rangelands, mine spoils, and other disturbed sites [227,462,653,665,690]. According to Finch et al. [254], it was the predominant taxon seeded following wildland fires in sage-grouse habitats as of 2015. Wyoming big sagebrush cultivars, such as 'Gordon Creek', were developed for use in restoration projects and on wild ungulate and sage-grouse winter ranges due to their palatability and nutritional value [798]. Wyoming big sagebrush × silver sagebrush hybrids were produced in hopes of maintaining sprouting shrubs on areas where cheatgrass has established a grass/fire cycle [783].

Wyoming big sagebrush is easily propagated from seeds under greenhouse, nursery, and common garden conditions [311,431] and has been successfully seeded directly into field sites, although results vary [653]. It has been planted in field sites using nursery-grown and wilding bareroot and containerized stock, often with high survival (e.g., [214,311,431,667,686,789,796]). Wyoming big sagebrush can be propagated from stems cuttings. In a greenhouse, 6% of stem cuttings rooted in 17 weeks [311]. Plantings may be more successful than seedings [202]. For example, Herriman [316] reported that outplanting survival of nursery-grown Wyoming big sagebrush seedlings is nearly double survival rates of seedlings resulting from direct seeding. In addition, plantings reach reproductive maturity and produce seeds more quickly than plants established from seeds (NRCS 1999, cited in [223]), although once mature, seed-derived plants may produce more seeds than containerized plants [780]. Wyoming big sagebrush plants may act as nurse plants for native perennial bunchgrasses and thereby aid in site restoration (e.g., [88,182,341,348]). However, because of the relatively high cost of producing and planting Wyoming big sagebrush plants, this approach usually is used to create small islands of sagebrush on a site, with the expectation that they will expand through self-seeding (NRCS 1999, cited in [223]). Conserving any existing Wyoming big sagebrush plants during postfire restoration or rehabilitation efforts is recommended [88].

Successful establishment of Wyoming big sagebrush after artificial seeding in areas with low precipitation, such as Wyoming big sagebrush/Sandberg bluegrass communities receiving <8 inches (200 mm) of annual precipitation, may be low and is likely to occur only in years with above-average precipitation [325]. Wet weather [188,510,645] (see Moisture availability), low cover of other vegetation [230,403,514,563,645,665,750,822] (see Interference and competition), and minimal browsing [557] increase Wyoming big sagebrush seedling establishment after seeding and outplanting. Using direct-placed topsoil with arbuscular mycorrhizal inoculum [645] and adding mycorrhizal fungi spores to the root zone of transplants [214,509] may help seedlings establish on dry sites (see Vesicular-arbuscular mycorrhizal fungi).

Seeding methods that distribute big sagebrush seeds on or near the soil surface result in the highest germination [437,514,789]. Seeding is recommended in fall and winter, at about the same time that seeds naturally disperse [410,482,690,789]. Seeding big sagebrush onto snow over disturbed soil has been successful at some sites [514,690]; however, on warm, dry sites snow cover may be inadequate to ensure successful Wyoming big sagebrush establishment and emergence [437,552], especially in large burns where soil surfaces dry rapidly [690]. Methods that entrap snow on the site until the time of seed germination in spring may increase seedling establishment [519,690].

Big sagebrush seeds are adapted to their climates of origin. Nonadapted seeds may germinate at inappropriate times, and seedlings may fail to emerge or persist [93,483] (see Germination). Thus, it is important to match seeds and plant collections to sites similar to where they were collected [93,484,514,789]. Mahalovich and McArthur [441] stated that when determining a seed mix, it is more important to match a species to its native environment than to choose a subspecies or cultivar based on wildlife or livestock preference. They recommended that seeds or plants not be moved farther than 300 miles (480 km) from the place of origin to the planting site [441].

Recommendations for planting and seeding Wyoming big sagebrush and other big sagebrush subspecies, including rates, timing, and seed bed preparation, are available (e.g., [80,358,410,437,514,519,552,652,690,789]).

OTHER USES:
Sagebrush is valued for its antifungal, antimicrobial, analgesic, and anesthetic properties in traditional herbal medicine [664,752]. American Indians use big sagebrush for many purposes. They use big sagebrush leaves and branches for medicinal teas [343,556] and as a "smudge" plant in cleansing rituals [664]. The seeds can be eaten [296,527]; the bark woven into ropes, mats, baskets, bags, and clothing [343,556]; and the plants used for fuel [346,664], bedding, and shelter [343,784].

Big sagebrush was little used by European-American settlers. They occasionally used the branches for thatching [751]. The wood produces a very hot fire, and was used in mine smelters [527]. Big sagebrush has little current commercial use. It is sometimes used for xeriscaping [321,527].

OTHER MANAGEMENT CONSIDERATIONS:

- **Changes in Land Cover**
- **Nonnative Invasive Plants**
- **Woodland Expansion**
- **Climate Change**

Changes in Land Cover: The land area historically occupied by sagebrush communities has been reduced and altered by the cumulative and interacting effects of altered fire regimes; livestock grazing and associated land management; proliferation of nonnative plants, particularly annual grasses; woodland expansion; climate changes; development for agriculture and energy; urbanization and infrastructure development, such as roads and powerlines; water extraction; and reservoir development [67,98,160,306,398,496,503,518,787]; however, few studies have compared historical and contemporary Wyoming big sagebrush distributions quantitatively. Miller et al. [496] estimated that only 55% of the area delineated on Kuchler's [406] maps as potentially dominated by sagebrush was occupied by sagebrush in 2011. In an assessment of the area encompassing the Interior Columbia Basin and portions of the Klamath Basin and Great Basin, Hann et al. [306] estimated that dry shrub communities, which included big sagebrush (Wyoming big sagebrush and basin big sagebrush), low sagebrush, threetip sagebrush, antelope bitterbrush, and salt desert shrub communities, occupied about 30% of the area from 1850 to 1900 and about 21% of the area from 1900 to 1997—a reduction of about 30%. Changes in area occupied by big sagebrush communities varied among the Ecological Reporting Units, and ranged from a 0.2% increase in the Central Idaho Mountains to a 41.8% reduction in the Upper Snake (table 7). Reductions were greatest at elevations below 3,900 feet (1,200 m), largely due to conversion to croplands, haylands, or pastures [306]. Bunting et al. [119] considered warm, dry Wyoming big sagebrush sites in the Columbia Basin the most highly altered of 17 rangeland vegetation types due to past livestock grazing, nonnative invasive species, and increased occurrence of fire [119].

Table 7—Comparison of the distribution of Wyoming big sagebrush and basin big sagebrush communities in the Interior Columbia Basin and portions of the Klamath Basin and Great Basin between two time periods. Asterisks indicate a significant difference in mean cover between time periods ($P < 0.05$) [306].

Ecological Reporting Unit	Area occupied from 1850-1900 (%)			Mean area occupied from 1900-1997 (%)	Change in area occupied (%)
	Minimum	Maximum	Mean		
Blue Mountains	6.79	8.55	8.55	6.79	-1.77*
Central Idaho Mountains	4.51	5.15	4.51	4.72	0.20
Columbia Plateau	27.43	39.6	39.6	21.30	-18.30*
Northern Cascades	3.31	3.61	3.38	0.68	-2.70*
Northern Glaciated Mountains	2.99	3.34	3.34	0.06	-3.28*
Northern Great Basin	37.57	61.04	61.04	58.71	-2.32*
Owyhee Uplands	31.03	52.03	52.03	41.20	-10.83
Snake Headwaters	6.89	7.72	7.72	0.08	-7.64*
Southern Cascades	2.55	4.67	4.67	1.35	-3.32*
Upper Clark Fork	0.02	0.14	0.02	0.02	≤0.01
Upper Klamath	1.05	1.39	1.39	1.39	0
Upper Snake	47.47	72.81	72.81	31.0	-41.81*
Total	16.36	24.54	24.54	16.43	-8.11*

Much of the area occupied by Wyoming big sagebrush communities is at risk of conversion to nonnative annual grassland or conifer woodland. About a third of the land formerly occupied by sagebrush communities has converted to other land cover types, including nonnative grasslands, nonsagebrush shrublands, and juniper woodlands [496]. Additional areas of big sagebrush are under threat of conversion. Of the 20.4 million acres (8.3 million ha) of sagebrush in the Central Basin and Range ecoregion present in 2005, 58% was estimated to be at moderate or high risk of displacement by cheatgrass by 2035. In 12.0 million acres (4.8 million ha) of sagebrush in the eastern Central Basin and Range, 41% was estimated at moderate or high risk of pinyon-juniper expansion by 2035. Wyoming big sagebrush-basin big sagebrush communities comprised 63% of the total sagebrush area in the Central Basin and Range and 72% was at moderate to high risk of displacement by cheatgrass. They comprised 59% of the total sagebrush area in the eastern Central Basin and Range, and 35% of this area was at moderate to high risk of pinyon-juniper expansion. When both threats are considered together, almost 90% of the total area occupied by sagebrush communities in the eastern Central Basin and Range, including 95% of the area occupied by Wyoming big sagebrush-basin big sagebrush communities, was estimated to be at moderate or high risk of displacement by cheatgrass or pinyon-juniper expansion by 2035 [702]. Climate change scenarios predict that Wyoming big sagebrush communities may decrease in extent if such changes result in either a grass/fire cycle that prevents sagebrush populations from reestablishing [243,712] or in conifer expansion [243] (see Climate Change).

Nonnative Invasive Plants: Because Wyoming big sagebrush communities occur on warm, dry sites, they are highly susceptible to nonnative plant invasions [142,143] (table 6, fig. 8). While many nonnative plant species have replaced native species in Wyoming big sagebrush communities, invasive annual grasses—particularly cheatgrass, but also medusahead and ventenata—are considered the most problematic in sagebrush ecosystems because they alter fuel characteristics on invaded sites and can lengthen the fire season and increase the frequency, size, spread rate, and duration of wildfires [9,22,158,397,428,496,559] (see Considerations for Nonnative Invasive Plants). Large areas of big sagebrush—especially Wyoming big sagebrush and basin big sagebrush—have converted to cheatgrass grasslands as a consequence of frequent wildfires [22,180,400,702]. Nonnative forbs are also a concern in many sagebrush communities. As of 2015, nonnative perennial forbs such as Russian knapweed, squarrose knapweed, Dalmatian toadflax, and Canada thistle were becoming increasingly harmful to sagebrush communities [9]. Analyses in 2011 (table 8) [496] and 1997 [306] considered Wyoming big sagebrush and basin big sagebrush communities highly susceptible to cheatgrass, Dyer's woad, and Mediterranean sage invasion. In 2015, cheatgrass cover was high (≥15%) across 31% of the Great Basin, and was particularly prevalent in the Snake River Plain and eastern Washington (fig. 17) [96]. Nonnative annual forbs, such as tall tumblemustard, may also be harmful to sagebrush communities by displacing native perennials [495,861].

Table 8—Susceptibility of upland community types to nonnative plant establishment and spread. Susceptibility is ranked as H=high, M=moderate, L=low, and U=unknown (compiled by [496]). Community types with Wyoming big sagebrush, basin big sagebrush, and threetip sagebrush are highlighted in yellow as are nonnative plant species ranked as high in these communities. For more information on fire effects on these nonnative plant species, see the FEIS Species Reviews and Miller et al. [493].

Nonnative plant species	Wyoming big sagebrush, basin big sagebrush, and threetip sagebrush	Mountain big sagebrush	Low sagebrush and black sagebrush	Salt desert shrub	Crested wheatgrass and other bunchgrasses
bull thistle	M	M	M	M	H
Canada thistle	M	M	M	M	H
cheatgrass	H	M	M	M	H
common crupina	L	M	L	L	M
Dalmatian toadflax	M	H	M	L	H
diffuse knapweed	M	M	M	L	H
Dyer's woad	H	L	H	L	H
halogeton	M	M	M	H	M
heart-podded hoary cress	M	M	M	M	M
leafy spurge	M	L	M	M	M
meadow hawkweed	L	L	L	L	L
Mediterranean sage	H	M	U	L	H
medusahead	M	M	L	M	M
musk thistle	U	M	U	M	M

orange hawkweed	L	M	L	L	L
oxeye daisy	U	U	U	L	M
perennial pepperweed	L	L	L	L	L
poison hemlock	L	L	L	L	L
purple loosestrife	L	M	L	L	L
rush skeletonweed	M	M	U	L	M
Russian knapweed	M	M	U	M	M
Russian-thistle	M	M	L	M	M
Scotch cottonthistle	M	L	U	L	M
sowthistles	M	M	M	M	M
spotted knapweed	M	M	U	L	H
squarrose knapweed	M	M	M	M	M
sulfur cinquefoil	U	M	U	L	H
tansy ragwort	U	U	U	U	U
yellow starthistle	M	M	M	L	H
yellow toadflax	M	M	U	L	M

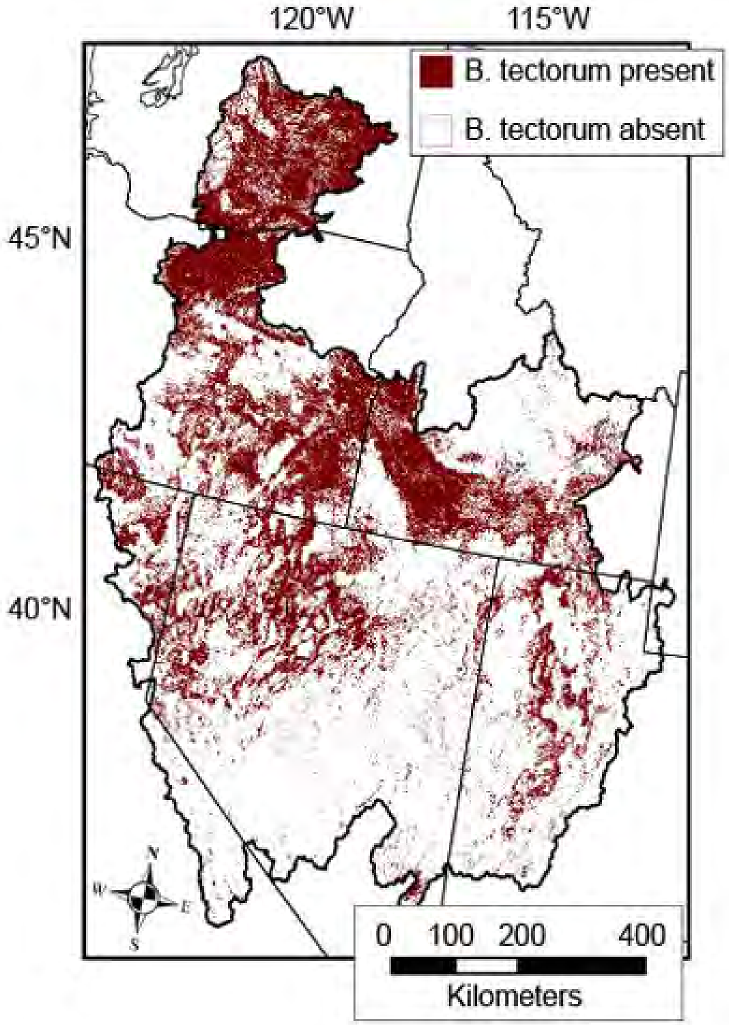


Figure 17—Cheatgrass presence in parts of the Great Basin and Columbia Plateau as of 2015. Image courtesy of Bethany Bradley.

Woodland Expansion: Even prior to European-American settlement in the mid- to late 1800s, juniper and pinyon-juniper communities were dynamic, expanding and contracting throughout the Holocene (last ~10,000 years) due largely to changing climate and fire patterns [228,490,506]. Historically, junipers and pinyons spread into nearby big sagebrush communities (primarily on cool to warm, relatively moist sagebrush sites [142,493]) when climate was suitable and the interval between fires was long enough for seedlings to establish and trees to mature [496]. All pinyons and most junipers are killed by fire. Pinyons are intolerant of fire at all life stages, while the probability of western juniper trees being killed by fire decreases for trees >50 years old on high-productivity sites and >90 years old on low-productivity sites [117,125,496,499].

Since European-American settlement, density of junipers and pinyons has increased in many sagebrush and woodland communities [493,505,623,857], while it has not changed or has declined in others [623]. A study that compared LANDFIRE Biophysical Settings and Existing Vegetation Type data for five subregions found that the area covered by pinyon-juniper communities has increased the most in the Great Basin and Semi Desert subregions, minimally in the Southern Greater Yellowstone subregion, and not at all in the Middle Rockies subregion. Pinyon-juniper communities have also increased, but to a lesser extent, in the Plateaus and the Uinta and Wasatch Front subregions [305]. Other sources suggest that juniper expansion is not common in the Middle Rockies and Wyoming Basin ecoregions (Williams 2014, personal communication in [413,414]).

The greatest proportion of conifer expansion has occurred on cool to warm, relatively moist sagebrush sites (table 6). These sites include mountain big sagebrush communities and low sagebrush communities on moderately deep soils as well as Wyoming big sagebrush and black sagebrush communities at the moister ends of their distribution [142,493]. Hann et al. [306] ranked plant communities from most to least susceptible to western juniper expansion as follows: mountain big sagebrush, basin big sagebrush, low sagebrush, quaking aspen, antelope bitterbrush, mountain-mahogany, Idaho fescue, ponderosa pine, bluebunch wheatgrass, stiff sagebrush, Wyoming big sagebrush, basin wildrye, and threetip sagebrush. Since the late 1800s, western juniper expansion has primarily been into mountain big sagebrush communities rather than into drier Wyoming big sagebrush communities [228,506].

The probability of woodlands replacing sagebrush communities increases on productive sites with fire-free intervals >50 years and nearby conifer seed sources [496]. Because of the availability of conifer seed sources, most expansion occurs close to pinyon-juniper-sagebrush ecotones [10]. In southern and central Utah, the pinyon-juniper-sagebrush ecotone occurred in a zone of 9 to 15 inches (240-370 mm) average annual precipitation, where communities with Wyoming big sagebrush, mountain big sagebrush, and/or their hybrids overlap with Utah juniper, twoneedle pinyon, and singleleaf pinyon communities [288].

In areas where conifer expansion into big sagebrush communities has occurred, the peak rate of expansion occurred in the late 1800s and early 1900s (e.g., [490,505,857]). For example, in northeastern California the oldest western juniper tree in a Wyoming big sagebrush site established in 1855, and 90% of western junipers established from 1890 to 1920 [857]. In seven study areas in Idaho, Oregon, Nevada, and Utah, the area occupied by singleleaf pinyon, western juniper, or Utah juniper increased by 125% to 625% from 1860 to 2001. Woodland expansion was not synchronous; it began at a similar time in Oregon, Utah, and Nevada, but 20 to 30 years earlier in Idaho [505].

Some authors attribute pinyon-juniper expansion since European-American settlement to the effects of a wet, mild climate in the late 1800s coincident with less frequent fire (e.g., [124,125,504]), while other authors debate the role of less frequent fire in explaining conifer expansion (e.g., [116,228]). Miller et al. [504] suggested that postsettlement western juniper expansion during the late 1880s and early 1900s was driven by mild temperatures and above-average precipitation that promoted conifer establishment and growth and decreased fire frequency, which allowed western junipers to mature and dominate a site. Decreased fire frequency was attributed to the reduction in burning by American Indians and the removal of fine fuels by heavy livestock grazing [504]. Burkhardt and Tisdale [124,125] examined several possible causes of and contributing factors to succession of sagebrush-grasslands to western juniper woodlands, and concluded that expansion was directly related to the combined effects of changes in climate and reduced fire frequency and spread due to fire exclusion, reduced fine fuels due to livestock grazing, and fragmentation of sagebrush communities due to development. Bukowski and Baker [116] stated that fire regimes in sagebrush communities are primarily controlled by weather or climate, and concluded that estimated fire rotations in Wyoming big sagebrush and mountain big sagebrush communities in four areas of Idaho, Nevada, Oregon, and Wyoming were generally too long for fire to be the only factor preventing conifers from establishing. In a review, Eddleman et al. [228] stated that the effects of fire suppression were insufficient to explain western juniper expansion until after World War II, when suppression efforts became more effective. Other interacting factors, including recovery from past disturbances, carbon dioxide fertilization, and overgrazing by livestock may have also contributed [228,623].

Pinyon-juniper density and cover have not changed or have declined in many areas of the West (e.g., [10,101,446,623]). Romme et al. [623] cautioned that "one cannot necessarily assume that pinyon and juniper are increasing in density in any particular portion of their range without local data". At Dinosaur National Monument and the surrounding area, a comparison of historical vegetation reconstructed using General Land Office survey records from 1910 and contemporary records (1981–2000) showed a net decline in pinyon-juniper woodlands and mixed montane shrublands and an increase in sagebrush ecosystems (Wyoming big sagebrush-basin big sagebrush steppe and shrubland and mountain big sagebrush steppe). However, some pinyon-juniper expansion was evident near historical pinyon-juniper-sagebrush ecotones, particularly at 6,600 to 7,900 feet (2,000-2,400 m) and on 10% to 30% slopes [10].

Potential consequences of increasing tree dominance in sagebrush communities include:

1. increases in the size of tree crowns and continuity of tree crown fuels and decreases in surface fuel abundance, density, and continuity that increase the potential for crown fires burning under severe fire weather;
2. changes in plant community composition and structure, including reduced cover of sagebrush, native grasses, and forbs;
3. an increase in aboveground carbon and nutrient pools; and
4. a reduction in water infiltration and an increase in soil erosion [44,187,297,493,504,581,584,803].

These changes result in plant communities that are less resilient to fire and other disturbances and less resistant to nonnative annual grass establishment and spread after fire [493].

Climate Change: Climate change models for the sagebrush biome predict increasing temperatures, increasing atmospheric carbon dioxide, more frequent severe weather (droughts and storms), and variable changes in the timing, frequency, and intensity of precipitation events [34,137,496,535,598]. Uncertainty in predictions for precipitation and in the physiological response of sagebrush to the effects of climate changes make projecting the effect of climate change on sagebrush distribution difficult [598].

A review of paleobotanical studies showed that big sagebrush communities have been resilient to historical climate changes in many locations throughout the West [787]. This suggests that these communities may be resilient to future climate changes, in the absence of changes not present historically (e.g., nonnative plant invasions). However, projected impacts of climate change on sagebrush are varied. Many projections predict widespread shifts in sagebrush by the end of the century, with some locations becoming less suitable for sagebrush and others becoming more suitable (e.g., [95,175,496,535,598,608,637,638,692]). Many studies indicate that the distribution of big sagebrush is likely to recede in the south and from low elevations and move northward and higher in elevation in response to warmer winter temperatures and summer drought associated with climate change (e.g., [95,243,395,535,608,637,692,712]). In addition, sagebrush communities are expected to become increasingly fragmented and threatened by nonnative grasses (e.g., [175,269,445,555,608,629,637,868]). Predicted climate changes are likely to favor the establishment and spread of cheatgrass [91,479,496,629] and thus contribute to the grass/fire cycle, which includes more frequent fire. A warming climate also has the potential to increase the frequency of insect outbreaks and alter population dynamics of diseases and pathogens, which could alter vegetation composition in sagebrush communities [255,629].

Alteration of precipitation patterns, especially in total precipitation and in precipitation timing, may cause major distributional shifts in Wyoming big sagebrush communities in the future [34,243,521,712]. Big sagebrush is most extensive in portions of the West where winter precipitation equals or exceeds summer precipitation (Dahl et al. 1976, cited in [751]) because winter precipitation favors deep-rooted species such as big sagebrush over more shallow-rooted grasses and forbs by enhancing water recharge in the lower part of the soil profile [34]. Big sagebrush is less extensive where winter precipitation is less than summer precipitation [372,401] (see Climate). Thus, changes in the relative amount of winter and summer precipitation may have a large impact on the long-term stability of Wyoming big sagebrush communities. In the future, warmer and drier summers may result in increased area covered by Wyoming big sagebrush communities, while warmer and wetter summers may result in decreased area covered by these communities [243,642,712], but model results depend on the amount of precipitation decrease and the resultant ratio of summer relative to winter precipitation [692]. For example, one study suggested that Wyoming big sagebrush and basin big sagebrush are predicted to expand their range primarily to the north and in higher elevations (increasing their range ~13%-22% of their current range) by the end of the 21st century under modeled climates that included warmer winter temperatures and slightly drier summers. Range increases are projected under all modeled future climate conditions—despite range contraction occurring along the southern extent of their current range—largely because Wyoming big sagebrush and basin big sagebrush can retreat into upper foothills and montane zones. The author stated that while Wyoming big sagebrush ecosystems "may be potentially robust to future climate change", they demonstrate a greater risk to cheatgrass invasion, which "could challenge long-term stability of sagebrush ecosystems" if it results in a grass/fire cycle that prevents sagebrush populations from reestablishing [712].

Models of three potential future climate scenarios in southeastern Oregon, predicted either increases or decreases in area occupied by Wyoming big sagebrush communities. The first model had warmer and drier conditions year-round with slightly more precipitation falling in spring and summer. The second model had a warmer and wetter conditions in winter and most precipitation falling in winter and spring. The third model had warmer and wetter conditions in summer with most precipitation falling in spring and summer. The first two models predicted an increase in the area covered by warm, dry Wyoming big sagebrush communities and an upward shift in elevation by these communities into mountain big sagebrush communities. Under these scenarios, suitability of climate to cheatgrass would increase, making Wyoming big sagebrush communities more vulnerable to displacement by cheatgrass if fires became frequent enough to prevent Wyoming big sagebrush establishment. The third model predicted that warm, dry Wyoming big sagebrush communities would contract and western junipers expand. Under this scenario, climate would disfavor cheatgrass, resulting in contraction in the area covered by cheatgrass and reduced vulnerability of sagebrush communities to cheatgrass invasion but increased vulnerability to juniper expansion [243]. A study that modeled climates with warmer and drier conditions year-round and a higher ratio of summer relative to winter precipitation predicted a 39% reduction in the area covered by Wyoming big sagebrush communities in 9 ecoregions of the western United States by 2050. Regions predicted to decrease in areas covered by Wyoming big sagebrush communities included the southern periphery of the subspecies' range, the western Great Plains, and low elevations of the Columbia Basin and Great Basin. Regions predicted to maintain or increase in area covered by Wyoming big sagebrush communities included western Wyoming, eastern Idaho, and high elevations in the Great Basin and the northern Great Plains [692].

Changes in shrub overstory composition, which are predicted by climate change models that include changes in precipitation patterns, may take decades to materialize [445]. A field experiment near Burns, Oregon, investigated the effects of altered timing of precipitation on a Wyoming big sagebrush-bunchgrass community in the northern Great Basin over 7 years. It showed that untreated plots where seasonal precipitation was winter-dominated (i.e., 60% of the total water came during October to April, 30% came from May to July, and the remaining 10% came from August to September) had less bare ground and more herbaceous biomass, cover, and density than treated plots where seasonal precipitation was spring/summer-dominated (i.e., 22% of the total water was applied from October to April, and 78% applied from May to July). However, cover and density of Wyoming big sagebrush was not affected by the short-term treatment. Because the changes in herbaceous plant productivity did not begin until the fourth posttreatment year and Wyoming big sagebrush productivity was not affected, the authors concluded that these communities were resilient to short-term shifts in precipitation timing [34].

Wyoming big sagebrush seedling survival and growth may be reduced by predicted climate warming. An experimental warming study at the Morley Nelson Snake River Birds of Prey National Conservation Area found lower Wyoming big sagebrush seedling survival and shorter seedlings on warmed plots than on untreated plots, indicating that warmer winters in the future could result in lower Wyoming big sagebrush survival and slower growth rates [92].

Several authors stated that polyploidy and inter- and intraspecific hybridization in big sagebrush is likely to help big sagebrush taxa adapt to climate changes [92,458,465]. Incorporation of hybridization into bioclimatic models where subspecies occur along ecotones could affect modeling results [692]. However, hybridization had not been included in such models as of 2019.

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APPENDICES:

Table A1: Plant species mentioned in this review

For further information on fire ecology of these taxa, follow the highlighted links to FEIS Species Reviews. Nonnative species are indicated with an asterisk (*).

Common name	Scientific name
Cacti	
plains pricklypear	*Opuntia polyacantha*
Forbs	
arrowleaf balsamroot	*Balsamorhiza sagittata*
bull thistle*	*Cirsium vulgare*
Canada thistle*	*Cirsium arvense*
common crupina*	*Crupina vulgaris*
Dalmatian toadflax*	*Linaria dalmatica*

diffuse knapweed*	*Centaurea diffusa*
Dyer's woad*	*Isatis tinctoria*
fleabane	*Erigeron* spp.
globemallow	*Sphaeralcea* spp.
halogeton*	*Halogeton glomeratus*
hawksbeard	*Crepis* spp.
heart-podded hoary cress*	*Cardaria draba*
leafy spurge*	*Euphorbia esula*
lupine	*Lupinus* spp.
meadow hawkweed*	*Hieracium caespitosum*
Mediterranean sage*	*Salvia aethiopis*
milkvetch	*Astragalus* spp.
musk thistle*	*Carduus nutans*
orange hawkweed*	*Hieracium aurantiacum*
oxeye daisy*	*Leucanthemum vulgare*
perennial pepperweed*	*Lepidium latifolium*
phlox	*Phlox* spp.
poison hemlock*	*Conium maculatum*
purple loosestrife*	*Lythrum salicaria*
pussytoes	*Antennaria* spp.
rush skeletonweed*	*Chondrilla juncea*
Russian knapweed*	*Acroptilon repens*
Russian-thistle*	*Salsola kali*
Scotch cottonthistle*	*Onopordum acanthium*
slender phlox	*Microsteris gracilis*
sowthistle	*Sonchus* spp.
spotted knapweed*	*Centaurea stoebe* subsp. *micranthos*
squarrose knapweed*	*Centaurea virgata*
sulfur cinquefoil*	*Potentilla recta*
tansy ragwort*	*Senecio jacobaea*
tall tumblemustard*	*Sisymbrium altissimum*
yellow starthistle*	*Centaurea solstitialis*
yellow toadflax*	*Linaria vulgaris*
Graminoids	
basin wildrye	*Leymus cinereus*
bluebunch wheatgrass	*Pseudoroegneria spicata*
blue grama	*Bouteloua gracilis*
cheatgrass*	*Bromus tectorum*
Columbia needlegrass	*Achnatherum nelsonii*
crested wheatgrass*	*Agropyron cristatum*
desert needlegrass	*Achnatherum speciosum*
desert wheatgrass*	*Agropyron desertorum*
Idaho fescue	*Festuca idahoensis*

Indian ricegrass	*Achnatherum hymenoides*
James' galleta	*Pleuraphis jamesii*
medusahead*	*Taeniatherum caput-medusae*
needle and thread	*Hesperostipa comata*
Sandberg bluegrass	*Poa secunda*
squirreltail	*Elymus elymoides*
thickspike wheatgrass	*Elymus lanceolatus*
Thurber needlegrass	*Achnatherum thurberianum*
ventenata*	*Ventenata dubia*
western wheatgrass	*Pascopyrum smithii*
Shrubs	
antelope bitterbrush	*Purshia tridentata*
big sagebrush Bonneville big sagebrush Mojave big sagebrush snowfield big sagebrush basin big sagebrush mountain big sagebrush Wyoming big sagebrush xeric big sagebrush	*Artemisia tridentata* *Artemisia tridentata* subsp. × *bonnevillensis* *Artemisia tridentata* subsp. *parishii* *Artemisia tridentata* subsp. *spiciformis* *Artemisia tridentata* subsp. *tridentata* *Artemisia tridentata* subsp. *vaseyana* *Artemisia tridentata* subsp. *wyomingensis*, this review *Artemisia tridentata* subsp. *xericensis*
black greasewood	*Sarcobatus vermiculatus*
black sagebrush	*Artemisia nova*
broom snakeweed	*Gutierrezia sarothrae*
forage kochia*	*Bassia prostrata*
fourwing saltbush	*Atriplex canescens*
fringed sagebrush	*Artemisia frigida*
Gardner's saltbush	*Atriplex gardneri*
green rabbitbrush	*Ericameria teretifolia*
low sagebrush alkali sagebrush gray low sagebrush Lahontan sagebrush	*Artemisia arbuscula* *Artemisia arbuscula* subsp. *longiloba* *Artemisia arbuscula* subsp. *arbuscula* *Artemisia arbuscula* subsp. *longicaulis*
rubber rabbitbrush	*Ericameria nauseosa*
sagebrush	*Artemisia* spp.
serviceberry	*Amelanchier* spp.
shadscale saltbush	*Atriplex confertifolia*
silver sagebrush plains silver sagebrush	*Artemisia cana* *Artemisia cana* subsp. *cana*
snowberry	*Symphoricarpos* spp.
spiny hopsage	*Grayia spinosa*
stiff sagebrush	*Artemisia rigida*
threetip sagebrush tall threetip sagebrush	*Artemisia tripartita* *Artemisia tripartita* subsp. *tripartita*
winterfat	*Krascheninnikovia lanata*
yellow rabbitbrush	*Chrysothamnus viscidiflorus*
Trees	

California juniper	*Juniperus californica*
curlleaf mountain-mahogany	*Cercocarpus ledifolius*
juniper	*Juniperus* spp.
mountain-mahogany	*Cercocarpus* spp.
oneseed juniper	*Juniperus monosperma*
pinyon	*Pinus* spp.
ponderosa pine Columbian ponderosa pine Rocky Mountain ponderosa pine	*Pinus ponderosa* *Pinus ponderosa* var. *ponderosa* *Pinus ponderosa* var. *scopulorum*
quaking aspen	*Populus tremuloides*
Rocky Mountain juniper	*Juniperus scopulorum*
singleleaf pinyon	*Pinus monophylla*
twoneedle pinyon	*Pinus edulis*
Utah juniper	*Juniperus osteosperma*
western juniper	*Juniperus occidentalis*

Table A2: Links to available FEIS Species Reviews on animals mentioned in this review

For further information on fire ecology of these species, follow the highlighted links to FEIS Species Reviews.

Amphibians	
Great Basin spadefoot	*Spea intermontana*
Birds	
ferruginous hawk	*Buteo regalis*
golden eagle	*Aquila chrysaetos*
greater sage-grouse	*Centrocercus urophasianus*
great horned owl	*Bubo virginianus*
Gunnison sage-grouse	*Centrocercus minimus*
pinyon jay	*Gymnorhinus cyanocephalus*
red-tailed hawk	*Buteo jamaicensis*
Mammals	
American badger	*Taxidea taxus*
bighorn sheep	*Ovis canadensis*
black-tailed jackrabbit	*Lepus californicus*
black-tailed prairie dog	*Cynomys ludovicianus*
bobcat	*Lynx rufus*
coyote	*Canis latrans*
elk	*Cervus elaphus*
Great Basin pocket mouse	*Perognathus mollipilosus*
North American deermouse	*Peromyscus maniculatus*
pronghorn	*Antilocapra americana*
pygmy rabbit	*Brachylagus idahoensis*
red fox	*Vulpes vulpes*

Townsend's ground squirrel	*Urocitellus townsendii*

REFERENCES:

1. Alldredge, A. William; Deblinger, Robert D.; Peterson, Jan. 1991. Birth and fawn bed site selection by pronghorns in a sagebrush-steppe community. The Journal of Wildlife Management. 55(2): 222-227. [15468]

2. Allen, Elizabeth A. 2006. Seed banks of pinyon-juniper woodlands: The effects of tree cover and prescribed burn. Reno, NV: University of Nevada, Reno. 77 p. Thesis. [91181]

3. Allen, Elizabeth A.; Chambers, Jeanne C.; Nowak, Robert S. 2008. Effects of a spring prescribed burn on the soil seed bank in sagebrush steppe exhibiting pinyon-juniper expansion. Western North American Naturalist. 68(3): 265-277. [75588]

4. Allred, B. W. 1941. Grasshoppers and their effect on sagebrush on the Little Power River in Wyoming and Montana. Ecology. 22(4): 387-392. [91049]

5. Anderson, Jay E.; Holte, Karl E. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in southeastern Idaho. Journal of Range Management. 34(1): 25-29. [319]

6. Anderson, Jay E.; Inouye, Richard S. 2001. Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. Ecological Monographs. 71(4): 531-556. [39482]

7. Anderson, Jay E.; Shumar, Mark L. 1986. Impacts of black-tailed jackrabbits at peak population densities on sagebrush vegetation. Journal of Range Management. 39(2): 152-155. [322]

8. Anderson, Loren. 1994. Chapter VII - terrestrial wildlife and habitat. In: Miller, Melanie, ed. Fire effects guide. PMS 481/NFES 2394. Boise, ID: National Wildfire Coordinating Group, Prescribed Fire and Fire Effects Working Team: 1-16. [69984]

9. Anderson, Pete; Boyd, Chad; Chambers, Jeanne; Christiansen, Tom; Davis, Dawn; Espinosa, Shawn; Havlina, Doug; Hopkins, Todd; Ielmini, Michael; Kemner, Don; Kurth, Laurie; Maestas, Jeremy; Mealor, Brian; Mayer, Kenneth; Pellant, Mike; Pyke, David; Tague, Joe; Vernon, Jason. 2015. Invasive plant management and greater sage-grouse conservation: A review and status report with strategic recommendations for improvement. Cheyenne, WY: Western Association of Fish & Wildlife Agencies. 47 p. [89478]

10. Arendt, Paul A. 2012. GLO surveys show change over the past century in a semiarid landscape in the area of Dinosaur National Monument, Colorado/Utah. Laramie, WY: University of Wyoming. 67 p. Thesis. [90821]

11. Arkle, Robert S.; Pilliod, David S.; Hanser, Steven E.; Brooks, Matthew L.; Chambers, Jeanne C.; Grace, James B.; Knutson, Kevin C.; Pyke, David A.; Welty, Justin L.; Wirth, Troy A. 2014. Quantifying restoration effectiveness using multi-scale habitat models: Implications for sage-grouse in the Great Basin. Ecosphere. 5(3): 1-32. [90060]

12. Asay, K. H.; Horton, W. H.; Jensen, K. B.; Palazzo, A. J. 2001. Merits of native and introduced Triticeae grasses on semiarid rangelands. Canadian Journal of Plant Science. 81(1): 45-52. [43354]

13. Asher, Jerry; Dewey, Steven; Olivarez, Jim; Johnson, Curt. 1998. Minimizing weed spread following wildland fires. In: Christianson, Kathy, ed. Western Society of Weed Science: Proceedings; 1998 March 10-12; Waikoloa, HI. In: Proceedings, Western Society of Weed Science. 51: 49. Abstract. [40409]

14. Astroth, Kirk A.; Frischknecht, Neil C. 1984. Managing Intermountain rangelands--research on the Benmore Experimental Range, 1940-84. Gen. Tech, Rep. INT-175. Ogden, UT: U.S. Department of

Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 44 p. [361]

15. Autenrieth, Robert E. 1981. Sage grouse management in Idaho. Wildlife Bulletin No. 9. Federal Aid in Wildlife Restoration: Project W-125-R & W-160-R. Boise, ID: Idaho Department of Fish and Game. 238 p. [40588]

16. Autenrieth, Robert. 1976. A study of birth sites selected by pronghorn does and the bed sites of fawns. In: Autenrieth, Robert, comp. Proceedings, 7th pronghorn antelope workshop; 1976 February 24-26; Twin Falls, ID. Boise, ID: Idaho Department of Fish and Game: 127-134. [25418]

17. Bai, Yuguang; Booth, D. Terrance; Roos, Eric E. 1997. Effect of seed moisture on Wyoming big sagebrush seed quality. Journal of Range Management. 50(4): 419-422. [92621]

18. Baker, William L. 2002. Indians and fire in the Rocky Mountains: The wilderness hypothesis renewed. In: Vale, Thomas R., ed. Fire, native peoples, and the natural landscape. Washington: Island Press: 41-76. [88508]

19. Baker, William L. 2006. Fire and restoration of sagebrush ecosystems. Wildlife Society Bulletin. 34(1): 177-185. [66367]

20. Baker, William L. 2011. Pre-Euro-American and recent fire in sagebrush ecosystems. In: Knick, Stephen T.; Connelly, John W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology No. 38. Berkeley, CA: University of California Press: 185-201. [86464]

21. Baker, William L.; Kennedy, Susan C. 1985. Presettlement vegetation of part of northwestern Moffat County, Colorado, described from remnants. The Great Basin Naturalist. 45(4): 747-783. [384]

22. Balch, Jennifer K.; Bradley, Bethany A.; D'Antonio, Carla M.; Gomez-Dans, Jose. 2013. Introduced annual grass increases regional fire activity across the arid western USA (1980-2009). Global Change Biology. 19(1): 173-183. [86928]

23. Baldwin, Bruce G.; Goldman, Douglas H.; Keil, David J.; Patterson, Robert; Rosatti, Thomas J.; Wilken, Dieter H., eds. 2012. The Jepson manual. Vascular plants of California, second edition. Berkeley, CA: University of California Press. 1568 p. [86254]

24. Bansal, Sheel; Sheley, Roger L. 2016. Annual grass invasion in sagebrush steppe: The relative importance of climate, soil properties and biotic interactions. Oecologia. 181(2): 543-557. [90652]

25. Barbour, Michael G.; Keeler-Wolf, Todd; Schoenherr, Allan A., eds. 2007. Terrestrial vegetation of California, 3rd ed. Berkeley, CA: University of California Press. 712 p. [82605]

26. Barga, Sarah; Leger, Elizabeth A. 2018. Shrub cover and fire history predict seed bank composition in Great Basin shrublands. Journal of Arid Environments. 154: 40-50. [92915]

27. Barker, Jerry R.; McKell, Cyrus M. 1983. Habitat differences between basin and Wyoming big sagebrush in contiguous populations. Journal of Range Management. 36(4): 450-454. [8100]

28. Barker, Jerry R.; McKell, Cyrus M. 1986. Differences in big sagebrush (Artemisia tridentata) plant stature along soil-water gradients: Genetic components. Journal of Range Management. 39(2): 147-151. [389]

29. Barney, Milo A.; Frischknecht, Neil C. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management. 27(2): 91-96. [397]

30. Barrington, Mac; Bunting, Steve; Wright, Gerald. 1988. A fire management plan for Craters of the Moon National Monument. Draft. Subagreement No. 5 to Cooperative Agreement CA-9000-8-0005. Moscow, ID: University of Idaho, Range Resources Department. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 52 p. [1687]

31. Bartolome, James W.; Heady, Harold F. 1978. Ages of big sagebrush following brush control. Journal of Range Management. 31(6): 403-406. [201]

32. Baruch-Mordo, Sharon; Evans, Jeffrey S.; Severson, John P.; Naugle, David E.; Maestas, Jeremy D.; Kiesecker, Joseph M.; Falkowski, Michael J.; Hagen, Christian A.; Reese, Kerry P. 2013. Saving sage-grouse from the trees: A proactive solution to reducing a key threat to a candidate species. Biological Conservation. 167: 233-241. [90144]

33. Baskin, Yvonne. 1999. Yellowstone fires: A decade later. Bioscience. 49(2): 93-97. [29468]

34. Bates, J. D.; Svejcar, T.; Miller, R. F.; Angell, R. A. 2006. The effects of precipitation timing on sagebrush steppe vegetation. Journal of Arid Environments. 64(4): 670-697. [60054]

35. Bates, J.; Davies, K.; Miller, R. 2004. Response of Wyoming big sagebrush communities to wildfire. 45-62. In: Ecology of the Wyoming big sagebrush alliance in the northern Great Basin: 2004 Progress Report. Burns, OR: Eastern Oregon Agricultural Research Center. [93037]

36. Bates, Jon D.; Davies, Kirk W.; Sharp, Rob N. 2008. Response of Wyoming big sagebrush communities to wildfire. In: Davies, Kirk W.; Nafus, Alet M., comps. Sagebrush steppe--Research Progress Report 2007. ARS Publication EOARC. Burns, OR: U.S. Department of Agriculture, Agricultural Research Service: 10-21. Available online: http://sagemap.wr.usgs.gov/Docs/Davies%20Sage%20Steppe_ProRep07.pdf. [86223]

37. Bates, Jon D.; Rhodes, Ed; Davies, Kirk; Sharp, Rob. 2008. Grazing after fire in the sagebrush-steppe. In: Bates, Jon; Bingham, Brett; Bohnert, David; Boyd, Chad; [and others]. Range field day 2008 progress report. Special report 1085. Corvalis, OR: Department of Oregon State University Department of Rangeland Ecology and Management; Burns, OR: USDA, Agricultural Research Service, Eastern Oregon Agricultural Research Center, U.S. Department of Agriculture: 9-23. [88645]

38. Bates, Jon D.; Rhodes, Edward C.; Davies, Kirk. 2011. The impacts of fire on sage-grouse habitat and diet resources. Natural Resources and Environmental Issues. 17(15): 111-127. [86086]

39. Bates, Jonathan D.; Davies, Kirk W. 2014. Cattle grazing and vegetation succession on burned sagebrush steppe. Rangeland Ecology and Management. 67(4): 412-422. [89450]

40. Bates, Jonathan D.; Davies, Kirk W.; Hulet, April; Miller, Richard F.; Roundy, Bruce. 2017. Sage grouse groceries: Forb response to pinyon-juniper treatments. Rangeland Ecology and Management. 70(1): 106-115. [91592]

41. Bates, Jonathan D.; Davis, Kirk W.; Sharp, Robert N. 2011. Shrub-steppe early succession following juniper cutting and prescribed fire. Environmental Management. 47(3): 468-481. [84612]

42. Bates, Jonathan D.; O'Connor, Rory; Davies, Kirk W. 2014. Vegetation recovery and fuel reduction after seasonal burning of western juniper. Fire Ecology. 10(3): 27-48. [89615]

43. Bates, Jonathan D.; Rhodes, Edward C.; Davies, Kirk W.; Sharp, Robert. 2009. Postfire succession in big sagebrush steppe with livestock grazing. Rangeland Ecology & Management. 62: 98-110. [73474]

44. Bates, Jonathan D.; Sharp, Robert N.; Davies, Kirk W. 2014. Sagebrush steppe recovery after fire varies by development phase of Juniperus occidentalis woodland. International Journal of Wildland Fire. 23(1): 117-130. [87793]

45. Beardall, Louis E.; Sylvester, Vern E. 1976. Spring burning for removal of sagebrush competition in Nevada. In: Proceedings, Tall Timbers fire ecology conference: Fire and land management symposium; 1974 October 8-10; Missoula, MT. No. 14. Tallahassee, FL: Tall Timbers Research Station: 539-547. [406]

46. Beck, Jeffrey L.; Connelly, John W.; Reese, Kerry P. 2009. Recovery of greater sage-grouse habitat features in Wyoming big sagebrush following prescribed fire. Restoration Ecology. 17(3): 393-403. [81602]

47. Beck, Jeffrey L.; Connelly, John W.; Wambolt Carl L. 2012. Consequences of treating Wyoming big sagebrush to enhance wildlife habitats. Rangeland Ecology and Management. 65(5): 444-455. [90068]

48. Beck, Jeffrey L.; Klein, J. Garrett; Wright, Justin; Wolfley, Kenneth P. 2011. Potential and pitfalls of prescribed burning big sagebrush habitat to enhance nesting and early brood-rearing habitats for greater sage-grouse. In: Wambolt, Carl L.; Kitchen, Stanley G.; Frisina, Michael R.; Sowell, Bok; Keigley, Richard B.; Palacios, Patsy; Robinson, Jill, comps. Proceedings--shrublands: Wildlands and wildlife habitats; 15th wildland shrub symposium; 2008 June 17-19; Bozeman, MT. Natural Resources and Environmental Issues, Volume XVI. Logan, UT: Utah State University, College of Natural Resources, S. J. and Jessie E. Quinney Natural Resources Research Library: 27-32. [83465]

49. Beck, Jeffrey L.; Mitchell, Dean L. 2000. Influences of livestock grazing on sage grouse habitat. Wildlife Society Bulletin. 28(4): 993-1002. [90146]

50. Beckstead, Julie; Augspurger, Carol K. 2004. An experimental test of resistance to cheatgrass invasion: Limiting resources at different life stages. Biological Invasions. 6(4): 417-432. [91651]

51. Beckstead, Julie; Street, Laura E.; Meyer, Susan E.; Allen, Phil S. 2011. Fire effects on the cheatgrass seed bank pathogen Pyrenophora semeniperda. Rangeland Ecology & Management. 64(2): 148-157. [91159]

52. Beetle, A. A. 1960. A study of sagebrush: The section Tridentatae of Artemisia. Bulletin 368. Laramie, WY: University of Wyoming, Agricultural Experiment Station. 83 p. [416]

53. Beetle, Alan A.; Johnson, Kendall L. 1982. Sagebrush in Wyoming. Bull. 779. Laramie, WY: University of Wyoming, Agricultural Experiment Station. 68 p. [421]

54. Beetle, Alan A.; Young, Alvin. 1965. A third subspecies in the Artemisia tridentata complex. Rhodora. 67: 405-406. [422]

55. Belnap, Jayne; Kaltenecker, Julie Hilty; Rosentreter, Roger; Williams, John; Leonard, Steve; Eldridge, David. 2001. Biological soil crusts: Ecology and management. Technical Reference 1730-2. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Information and Communications Group. 110 p. [40277]

56. Belnap, Jayne; Williams, John; Kaltenecker, Julie. 1999. Structure and function of biological soil crusts. In: Meurisse, Robert T.; Ypsilantis, William G.; Seybold, Cathy, tech. eds. Proceedings: Pacific Northwest forest and rangeland soil organism symposium; 1998 March 17-19; Corvallis, OR. Gen. Tech. Rep. PNW-GTR-461. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 161-178. [38449]

57. Bendell, J. F. 1974. Effects of fire on birds and mammals. In: Kozlowski, T. T.; Ahlgren, C. E., eds. Fire and ecosystems. New York: Academic Press: 73-138. [16447]

58. Benkobi, Lakhdar; Uresk, Daniel W. 1996. Seral stage classification and monitoring model for big sagebrush/western wheatgrass/blue grama habitat. In: Barrow, Jerry R.; McArthur, E. Durant; Sosebee, Ronald E.; Tausch, Robin J., comps. Proceedings: Shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 69-73. [27033]

59. Benkobi, Lakhdar; Uresk, Daniel W.; Child, R. Dennis. 2007. Ecological classification and monitoring model for the Wyoming big sagebrush shrubsteppe habitat type of northeastern Wyoming. Western North American Naturalist. 67(3): 347-358. [92986]

60. Benson, Lee A.; Braun, Clait E.; Leininger, Wayne C. 1991. Sage grouse response to burning in the big sagebrush type. In: Davis, P.; Rush, S.; Todd, J., eds.; Comer, Robert D., contributor. Issues and technology in the management of impacted wildlife: Proceedings of a national symposium; 1991 April 8-10; Snowmass Resort, CO. Boulder, CO: Thorne Ecological Institute: 97-104. [21766]

61. Best, Troy L. 1996. Lepus californicus. Mammalian Species. 530: 1-10. [93122]

62. Bethlenfalvay, Gabor J.; Dakessian, Suren. 1984. Grazing effects on mycorrhizal colonization and floristic composition of the vegetation on a semiarid range in northern Nevada. Journal of Range Management. 37(4): 312-316. [439]

63. Beyers, Jan L. 2004. Postfire seeding for erosion control: Effectiveness and impacts on native plant communities. Conservation Biology. 18(4): 947-956. [50079]

64. Billings, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 22-30. [24248]

65. Blackburn, W. H.; Beall, R.; Bruner, A.; Klebenow, D.; Mason, R.; Roundy, B.; Stager, W.; Ward, K. 1975. Controlled fire as a management tool in the pinyon-juniper woodland, Nevada. Annual Progress Report FY 1975. Unpublished report on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 77 p. [453]

66. Blaisdell, James P. 1953. Ecological effects of planned burning of sagebrush-grass range on the upper Snake River Plains. Tech. Bull. 1975. Washington, DC: U.S. Department of Agriculture. 39 p. [462]

67. Blaisdell, James P.; Murray, Robert B.; McArthur, E. Durant. 1982. Managing Intermountain rangelands--sagebrush-grass ranges. Gen. Tech. Rep. INT-134. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 41 p. [467]

68. Blank, R. R.; Chambers, J.; Roundy, B.; Whittaker, A. 2007. Nutrient availability in rangeland soils: Influence of prescribed burning, herbaceous vegetation removal, overseeding with Bromus tectorum, season, and elevation. Rangeland Ecology & Management. 60(6): 644-655. [74042]

69. Blank, Robert R.; Allen, Fay; Young, James A. 1994. Extractable anions in soils following wildfire in a sagebrush-grass community. Soil Science Society of America Journal. 58(2): 564-570. [43173]

70. Blank, Robert R.; Allen, Fay; Young, James A. 1994. Growth and elemental content of several sagebrush-steppe species in unburned and post-wildfire soil and plant effects on soil attributes. Plant and Soil. 164(1): 35-41. [26887]

71. Block, W. M.; Conner, L. M.; Brewer, P. A.; Ford, P.; Haufler, J.; Litt, A.; Masters, R. E.; Mitchell; L. R.; Park, J. 2016. Effects of prescribed fire on wildlife and wildlife habitat in selected ecosystems of North America. The Wildlife Society, Technical Review 16-01. Bethesda, MD: The Wildlife Society. 69 p. [92801]

72. Bloom-Cornelius, Ilana V. 2011. Vegetation response to fire and domestic and native ungulate herbivory in a Wyoming big sagebrush ecosystem. Stillwater, OK: Oklahoma State University. 60 p. Thesis. [92985]

73. Bock, Carl E.; Bock, Jane H. 1987. Avian habitat occupancy following fire in a Montana shrubsteppe. Prairie Naturalist. 19(3): 153-158. [2806]

74. Bodie, Walter L. 1979. Factors affecting pronghorn fawn mortality in central Idaho. Missoula, MT: University of Montana. 90 p. Thesis. [93070]

75. Boltz, Mike. 1994. Factors influencing postfire sagebrush regeneration in south-central Idaho. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 281-290. [24298]

76. Boltz, Mike; Jones, Chuck; Green, Galen; Johansen, Jim. 1987. Jarbidge Resource Area: normal year fire rehab plan; greenstripping plan; sagebrush management plan. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office. 179 p. [483]

77. Bombaci, Sara P.; Gallo, Travis; Pejchar, Liba. 2017. Small-scale woodland reduction practices have neutral or negative short-term effects on birds and small mammals. Rangeland Ecology and Management.

70(3): 363-373. [93171]

78. Bombaci, Sara; Pejchar, Liba. 2016. Consequences of pinyon and juniper woodland reduction for wildlife in North America. Forest Ecology and Management. 365: 34-50. [90393]

79. Bonham, C. D.; Cottrell, T. R.; Mitchell, J. E. 1991. Inferences for life history strategies of Artemisia tridentata subspecies. Journal of Vegetation Science. 2(3): 339-344. [16599]

80. Booth, D. T.; Bai, Y. 2000. Seeds and seedling establishment of Wyoming big sagebrush. In: Schuman, Gerald E.; Richmond, Timothy C.; Neuman, Dennis R., eds. Sagebrush establishment on mined lands: Ecology and research: Proceedings of symposium; 2000 March 20; Billings, MT. [Part of the 2000 Billings land reclamation symposium; 2000 March 20-24; Billings, MT]. Bozeman, MT: Montana State University, Reclamation Research Unit: 24-31. [42419]

81. Booth, D. T.; Bai, Y.; Roos, E. E. 2004. Cultural methods for enhancing Wyoming big sagebrush seed production. In: Hild, Ann L.; Shaw, Nancy L.; Meyer, Susan E.; Booth, D. Terrance; McArthur, E. Durant, comps. Seed and soil dynamics in shrubland ecosystems: Proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 95-99. [49101]

82. Booth, D. Terrance. 2002. Seed longevity and seedling strategies affect sagebrush revegetation. Journal of Range Management. 55(2): 188-193. [41661]

83. Booth, D. Terrance; Bai, Yuguang; Roose, Eric E. 1997. Preparing sagebrush seed for market: Effects of debearder processing. Journal of Range Management. 50(1): 51-54. [92620]

84. Booth, Gordon D.; Welch, Bruce L.; Jacobson, Tracy L. C. 1990. Seedling growth rate of 3 subspecies of big sagebrush. Journal of Range Management. 43(5): 432-436. [11005]

85. Booth, Mary S.; Caldwell, Martyn M.; Stark, John M. 2003. Overlapping resource use in three Great Basin species: Implications for community invasibility and vegetation dynamics. Journal of Ecology. 91: 36-48. [44061]

86. Bourne, Andrea; Bunting, Stephen C. 2011. Guide for quantifying post-treatment fuels in the sagebrush steppe and juniper woodlands of the Great Basin. Tech. Note 437. Denver, CO: U.S. Department of the Interior, Bureau of Land Management. 115 p. [88012]

87. Bowman, Tiffanny R. Sharp; McMillan, Brock R.; St. Clair, Samuel B. 2017. A comparison of the effects of fire on rodent abundance and diversity in the Great Basin and Mojave Deserts. PLoS ONE. 12(11): e0187740. [92741]

88. Boyd, C. S.; Davies, K. W. 2012. Differential seedling performance and environmental correlates in shrub canopy vs. interspace microsites. Journal of Arid Environments. 87: 50-57. [86372]

89. Boyd, Chad S.; Davies, Kirk W. 2010. Shrub microsite influences post-fire perennial grass establishment. Rangeland Ecology & Management. 63(2): 248-252. [82388]

90. Boyer, Donald E.; Dell, John D. 1980. Fire effects on Pacific Northwest forest soils. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Watershed Management and Aviation and Fire Management. 59 p. [5282]

91. Boyte, Stephen P.; Wylie, Bruce K.; Major, Donald J. 2016. Cheatgrass percent cover change: Comparing recent estimates to climate change-driven predictions in the Northern Great Basin. Society for Range Management. 69(4): 265-279. [90820]

92. Brabec, Martha M. 2014. Big sagebrush (Artemisia tridentata) in a shifting climate context: Assessment of seedling responses to climate. Boise, ID: Boise State University. 116 p. Thesis. [88557]

93. Brabec, Martha M.; Germino, Matthew J.; Richardson, Bryce A. 2017. Climate adaption and post-fire restoration of a foundational perennial in cold desert: Insights from intraspecific variation in response to

weather. Journal of Applied Ecology. 54(1): 293-302. [91475]

94. Bradford, John B.; Lauenroth, William K. 2006. Controls over invasion of Bromus tectorum: the importance of climate, soil, disturbance and seed availability. Journal of Vegetation Science. 17: 693-704. [68856]

95. Bradley, Bethany A. 2010. Assessing ecosystem threats from global and regional change: Hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. Ecography. 33: 198-208. [91466]

96. Bradley, Bethany A.; Curtis, Caroline A.; Fusco, Emily J.; Abatzoglou, John T.; Balch, Jennifer K.; Dadashi, Sepideh; Tuanmu, Mao-Ning. 2018. Cheatgrass (Bromus tectorum) distribution in the intermountain western United States and its relationship to fire frequency, seasonality, and ignitions. Biological Invasions. 20: 1493-1506. [92906]

97. Branson, Farrel A.; Miller, Reuben F. 1981. Effects of increased precipitation and grazing management on northeastern Montana rangelands. Journal of Range Management. 34(1): 3-10. [7507]

98. Braun, Clait E. 1998. Sage grouse declines in western North America: What are the problems? In: Proceedings, WAFWA; 1998, June 26-July 2; Jackson, WY. Cheyenne, WY: Western Association of Fish and Wildlife Agencies: 139-156. [35365]

99. Braun, Clait E.; Connelly, John W.; Schroeder, Michael A. 2005. Seasonal habitat requirements for sage-grouse: Spring, summer, fall, and winter. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 38-42. [63180]

100. Bray, Robert O.; Wambolt, Carl L.; Kelsey, Rick G. 1991. Influence of sagebrush terpenoids on mule deer preference. Journal of Chemical Ecology. 17(11): 2053-2062. [28439]

101. Breshears, David D.; Cobb, Niel S.; Rich, Paul M.; Price, Kevin P.; Allen, Craig D.; Balice, Randy G.; Romme, William H.; Kastens, Jude H.; Floyd, M. Lisa; Belnap, Jayne; Anderson, Jesse J.; Myers, Orrin B.; Meyer, Clifton W. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences. 102(42): 15144-15148. [91632]

102. Brewerton, Adam B. 2012. Avian response to post wildland fire reseeding treatments in Great Basin shrubsteppe. Logan, UT: Utah State University. 41 p. Thesis. [88042]

103. Britton, Carlton M. 1979. Fire on the range. Western Wildlands. 5(4): 32-33. [514]

104. Britton, Carlton M.; Clark, Robert G. 1985. Effects of fire on sagebrush and bitterbrush. In: Saunders, Ken; Durham, Jack; [and others], eds. Rangeland fire effects: Proceedings of the symposium; 1984 November 27-29; Boise, ID. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 22-26. [515]

105. Britton, Carlton M.; Clark, Robert G.; Sneva, Forrest A. 1981. Will your sagebrush range burn? Rangelands. 3(5): 207-208. [517]

106. Brooks, Mathew L.; Chambers, Jeanne C. 2011. Resistance to invasion and resilience to fire in desert shrublands of North America. Rangeland Ecology and Management. 64(5): 431-438. [84701]

107. Brooks, Matthew L. 2008. Effects of fire suppression and postfire management activities on plant invasions. In: Zouhar, Kristin; Smith, Jane Kapler; Sutherland, Steve; Brooks, Matthew L., eds. Wildland fire in ecosystems: Fire and nonnative invasive plants. Gen. Tech. Rep. RMRS-GTR-42-vol. 6. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 269-280. [70909]

108. Brooks, Matthew L.; D'Antonio, Carla M.; Richardson, David M.; Grace, James B.; Keeley, Jon E.; DiTomaso, Joseph M.; Hobbs, Richard J.; Pellant, Mike; Pyke, David. 2004. Effects of invasive alien plants

on fire regimes. BioScience. 54(7): 677-688. [50224]

109. Brooks, Matthew L.; Pyke, David A. 2001. Invasive plants and fire in the deserts of North America. In: Galley, Krista E. M.; Wilson, Tyrone P., eds. Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species; Fire conference 2000: 1st national congress on fire ecology, prevention, and management; 2000 November 27 - December 1; San Diego, CA. Misc. Publ. No. 11. Tallahassee, FL: Tall Timbers Research Station: 1-14. [40491]

110. Brown, James K. 1982. Fuel and fire behavior prediction in big sagebrush. Research Paper INT-290. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p. [543]

111. Brown, James K. 1985. Role and use of fire in aspen. In: Foresters' future: Leaders or followers? Proceedings of the 1985 Society of American Foresters national convention; 1985 July 28-31; Fort Collins, CO. SAF Publ. 85-13. Bethesda, MD: Society of American Foresters: 101-105. [5104]

112. Brown, Lindsay J. 2007. A historic perspective: The response of breeding passerines to rangeland alteration in Rich County, Utah. Logan, UT: Utah State University. 57 p. Thesis. [91422]

113. Bruce, J. R.; Robinson, W. D.; Petersen, S. L.; Miller, R. F. 2011. Greater sage-grouse movements and habitat use during winter in central Oregon. Western North American Naturalist. 71(3): 418-424. [93176]

114. Bryant, Fred C. 1991. Managed habitats for deer in juniper woodlands of west Texas. In: Rodiek, Jon E.; Bolen, Eric G., eds. Wildlife and habitats in managed landscapes. Island Press: Washington, DC: 56-75. [85242]

115. Bukowski, Beth E.; Baker, William L. 2013. Historical fire in sagebrush landscapes of the Gunnison sage-grouse range from land-survey records. Journal of Arid Environments. 98: 1-9. [87644]

116. Bukowski, Beth E.; Baker, William L. 2013. Historical fire regimes, reconstructed from land-survey data, led to complexity and fluctuation in sagebrush landscapes. Ecological Applications. 23(3): 546-564. [88857]

117. Bunting, Stephen C. 1984. Prescribed burning of live standing western juniper and post-burning succession. In: Oregon State University, Department of Rangeland Resources. Proceedings--western juniper management short course; 1984 October 15-16; Bend, OR. Corvallis, OR: Oregon State University, Extension Service; Oregon State University, Department of Rangeland Resources; 69-73. [557]

118. Bunting, Stephen C.; Kilgore, Bruce M.; Bushey, Charles L. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. Gen. Tech. Rep. INT-231. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 33 p. [5281]

119. Bunting, Stephen C.; Kingery, James L.; Hemstrom, Miles A.; Schroeder, Michael A.; Gravenmier, Rebecca A.; Hann, Wendel J. 2002. Altered rangeland ecosystems in the interior Columbia Basin. Gen. Tech. Rep. PNW-GTR-553. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 71 p. (Quigley, Thomas M., ed.; Interior Columbia Basin Ecosystem Project: scientific assessment). [43462]

120. Bunting, Stephen C.; Kingery, James L.; Schrieder, Michael A. 2003. Assessing the restoration potential of altered rangeland ecosystems in the Interior Columbia Basin. Ecological Restoration. 21(2): 77-86. [93276]

121. Buranek, Shelley. 2017. Personal communication [Email to Robin Innes]. 19 January. Regarding use of Rx fire in big sagebrush communities within the John Day Fossil Beds National Monument. Casper, OR: U.S. Department of the Interior, National Park Service, John Day Fossil Beds National Monument. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [91633]

122. Burke, Ingrid C. 1989. Control of nitrogen mineralization in a sagebrush steppe landscape. Ecology. 70(4): 1115-1126. [7974]

123. Burke, Ingrid C.; Reiners, William A.; Olson, Richard K. 1989. Topographic control of vegetation in a mountain big sagebrush steppe. Vegetatio. 84(2): 77-86. [11178]

124. Burkhardt, J. Wayne; Tisdale, E. W. 1969. Nature and successional status of western juniper vegetation in Idaho. Journal of Range Management. 22(4): 264-270. [564]

125. Burkhardt, Wayne J.; Tisdale, E. W. 1976. Causes of juniper invasion in southwestern Idaho. Ecology. 57(3): 472-484. [565]

126. Buseck, Rebecca S.; Keinath, Douglas A.; McGee, Matthew H. 2004. Species assessment for sage thrasher (Oreoscoptes montanus) in Wyoming. Cheyenne, WY: U.S. Department of the Interior, Bureau of Land Management, Wyoming State Office. 72 p. [91430]

127. Bushey, C. L.; Kilgore, B. M. 1984. Sagebrush-grass vegetative, fuel, and fire behavior parameters (Preliminary results from the demonstration of prescribed burning on selected BLM districts project). Final Report of the Cooperative Agreement #22-C-3-INT-26. November 15. On file at: U.S. Department of Agriculture, Forest Service Rocky Mountain Research Station, Ogden, UT. 97 p. [93121]

128. Bushey, Charles L. 1985. Summary of results from the Galena Gulch 1982 spring burns (Units 1b). Missoula, MT: Systems for Environmental Management. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 9 p. [567]

129. Bushey, Charles L. 1987. Short-term vegetative response to prescribed burning in the sagebrush/grass ecosystem of the northern Great Basin: Three years of postburn data from the demonstration of prescribed burning on selected Bureau of Land Management districts. Final Report. Cooperative Agreement 22-C-4-INT-33. Missoula, MT: Systems for Environmental Management. 77 p. [568]

130. Butler, Bret W.; Reynolds, Timothy D. 1997. Wildfire case study: Butte City Fire, southeastern Idaho, July 1, 1994. Gen. Tech. Rep. INT-GRT-351. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 15 p. [27526]

131. Byrne, Michael W. 2002. Habitat use by female greater sage grouse in relation to fire at Hart Mountain National Antelope Refuge, Oregon. Corvallis, OR: Oregon State University. 45 p. Thesis. [90039]

132. Calkin, David E.; Gebert, Krista M.; Jones, J. Greg; Neilson, Ronald P. 2005. Forest Service large fire area burned and suppression expenditure trends, 1970-2002. Journal of Forestry. 103(4): 179-163. [92567]

133. Call, Mayo W. 1979. Habitat requirements and management recommendations for sage grouse. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, Denver Service Center. 37 p. [591]

134. Call, Mayo W.; Maser, Chris. 1985. Wildlife habitats in managed rangelands--the Great Basin of southeastern Oregon: Sage grouse. Gen. Tech. Rep. PNW-187. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 30 p. [592]

135. Casazza, Michael L.; Coates, Peter S.; Overton, Cory T. 2011. Linking habitat selection and brood success in greater sage-grouse. In: Sandercock, Brett K.; Martin, Kathy; Segelbacher, Gernot, eds. Ecology, conservation, and management of grouse. Studies in Avian Biology, No. 39. Berkeley, CA: University of California Press: 151-167. [90143]

136. Cawker, Kenneth B. 1980. Evidence of climatic control from population age structure of Artemisia tridentata Nutt. in southern British Columbia. Journal of Biogeography. 7(3): 237-248. [91226]

137. Chambers, Jeanne C. 2008. Climate change and the Great Basin. Gen. Tech. Rep. RMRS-GTR-204. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 32 pages. [91464]

138. Chambers, Jeanne C.; Beck, Jeffrey L.; Bradford, John B.; Bybee, Jared; Campbell, Steve; Carlson, John; Christiansen, Thomas J.; Clause, Karen J.; Collins, Gail; Crist, Michele R.; Dinkins, Jonathan B.; Doherty, Kevin E.; Edwards, Fred; Espinosa, Shawn; Griffin, Kathleen A.; Griffin, Paul; Haas, Jesscia R.; Hanser, Steven E.; Havlina, Douglas W.; Henke, Kenneth F.; Hennig, Jacob D.; Joyce, Linda A.; Kilkenny, Francis F.; Kulpa, Sarah M.; Kurth, Laurie L.; Maestas, Jeremy D.; Manning, Mary; Mayer, Kenneth F.; Mealor, Brian A.; McCarthy, Clinton; Pellant, Mike; Perea, Marco A.; Prentice, Karen L.; Pyke, David A.; Wiechman, Lief A.; Wuenschel, Amanda. 2017. Science framework for conservation and restoration of the sagebrush biome: Linking the department of the Interior's integrated Rangeland Fire Management Strategy to long-term strategic conservation actions. Gen. Tech. Rep. RMRS-GTR-360. Fort Collins, CO: U.S Department of Agriculture, Forest Service, Rocky Mountain Research Station. 134 p. [+ appendices]. [92358]

139. Chambers, Jeanne C.; Bradley, Bethany A.; Brown, Cynthia S.; D'Antonio, Carla; Germino, Matthew J.; Grace, James B.; Hardegree, Stuart P.; Miller, Richard F.; Pyke, David A. 2014. Resilience to stress and disturbance, and resistance to Bromus tectorum L. invasion in cold desert shrublands of western North America. Ecosystems. 17(2): 360-375. [91554]

140. Chambers, Jeanne C.; Jeffrey L. Beck, Steve Campbell, John Carlson, Thomas J. Christiansen, Clause, Karen J.; Dinkins, Jonathan B.; Doherty, Kevin E.; Griffin, Kathleen A.; Havlina, Douglas W.; Henke, Kenneth F.; Hennig, Jacob D.; Kurth, Laurie L.; Maestas, Jeremy D.; Manning, Mary Manning, Mayer, Kenneth E.; Mealor, Brian A.; McCarthy, Clinton; Perea, Marco A.; Pyke, David A. 2016. Using resilience and resistance concepts to manage threats to sagebrush ecosystems, Gunnison sage-grouse, and Greater sage-grouse in their eastern range: A strategic multi-scale approach. Gen. Tech. Rep. RMRS-GTR-356. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 143 p. [91650]

141. Chambers, Jeanne C.; Miller, Richard F.; Board, David I.; Pyke, David A.; Roundy, Bruce A.; Grace, James B.; Schupp, Eugene W.; Tausch, Robin J. 2014. Resilience and resistance of sagebrush ecosystems: Implications for state and transition models and management treatments. Rangeland Ecology and Management. 67(5): 440-454. [89207]

142. Chambers, Jeanne C.; Pyke, David A.; Maestas, Jeremy D.; Pellant, Mike; Boyd, Chad S.; Campbell, Steven B.; Espinosa, Shawn; Havlina, Douglas W.; Mayer, Kenneth E.; Wuenschel, Amarina. 2014. Using resistance and resilience concepts to reduce impacts of invasive annual grasses and altered fire regimes on the sagebrush ecosystem and greater sage-grouse: A strategic multi-scale approach. Gen. Tech. Rep. RMRS-GTR-326. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 73 p. [89518]

143. Chambers, Jeanne C.; Roundy, Bruce A.; Blank, Robert R.; Meyer, Susan E.; Whittaker, A. 2007. What makes Great Basin sagebrush ecosystems invasible by Bromus tectorum? Ecological Monographs. 77(1): 117-145. [66809]

144. Chaplin, M. R.; Winward, A. H. 1982. The effect of simulated fire on emergence of seeds found in the soil of big sagebrush communities. In: Society for Range Management Abstracts: Proceedings, 35th Annual Meeting of the Society for Range Management; [Date of conference unknown]; Calgary, AB. Denver, CO: Society for Range Management: 37. Abstract. [9800]

145. Chaplin, Mark R. 1982. Big sagebrush (Artemisia tridentata) ecology and management with emphasis on prescribed burning. Corvallis, OR: Oregon State University. 136 p. Dissertation. [9484]

146. Chapman, Joseph A.; Feldhamer, George A., eds. 1982. Wild mammals of North America. Baltimore, MD: The Johns Hopkins University Press. 1147 p. [21085]

147. Clark, Patrick E.; Lee, Jaechoul; Ko, Kyungduk; Nielson, Ryan M.; Johnson, Douglas E.; Ganskopp, David C.; Pierson, Frederick B.; Hardegree, Stuart P. 2016. Prescribed fire effects on resource selection by cattle in mesic sagebrush steppe. Part 2: Mid-summer grazing. Journal of Arid Environments. 124: 398-412. [89947]

148. Clark, Robert G.; Starkey, Edward E. 1990. Use of prescribed fire in rangeland ecosystems. In: Walstad, John D.; Radosevich, Steven R.; Sandberg, David V., eds. Natural and prescribed fire in Pacific Northwest forests. Corvallis, OR: Oregon State University Press: 81-91. [46959]

149. Clifton, Nancy A. 1981. Response to prescribed fire in a Wyoming big sagebrush/bluebunch wheatgrass habitat type. Moscow, ID: University of Idaho. 39 p. Thesis. [650]

150. Cluff, Greg J.; Young, James A.; Evans, Raymond A. 1983. Edaphic factors influencing the control of Wyoming big sagebrush and seedling establishment of crested wheatgrass. Journal of Range Management. 36(6): 786-792. [656]

151. Cluff, L. K.; Welch, B. L.; Pederson, J. C.; Brotherson, J. D. 1982. Concentration of monoterpenoids in the rumen ingesta of wild mule deer. Journal of Range Management. 35(2): 192-194. [91419]

152. Coates, Peter S.; Prochazka, Brian G.; Ricca, Mark A.; Gustafson, K. Ben; Ziegler, Pilar; Casazza, Michael L. 2016. Pinyon and juniper encroachment into sagebrush ecosystems impacts distribution and survival of greater sage-grouse. Rangeland Ecology and Management. 70(1): 25-38. [91613]

153. Colket, Elizabeth C. 2003. Long-term vegetation dynamics and post-fire establishment patterns of sagebrush steppe. Moscow, ID: University of Idaho. 144 p. Thesis. [92626]

154. Collins, P. D.; Harper, K. T. 1982. Habitat types of the Curlew National Grassland, Idaho. Provo, UT: Brigham Young University, Department of Botany and Range Science. 46 p. [Editorial draft]. [663]

155. Colorado Parks and Wildlife. 2005. Sagebrush vole (Lemmiscus curtatus), [Online]. Colorado sagebrush: A conservation assessment and strategy. A82-A90. Colorado Parks & Wildlife (Producer). Available: https://cpw.state.co.us/Documents/WildlifeSpecies/Sagebrush/SagebrushVole.pdf [2017, January 12]. [91439]

156. Condon, Lea; Weisberg, Peter J.; Chambers, Jeanne C. 2011. Abiotic and biotic influences on Bromus tectorum invasion and Artemisia tridentata recovery after fire. International Journal of Wildland Fire. 20(4): 597-604. [83125]

157. Connell, L. C.; Scasta, J. D.; Porensky, L. M. 2018. Prairie dogs and wildfires shape vegetation structure in a sagebrush grassland more than does rest from ungulate grazing. Ecoshere. 9(8): e02390. 10.1002/ecs2.2390. [93199]

158. Connelly, J. W.; Knick, S. T.; Schroeder, M. A.; Stiver, S. J. 2011. Conservation assessment of greater sage-grouse and sagebrush habitats. Cheyenne, WY: Western Association of Fish and Wildlife Agencies. Unpublished Report. 610 p. [92979]

159. Connelly, John W.; Hagan, Christian A.; Schroeder, Michael A. 2011. Characteristics and dynamics of greater sage-grouse populations. Chapter 3. In: Knick, Steven T.; Connelly, John W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology, No. 38. Berkeley, CA: University of California Press: 53-67. [89609]

160. Connelly, John W.; Rinkes, E. Thomas; Braun, Clait E. 2011. Characteristics of greater sage-grouse habitats: A landscape species at micro- and macroscales. In: Knick, Steven T.; Connelly, John W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology, No. 38. Berkeley, CA: University of California Press: 69-83. [89612]

161. Connelly, John W.; Schroeder, Michael A.; Sands, Alan R.; Braun, Clait E. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin. 28(4): 967-985. [89610]

162. Connelly, John W.; Wakkinen, Wayne L.; Apa, Anthony D.; Reese, Kerry P. 1991. Sage grouse use of nest sites in southeastern Idaho. The Journal of Wildlife Management. 55(3): 521-524. [35154]

163. Cook, Amy. 2015. Greater sage-grouse seasonal habitat models, response to juniper reduction and effects of capture behavior on vital rates, in northwest Utah. Logan, UT, Utah State University. 159 p.

Thesis. [93186]

164. Cook, John G.; Hershey, Terry J.; Irwin, Larry L. 1994. Vegetative response to burning on Wyoming mountain-shrub big game ranges. Journal of Range Management. 47(4): 296-302. [23449]

165. Cooper, Stephen V.; Jean, Catherine. 2001. Wildfire succession in plant communities natural to the Alkali Creek vicinity, Charles M. Russell National Wildlife Refuge, Montana. Unpublished report prepared for the U.S. Fish and Wildlife Service: USFWS Agreement Number 60181-0-J206. Helena, MT: Montana Natural Heritage Program. On file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 32 p. [70496]

166. Cooper, Stephen V.; Lesica, Peter; Kudray, Greg M. 2011. Post-fire recovery of Wyoming big sagebrush shrub-steppe in central and southeast Montana. Natural Resources and Environmental Issues. 16(12): 1-16. [90212]

167. Cooper, Stephen V.; Lesica, Peter; Kudray, Greg M. 2011. Post-fire recovery of Wyoming big sagebrush steppe in central and southeast Montana. In: Wambolt, Carl L.; Kitchen, Stanley G.; Frisina, Michael R.; Sowell, Bok; Keigley, Richard B.; Palacios, Patsy; Robinson, Jill, comps. Proceedings--shrublands: Wildlands and wildlife habitats; 15th wildland shrub symposium; 2008 June 17-19; Bozeman, MT. Natural Resources and Environmental Issues, Volume XVI. Logan, UT: Utah State University, College of Natural Resources, S. J. and Jessie E. Quinney Natural Resources Research Library: 79-87. [83472]

168. Cooper, Stephen; Lesica, Peter. 2018. Unpublished data on Wyoming big sagebrush postfire recovery. In: Personal communication [Email to Robin Innes]. 5 October. Documents on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. 3 p. [93108]

169. Cottrell, Thomas R.; Bonham, Charles D. 1992. Characteristics of sites occupied by subspecies of Artemisia tridentata in the Piceance Basin, Colorado. The Great Basin Naturalist. 52(2): 174-178. [19688]

170. Courtois, Danielle R.; Perryman, Barry L.; Hussein, Hussein S. 2004. Vegetation change after 65 years of grazing and grazing exclusion. Journal of Range Management. 57(6): 574-582. [30319]

171. Cox, Robert D.; Anderson, Val Jo. 2004. Increasing native diversity of cheatgrass dominated rangeland through assisted succession. Journal of Range Management. 57(2): 203-210. [91652]

172. Crawford, John A.; Olson, Rich A.; West, Neil E.; Mosley, Jeffrey C.; Schroeder, Michael A.; Whitson, Tom D.; Miller, Richard F.; Gregg, Michael A.; Boyd, Chad S. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management. 57(1): 2-19. [47019]

173. Crawford, John Earl, Jr. 1960. The movements, productivity, and management of sage grouse in Clark and Fremont Counties, Idaho. Moscow, ID: University of Idaho. 85 p. Thesis. [5845]

174. Crawford, Justin A.; Anthony, Robert G.; Forbes, James T.; Lorton, Glenn A. 2010. Survival and causes of mortality for pygmy rabbits (Brachylagus idahoensis) in Oregon and Nevada. Journal of Mammalogy. 91(4): 838-847. [93123]

175. Creutzburg, Megan K.; Halofsky, Jessica E.; Halofsky, Joshua S.; Christopher, Treg A. 2014. Climate change and land management in the rangelands of central Oregon. Environmental Management. 55(1): 43-55. [90145]

176. Creutzburg, Megan K.; Holofsky, Joshua S.; Hemstrom, Miles A. 2012. Using state-and-transition models to project cheatgrass and juniper invasion in southeastern Oregon sagebrush steppe. In: Kerns, Becky K.; Shlisky, Ayn J.; Daniel, Colin J., tech. eds. Proceedings of the first landscape state-and-transition simulation modeling conference; 2011 June 14-16; Portland, OR. Gen. Tech. Rep. PNW-GTR-869. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 73-84. [92629]

177. Crist, Michele R.; Chambers, Jeanne C.; Phillips, Susan L.; Prentice, Karen L.; Wiechman, Lief A., eds. 2019. Science framework for conservation and restoration of the sagebrush biome: Linking the department of the Interior's integrated Rangeland Fire Management Strategy to long-term strategic conservation actions. Part 2. Management Applications. Gen. Tech. Rep. RMRS-GTR-389. Fort Collins, CO: U.S Department of Agriculture, Forest Service, Rocky Mountain Research Station. 237 p. [93303]

178. Cronquist, Arthur; Holmgren, Arthur H.; Holmgren, Noel H.; Reveal, James L.; Holmgren, Patricia K. 1994. Intermountain flora: Vascular plants of the Intermountain West, U.S.A. Vol. 5: Asterales. New York: The New York Botanical Garden. 496 p. [28653]

179. Crow, Claire; van Riper, Charles, III. 2010. Avian responses to mechanical thinning of a pinyon-juniper woodland: specialist sensitivity to tree reduction. Natural Areas Journal. 30(2): 191-201. [93184]

180. D'Antonio, Carla M.; Vitousek, Peter M. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics. 23: 63-87. [20148]

181. Dalhgren, David K.; Larsen, Randy T.; Danvir, Rick; Wilson, George; Thacker, Eric T.; Black, Todd A.; Naugle, David E.; Connelly, John W.; Messmer, Terry A. 2015. Greater sage-grouse and range management: Insights from a 25-year case study in Utah and Wyoming. Rangeland Ecology and Management. 68(5): 375-382. [90435]

182. Dalzell, Cynthia R. 2004. Post-fire establishment of vegetation communities following reseeding on southern Idaho's Snake River Plain. Boise, ID: Boise State University. 112 p. Thesis. [62175]

183. Dangi, S. R.; Stahl, P. D.; Pendall, E.; Cleary, M. B.; Buyer, J. S. 2010. Recovery of soil microbial community structure after fire in a sagebrush-grassland ecosystem. Land degradation and development. 21(5): 423-432. [91653]

184. Daubenmire, R. 1970. Steppe vegetation of Washington. Tech. Bull. 62. Pullman, WA: Washington State University, College of Agriculture; Washington Agricultural Experiment Station. 131 p. [733]

185. Daubenmire, Rexford F. 1975. Ecology of Artemisia tridentata subsp. tridentata in the state of Washington. Northwest Science. 49(1): 24-35. [744]

186. Davies, K. W.; Bates, J. D.; Boyd, C. S. 2016. Effects of intermediate-term grazing rest on sagebrush communities with depleted understories: Evidence of a threshold. Rangeland Ecology & Management. 69: 173-178. [90825]

187. Davies, K. W.; Bates, J. D.; Madsen, M. D.; Nafus, A. M. 2014. Restoration of mountain big sagebrush steppe following prescribed burning to control western juniper. Environmental Management. 53(5): 1015-1022. [87988]

188. Davies, K. W.; Boyd, C. S.; Madsen, M. D.; Hulet, A. 2018. Evaluating a seed technology for sagebrush restoration across an elevation gradient: Support for bet hedging. Rangeland Ecology and Management. 71: 19-24. [93129]

189. Davies, K. W.; Nafus, A. M.; Boyd, C. S.; Hulet, A.; Bates, J. D. 2016. Effects of using winter grazing as a fuel treatment on Wyoming big sagebrush plant communities. Rangeland Ecology & Management. 69(3): 179-184. [90827]

190. Davies, K. W.; Svejcar, T. J.; Bates, J. D. 2009. Interaction of historical and nonhistorical disturbances maintains native plant communities. Ecological Applications. 19(6): 1536-1545. [83027]

191. Davies, Kirk W.; Bates, Jon D. 2010. Native perennial forb variation between mountain big sagebrush and Wyoming big sagebrush plant communities. Environmental Management. 46(3): 452-458. [90213]

192. Davies, Kirk W.; Bates, Jon D. 2010. Vegetation characteristics of mountain and Wyoming big sagebrush plant communities in the Northern Great Basin. Rangeland Ecology and Management. 63(4): 461-466. [92625]

193. Davies, Kirk W.; Bates, Jon D. 2017. Restoring big sagebrush after controlling encroaching western juniper with fire: Aspect and subspecies effects. Restoration Ecology. 25(1): 33-41. [91446]

194. Davies, Kirk W.; Bates, Jonathan D.; Johnson, Dustin D.; Nafus, Aleta M. 2009. Influence of mowing Artemisia tridentata spp. wyomingensis on winter habitat for wildlife. Environmental Management. 44(1): 84-92. [91448]

195. Davies, Kirk W.; Bates, Jonathan D.; Miller, Richard F. 2006. Vegetation characteristics across part of the Wyoming big sagebrush alliance. Rangeland Ecology and Management. 59(6): 567-575. [92977]

196. Davies, Kirk W.; Bates, Jonathan D.; Miller, Richard F. 2007. Short-term effects of burning Wyoming big sagebrush steppe in southeast Oregon. Rangeland Ecology and Management. 60(5): 515-522. [69744]

197. Davies, Kirk W.; Bates, Jonathan D.; Svejcar, Tony J.; Boyd, Chad S. 2010. Effects of long-term livestock grazing on fuel characteristics in rangelands: An example from the sagebrush steppe. Rangeland Ecology & Management. 63(6): 662-669. [82380]

198. Davies, Kirk W.; Boyd, Chad S.; Bates, Jon D.; Hulet, April. 2015. Dormant season grazing may decrease wildfire probability by increasing fuel moisture and reducing fuel amount and continuity. International Journal of Wildland Fire. 24(6): 849-856. [89745]

199. Davies, Kirk W.; Boyd, Chad S.; Bates, Jon D.; Hulet, April. 2015. Winter grazing can reduce wildfire size, intensity and behavior in a shrub-grassland. International Journal of Wildland Fire. 25: 191-199. [92975]

200. Davies, Kirk W.; Boyd, Chad S.; Bates, Jon D.; Hulet, April. 2015. Winter grazing can reduce wildfire size, intensity and behaviour in a shrub-grassland. International Journal of Wildland Fire. 25(2): 191-199. [90949]

201. Davies, Kirk W.; Boyd, Chad S.; Beck, Jeffrey L.; Bates, Jon D.; Svejcar, Tony J.; Gregg, Michael A. 2011. Saving the sagebrush sea: An ecosystem conservation plan for big sagebrush plant communities. Biological Conservation. 144(11): 2573-2584. [83899]

202. Davies, Kirk W.; Boyd, Chad S.; Nafus, Aleta M. 2013. Restoring the sagebrush component in crested wheatgrass-dominated communities. Rangeland Ecology and Management. 66(4): 472-478. [93148]

203. Davies, Kirk W.; Gearhart, Amanda; Boyd, Chad S.; Bates, Jonathan D. 2017. Fall and spring grazing influence fire ignitability and initial spread in shrub steppe communities. International Journal of Wildland Fire. 26(6): 485-490. [92015]

204. Davies, Kirk W.; Nafus, Aleta M. 2013. Exotic annual grass invasion alters fuel amounts, continuity and moisture content. International Journal of Wildland Fire. 22(3): 353-358. [87876]

205. Davies, Kirk W.; Sheley, Roger L.; Bates, Jonathan D. 2008. Does fall prescribed burning Artemisia tridentata steppe promote invasion or resistance to invasion after a recovery period? Journal of Arid Environments. 72(6): 1076-1085. [70511]

206. Davis, Dawn M. 2002. Breeding season habitat use and response to management activities by greater sage-grouse on Sheldon National Wildlife Refuge, Nevada. Corvallis, OR: Oregon State University. 120 p. Thesis. [93178]

207. Davis, Dawn M.; Crawford, John A. 2014. Case study: Short-term response of greater sage-grouse habitats to wildfire in mountain big sagebrush communities. Wildlife Society Bulletin. 39(1): 1-9. [90066]

208. Davison, Jason C.; Smith, Edwin G. 2007. Imazapic provides 2-year control of weedy annuals in a seeded Great Basin fuelbreak. Native Plants. 8(2): 93-95. [93143]

209. Davison, Jason. 1996. Livestock grazing in wildland fuel management programs. Rangelands. 18(6): 242-245. [28895]

210. Dealy, J. Edward; Leckenby, Donavin A.; Concannon, Diane M. 1981. Wildlife habitats on managed rangelands--the Great Basin of southeastern Oregon: Plant communities and their importance to wildlife. Gen. Tech. Rep. PNW-120. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest and Range Experiment Station. 66 p. [786]

211. Dean, Sheila; Burkhardt, J. Wayne; Meeuwig, Richard O. 1981. Estimating twig and foliage biomass of sagebrush, bitterbrush, and rabbitbrush in the Great Basin. Journal of Range Management. 34(3): 224-227. [787]

212. DeByle, Norbert V. 1985. Managing wildlife habitat with fire in the aspen ecosystem. In: Lotan, James E.; Brown, James K., comps. Fire's effects on wildlife habitat--symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 73-82. [8336]

213. Deming, O. V. 1963. Antelope and sagebrush. In: Yoakum, Jim, comp. Transactions, Interstate antelope conference; 1963 December 4-5; Alturas, CA. Reno, NV: Interstate Antelope Conference: 55-60. [25687]

214. Dettweiler-Robinson, E.; Bakker, Jonathan D.; Evans, James R.; Newsome, Heidi; Davies, G. Matt; Wirth, Troy A.; Pyke, David A.; Easterly, Richard T.; Salstrom, Debra; Dunwiddie, Peter W. 2013. Outplanting Wyoming big sagebrush following wildfire: stock performance and economics. Rangeland Ecology and Management. 66(6): 657-666. [89699]

215. Diamond, Joel M.; Call, Christopher A.; Devoe, Nora. 2009. Effects of targeted cattle grazing on fire behavior of cheatgrass-dominated rangeland in the northern Great Basin, USA. International Journal of Wildland Fire. 18(8): 944-950. [81834]

216. Dicus, Christopher, A.; Delfino, Kenneth; Weise, David R. 2009. Predicted fire behavior and societal benefits in three eastern Sierra Nevada vegetation types. Fire Ecology. 5(1): 67-78. [81039]

217. Diettert, R. A. 1938. The morphology of Artemisia tridentata Nutt. Lloydia. 1(1-4): 3-74. [46939]

218. Dinkins, J. B.; Conover, M. R.; Kirol, C. P.; Beck, J. L.; Frey, S. N. 2014. Greater sage-grouse (Centrocercus urophasianus) hen survival: Effects of raptors, anthropogenic and landscape features, and hen behavior. Canadian Journal of Zoology. 92(4): 319-330. [89363]

219. Doescher, P. S.; Miller, R. F.; Swanson, S. R.; Winward, A. H. 1986. Identification of the Artemisia tridentata ssp. wyomingensis/Festuca idahoensis habitat type in eastern Oregon. Northwest Science. 60(1): 55-60. [815]

220. Dorn, Robert D. 1988. Vascular plants of Wyoming. Cheyenne, WY: Mountain West Publishing. 340 p. [6129]

221. Ducherer, Kim; Bai, Yuguang; Thompson, Don; Broersma, Klaas. 2009. Dynamic responses of a British Columbian forest-grasslands interface to prescribed burning. Western North American Naturalist. 69(1): 75-87. [81844]

222. Duncan, Corinne M. 2008. Seed bank response to juniper expansion in the semi-arid lands of Oregon, USA. Corvallis, OR: Oregon State University. 81 p. Thesis. [88013]

223. Dunwiddie, Peter; Camp, Pam. 2013. Enhancement of degraded shrub-steppe habitat with an emphasis on potential applicability in eastern Washington. Tech. Note 443. Bureau of Land Management, Spokane District, Spokane, WA. 89 p. [92974]

224. Earnst, Susan L.; Holmes, Aaron L. 2012. Bird-habitat relationships in interior Columbia Basin shrubsteppe. The Condor. 114(1): 15-29. [91519]

225. Earnst, Susan L.; Newsome, Heidi L.; LaFromboise, William L.; LaFromboise, Nancy. 2009. Avian response to wildfire in Interior Columbia Basin shrubsteppe. The Condor. 111(2): 370-376. [91431]

226. Eberhardt, L. L.; White, P. J.; Garrott, R. A.; Houston, D. B. 2007. A seventy-year history of trends in Yellowstone's northern elk herd. The Journal of Wildlife Management. 71(2): 594-602. [83765]

227. Eddleman, Lee E.; Doescher, Paul S. 1978. Selection of native plants for spoils revegetation based on regeneration characteristics and successional status. In: ANL/LRP-2. Annual report July 1976-October 1977. Argonne, IL: Argonne National Laboratory, Energy & Environmental Systems Division, Land Reclamation Program: 132-138. [5729]

228. Eddleman, Lee E.; Miller, Patricia M.; Miller, Richard F.; Dysart, Patricia L. 1994. Western juniper woodlands (of the Pacific Northwest): Science assessment. Walla Walla, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Interior Columbia Basin Ecosystem Management Project. 131 p. [27969]

229. Eichhorn, Larry C.; Watts, C. Robert. 1984. Plant succession on burns in the river breaks of central Montana. Proceedings, Montana Academy of Sciences. 43: 21-34. [90210]

230. Eissenstat, D. M.; Caldwell, M. M. 1988. Competitive ability is linked to rates of water extraction: A field study of two aridland tussock grasses. Oecologia. 75(1): 1-7. [13055]

231. Eiswerth, Mark E.; Krauter, Karl; Swanson, Sherman R.; Zielinski, Mike. 2009. Post-fire seeding on Wyoming big sagebrush ecological sites: regression analyses of seeded nonnative and native species densities. Journal of Environmental Management. 90: 1320-1325. [72895]

232. Ellison, Lincoln. 1960. Influence of grazing on plant succession of rangelands. Botanical Review. 26(1): 1-78. [862]

233. Ellison, Lincoln; Woolfolk, E. J. 1937. Effects of drought on vegetation near Miles City, Montana. Ecology. 18(3): 329-336. [6264]

234. Ellsworth, L. M.; Wrobleski, D. W.; Kaufman, J. B.; Reis, S. A. 2016. Ecosystem resilience is evident 17 years after fire in Wyoming big sagebrush ecosystems. Ecosphere. 7(12): e01618.10.1002/ecs2.1618. [92973]

235. Emmerich, F. L.; Tipton, F. H.; Young, J. A. 1993. Cheatgrass: Changing perspectives and management strategies. Rangelands. 15(1): 37-40. [20463]

236. Epanchin-Niell, Rebecca; Englin, Jeffrey; Nalle, Darek. 2009. Investing in rangeland restoration in the Arid West, USA: Countering the effects of an invasive weed on the long-term fire cycle. Journal of Arid Environments. 91(2): 370-379. [81857]

237. Erikson, Heidi Jo. 2011. Herbaceous and avifauna responses to prescribed fire and grazing timing in a high-elevation sagebrush ecosystem. Fort Collins, CO: Colorado State University. 165 p. Thesis. [90063]

238. Evans, Raymond A.; Young, James A. 1970. Plant litter and establishment of alien annual weed species in rangeland communities. Weed Science. 18(6): 697-703. [877]

239. Evans, Raymond A.; Young, James A. 1978. Effectiveness of rehabilitation practices following wildfire in a degraded big sagebrush-downy brome community. Journal of Range Management. 31(3): 185-188. [880]

240. Evenden, Angela G. 1989. Ecology and distribution of riparian vegetation in the Trout Creek Mountains of southeastern Oregon. Corvallis, OR: Oregon State University. 156 p. Dissertation. [10231]

241. Everett, Richard L.; Sharrow, Steven H.; Meeuwig, Richard O. 1983. Pinyon-juniper woodland understory distribution patterns and species associations. Torrey Botanical Club. 110(4): 454-463. [899]

242. Evers, Louisa B.; Miller, Richard F.; Doescher, Paul S.; Hemstrom, Miles; Neilson, Ronald P. 2013. Stimulating current successional trajectories in sagebrush ecosystems with multiple disturbances using a state-and-transition modeling framework. Rangeland Ecology & Management. 66(3): 313-329. [87377]

243. Evers, Louisa. 2010. Modeling sage-grouse habitat using a state-and-transition model. Corvallis, OR: Oregon State University. 162 p. Dissertation. [90037]

244. Evers, Louisa. 2014. Beyond anyone's control. Northwest Science. 88(1): 65-67. [90186]

245. Ewers, B. E.; Pendall, E. 2008. Spatial patterns in leaf area and plant functional type cover across chronosequences of sagebrush ecosystems. Plant Ecology. 194(1): 67-83. [91476]

246. Fagerstone, Kathleen A.; Lavoie, G. Keith; Griffith, Richard E., Jr. 1980. Black-tailed jackrabbit diet and density on rangeland and near agricultural crops. Journal of Range Management. 33(3): 229-233. [21756]

247. Fairchild, John A. 1999. Pinyon-juniper chaining design guidelines for big game winter range enhancement projects. In: Monsen, Stephen B.; Stevens, Richard, comps. Proceedings: Ecology and management of pinyon-juniper communities within the Interior West: Sustaining and restoring a diverse ecosystem; 1997 September 15-18; Provo, UT. Proceedings RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 278-280. [30565]

248. Fajemisin, B.; Ganskopp, D.; Cruz, R.; Vavra, M. 1996. Potential for woody plant control by Spanish goats in the sagebrush steppe. Small Ruminant Research. 20(3): 229-238. [29196]

249. Ferguson, Charles Wesley. 1964. Annual rings in big sagebrush, Artemisia tridentata. Papers of the Laboratory of Tree-Ring Research: No. 1. Tucson, AZ: University of Arizona Press. 95 p. [30179]

250. Fernandez, Osvaldo A.; Caldwell, Martyn M. 1975. Phenology and dynamics of root growth of three cool semi-desert shrubs under field conditions. Journal of Ecology. 63: 703-714. [919]

251. Fetcher, Ned; Trlica, M. J. 1980. Influence of climate on annual production of seven cold desert forage species. Journal of Range Management. 33(1): 35-37. [38662]

252. Fielding, Dennis J.; Brusven, M. A. 1993. Spatial analysis of grasshopper density and ecological disturbance on southern Idaho rangeland. Agriculture, Ecosystems and Environment. 43: 31-47. [43524]

253. Fielding, Dennis J.; Brusven, Merlyn A. 1994. Grasshopper community responses to shrub loss, annual grasslands, and crested wheatgrass seedlings: management implications. In: Monsen, Stephen B.; Kitchen, Stanley G., compilers. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 162-166. [24273]

254. Finch, D.; Boyce, D.; Chambers, J.; Colt, C.; McCarthy, C.; Kitchen, S.; Richardson, B.; Rowland, M.; Rumble, M.; Schwartz, M.; Tomosy, M.; Wisdom, M. 2015. USDA Forest Service: Sage-grouse conservation science strategy. Washington, DC: U.S. Department of Agriculture, Forest Service. 39 p. [93071]

255. Finch, Deborah M.; Smith, D. Max; LeDee, Olivia; Cartron, Jean-Luc E.; Rumble, Mark A. 2012. Climate change, animal species, and habitats: Adaptation and issues. In: Finch, Deborah M., ed. Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Gen. Tech. Rep. RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1-20. [91462]

256. Fischer, Richard A.; Apa, Anthony D.; Wakkinen, Wayne L.; Reese, Kerry P. 1993. Nesting-area fidelity of sage grouse in southeastern Idaho. The Condor. 95(4): 1038-1041. [22544]

257. Fischer, Richard A.; Reese, Kerry P.; Connelly, John W. 1996. An investigation on fire effects within xeric sage grouse brood habitat. Journal of Range Management. 49(3): 194-198. [26598]

258. Flora of North America Editorial Committee, eds. 2019. Flora of North America north of Mexico, [Online]. Flora of North America Association (Producer). Available: http://www.efloras.org/flora_page.aspx?flora_id=1. [36990]

259. Forbis, Tara A.; Provencher, Louis; Turner, Lee; Medlyn, Gary; Thompson, Julie; Jones, Gina. 2007. A method for landscape-scale vegetation assessment: Application to Great Basin rangeland ecosystems. Rangeland Ecology & Management. 60(3): 209-217. [91220]

260. Fortier, M. I.; Schuman, G. E.; Hild, A. L.; Vicklund, L. E. 2000. Effects of seeding rates and competition on sagebrush establishment on mined lands. In: Schuman, Gerald E.; Richmond, Timothy C.; Neuman, Dennis R., eds. Sagebrush establishment on mined lands: Ecology and research: Proceedings of symposium; 2000 March 20; Billings, MT. [Part of: 2000 Billings land reclamation symposium; 2000 March 20-24; Billings, MT]. Bozeman, MT: Montana State University, Reclamation Research Unit: 43-49. [42421]

261. Foster, Lee J.; Dugger, Katie M.; Hagen, Christian A.; Budeau, David A. 2019. Greater sage-grouse vital rates after wildfire. The Journal of Wildlife Management. 83(1): 121-134. [93200]

262. Fraas, W. Wyatt; Wambolt, Carl L.; Frisina, Michael R. 1992. Prescribed fire effects on a bitterbrush--mountain big sagebrush--bluebunch wheatgrass community. In: Clary, Warren P.; McArthur, E. Durant; Bedunah, Don; Wambolt, Carl L., comps. Proceedings--symposium on ecology and management of riparian shrub communities; 1991 May 29-31; Sun Valley, ID. Gen. Tech. Rep. INT-289. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 212-216. [19124]

263. Francis, Richard E. 1983. Sagebrush-steppe habitat types in northern Colorado: A first approximation. In: Moir, W. H.; Hendzel, Leonard, tech. coords. Proceedings of the workshop on southwestern habitat types; 1983 April 6-8; Albuquerque, NM. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region: 67-71. [955]

264. Frandsen, William H. 1983. Modeling big sagebrush as a fuel. Journal of Range Management. 36(5): 596-600. [958]

265. Frank, Carolyn T.; Smith, Bruce N.; Welch, Bruce L. 1986. Photosynthesis, growth, transpiration, and 13C relationships among three subspecies of big sagebrush (Artemisia tridentata Nutt.). In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 332-335. [960]

266. Freeman, D. Carl; Wang, Han; Sanderson, Stewart; McArthur, E. Durant. 1999. Characterization of a narrow hybrid zone between two subspecies of big sagebrush (Artemisia tridentata, Asteraceae): VII. Community and demographic analyses. Evolutionary Ecology Research. 1: 487-502. [91018]

267. Frenzel, R. W.; Starkey E. E.; Black, H. C. 1979. Effects of prescribed burning on small-mammal communities in Lava Beds National Monument, California. In: Linn, Robert M., ed. Proceedings, 1st conference on scientific research in the National Parks: Vol. 1; 1976 November 9-12; New Orleans, LA. National Park Service Transactions and Proceedings No. 5. Washington, DC: U.S. Department of the Interior, National Park Service: 287-292. [970]

268. Frey, S. Nicole; Curtis, Rachel; Heaton, Kevin. 2013. Response of a small population of greater sage-grouse to tree removal: Implications of limiting factors. Human-Wildlife Interactions. 7(2): 260-272. [93179]

269. Friggens, Megan M.; Warwell, Marcus V.; Chambers, Jeanne C.; Kitchen, Stanley G. 2012. Modeling and predicting vegetation response of western USA grasslands, shrublands, and deserts to climate change. In: Finch, Deborah M., ed. Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Gen. Tech. Rep. RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1-20. [90151]

270. Frischknecht, Neil C. 1962. Factors influencing brush invasion of crested wheatgrass range. Bulletin of the Ecological Society of America. 43(3): 53. [3832]

271. Frischknecht, Neil C.; Baker, Maurice F. 1972. Voles can improve sagebrush rangelands. Journal of Range Management. 25(6): 466-468. [91453]

272. Frischknecht, Neil C.; Harris, Lorin E. 1973. Sheep can control sagebrush on seeded range if... Utah Science. 34(1): 27-30. [91610]

273. Frischknecht, Niel C.; Harris, Lorin E.; Woodward, Harry K. 1953. Cattle gains and vegetal changes as influences by grazing treatments in crested wheatgrass. Journal of Range Management. 6(3): 151-158. [91231]

274. Frisina, Michael R.; Wambolt, Carl L. 2004. Keying in on big sagebrush. Rangelands. 26(1): 12-16. [47232]

275. Frye, Graham G.; Connelly, John W.; Musil, David D.; Forbey, Jennifer S. 2013. Phytochemistry predicts habitat selection by an avian herbivore at multiple spatial scales. Ecology. 94(2): 308-314. [90118]

276. Fulbright, Timothy E.; Davies, Kirk W.; Archer, Steven R. 2018. Wildlife responses to brush management: A contemporary evaluation. Rangeland Ecology and Management. 71(1): 35-44. [93158]

277. Ganskopp, Dave; Bohnert, Dave; Johnson, Dustin; Munday, Kristen. 2009. Pre- and post-burn cattle distribution patterns in sagebrush steppe. In: Bohnert, Dave; Boyd, Chad; Clark, Pat; Cooke, Reinaldo; [and others]. Range field day 2009 progress report. Special report 1092. Corvalis, OR: Department of Oregon State University Department of Rangeland Ecology and Management; Burns, OR: USDA, Agricultural Research Service, Eastern Oregon Agricultural Research Center, U.S. Department of Agriculture: 25-38. [88677]

278. Garcia, Sonia; Canela, Miguel A.; Garnatje, Teresa; McArthur, E. Durant; Pellicer, Jaume; Sanderson, Stewart C.; Valles, Joan. 2008. Evolutionary and ecological implications of genome size in the North American endemic sagebrushes and allies (Artemisia, Asteraceae). Biological Journal of the Linnean Society. 94(3): 631-649. [75469]

279. Garrison, Heather D.; Shultz, Leila M.; McArthur, E. Durant. 2013. Studies of a new hybrid taxon in the Artemisia tridentata (Asteraceae: Anthemideae) complex. Western North American Naturalist. 73(1): 1-19. [91014]

280. Gates, Dillard H. 1964. Sagebrush infested by leaf defoliating moth. Journal of Range Management. 17: 209-210. [91452]

281. Gates, Robert John. 1983. Sage grouse, lagomorph, and pronghorn use of a sagebrush grassland burn site on the Idaho National Engineering Laboratory. Bozeman, MT: Montana State University. 125 p. Thesis. [90177]

282. Gentilcore, Dominic M. 2015. Response of pinyon-juniper woodlands to fire, chaining, and hand thinning. Reno, NV: University of Nevada. 109 p. Thesis. [90223]

283. Germain, Sara J.; Mann, Rebecca K. 2018. Short-term regeneration dynamics of Wyoming big sagebrush at two sites in northern Utah. Western North American Naturalist. 78(1): 7-16. [92895]

284. Gifford, Gerald F. 1981. Impact of burning pinyon-juniper debris on select soil properties. Journal of Range Management. 34(5): 357-359. [1016]

285. Goodrich, Sherel. 2005. Classification and capabilities of woody sagebrush communities of western North America with emphasis on sage-grouse habitat. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 17-37. [63179]

286. Goodrich, Sherel; Huber, Allen. 2001. Mountain big sagebrush communities on the Bishop Conglomerate in the eastern Uinta Mountains. In: McArthur, E. Durant; Fairbanks, Daniel J., comps. Shrubland ecosystem genetics and biodiversity: Proceedings; 2000 June 13-15; Provo, UT. Proc. RMRS-P-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 336-343. [41998]

287. Goodrich, Sherel; Huber, Allen; Monroe, Brian. 2008. Trend of mountain big sagebrush crown cover and ground cover on burned sites, Uinta Mountains and West Tavaputs Plateau, Utah. In: Kitchen, Stanley G.; Pendleton, Rosemary L.; Monaco, Thomas A.; Vernon, Jason, comps. Proceedings--shrublands under fire: Disturbance and recovery in a changing world; 2006 June 6-8; Cedar City, UT. Proc. RMRS-P-52. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 151-160. [73290]

288. Goodrich, Sherel; McArthur, E. Durant; Winward, Alma H. 1999. Sagebrush ecotones and average annual precipitation. In: McArthur, E. Durant; Ostler, W. Kent; Wambolt, Carl L., comps. Proceedings: Shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 88-94. [36068]

289. Goodrich, Sherel; Nelson, Dwain; Gale, Natalie. 1999. Some features of Wyoming big sagebrush communities on gravel pediments of the Green River in Daggett County, Utah. In: McArthur, E. Durant; Ostler, W. Kent; Wambolt, Carl L., comps. Proceedings: Shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 159-167. [36077]

290. Goodwin, Duwayne Leroy. 1956. Autecological studies of Artemisia tridentata, Nutt. Pullman, WA: State College of Washington. 79 p. Dissertation. [1035]

291. Goodwin, Kim; Sheley, Roger; Clark, Janet. 2002. Integrated noxious weed management after wildfires. EB-160. Bozeman, MT: Montana State University, Extension Service (Producer). 46 p. Available online: http://www.msuextension.org/store/Products/Integrated-Noxious-Weed-Management-After-Wildfires__EB0160.aspx [2011, January 20]. [45303]

292. Graham, John H.; Freeman, D. Carl; McArthur, E. Durant. 1995. Narrow hybrid zone between two subspecies of big sagebrush (Artemisia tridentata: Asteraceae). II. Selection gradients and hybrid fitness. American Journal of Botany. 82(6): 709-716. [26072]

293. Green, Jeffery, S.; Flinders, Jerran T. 1980. Habitat and dietary relationships of the pygmy rabbit. Journal of Range Management. 33(2): 136-142. [6257]

294. Green, Jeffrey S.; Flinders, Jerran T. 1980. Brachylagus idahoensis. Mammalian Species. 125: 1-4. [23631]

295. Gregg, Michael A.; Crawford, John A.; Drut, Martin S.; DeLong, Anita K. 1994. Vegetational cover and predation of sage grouse nests in Oregon. The Journal of Wildlife Management. 58(1): 162-166. [25626]

296. Griffin, Duane. 2002. Prehistoric human impacts on fire regimes and vegetation in the northern Intermountain West. In: Vale, Thomas R., ed. Fire, native peoples, and the natural landscape. Washington: Island Press: 77-100. [88509]

297. Grove, Adam J. 1998. Effects of Douglas fir establishment in southwestern Montana mountain big sagebrush communities. Bozeman, MT: Montana State University, Department of Animal and Range Science. 150 p. Thesis. [46897]

298. Grove, Adam J.; Wambolt, Carl L.; Frisina, Michael R. 2005. Douglas-fir's effect on mountain big sagebrush wildlife habitats. Wildlife Society Bulletin. 33(1): 74-80. [91221]

299. Gruell, George E. 1983. Fire and vegetative trends in the northern Rockies: Interpretations from 1871-1982 photographs. Gen. Tech. Rep. INT-158. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 117 p. [5280]

300. Gruell, George E. 1985. Fire on the early western landscape: An annotated record of wildland fire. Northwest Science. 59(2): 97-107. [15660]

301. Gruell, George E. 2012. Nevada's changing wildlife habitat: An ecological history. Reno, Nevada: University of Nevada Press. 178 p. [92540]

302. Gunnell, Kevin L.; Williams, Justin R.; Monaco, Thomas A. 2011. Clarifying potential successional trajectories in sagebrush communities historically seeded with crested wheatgrass. In: Wambolt, Carl L.; Kitchen, Stanley G.; Frisina, Michael R.; Sowell, Bok; Keigley, Richard B.; Palacios, Patsy; Robinson, Jill, comps. Proceedings--shrublands: Wildlands and wildlife habitats; 15th wildland shrub symposium; 2008 June 17-19; Bozeman, MT. Natural Resources and Environmental Issues, Volume XVI. Logan, UT: Utah State University, College of Natural Resources, S. J. and Jessie E. Quinney Natural Resources Research Library: 131-137. [83477]

303. Hagen, Christian A.; Connelly, John W.; Schroeder, Michael A. 2007. A meta-analysis of greater sage-grouse Centrocercus urophasianus nesting and brood-rearing habitats. Wildlife Biology. 13(Suppl. 1): 42-50. [89954]

304. Hall, Harvey M.; Clements, Frederic E. 1923. The phylogenetic method in taxonomy: The North American species of Artemisia, Chrysothamnus, and Atriplex. Publication No. 326. Washington, DC: The Carnegie Institute of Washington. 355 p. [43183]

305. Halofsky, Jessica E.; Peterson, David L.; Ho, Joanne J.; Little, Natalie, J.; Joyce, Linda A., eds. 2018. Climate change vulnerability and adaptation in the Intermountain Region. Part 1. Gen. Tech. Rep. RMRS-GTR-375. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 197 p. [92809]

306. Hann, Wendel J.; Jones, Jeffrey L.; Karl, Michael G. "Sherm"; Hessburg, Paul F.; Keane, Robert E.; Long, Donald G.; Menakis, James P.; McNicoll, Cecilia H.; Leonard, Stephen G.; Gravenmier, Rebecca A.; Smith, Bradley G. 1997. Landscape dynamics of the Basin. In: Quigley, Thomas M.; Arbelbide, Sylvia, tech. eds. An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 337-968. [89980]

307. Hardegree, Stuart P. 1994. Matric priming increases germination rate of Great Basin native perennial grasses. Agronomy Journal. 86(2): 289-293. [41619]

308. Harniss Roy O.; McDonough, W. T. 1976. Yearly variation in germination in three subspecies of big sagebrush. Journal of Range Management. 29(2): 167-168. [1084]

309. Harniss, R. O.; McDonough, W. T. 1975. Seedling growth of three big sagebrush subspecies under controlled temperature regimens. Journal of Range Management. 28(3): 243-244. [91467]

310. Harrell, Destin. 2016. Personal communication [Phone call with Robin Innes]. 19 May. Regarding use of prescribed fire in greater sage-grouse habitats within the Cody field office. Cody, WY: U.S. Department of the Interior, Bureau of Land Management, Wind River/Bighorn Basin District, Cody Field Office. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [90480]

311. Harvey, Stephen John. 1981. Life history and reproductive strategies in Artemisia. Bozeman, MT: Montana State University. 132 p. Thesis. [1102]

312. Hassan, M. A.; West, N. E. 1986. Dynamics of soil seed pools in burned and unburned sagebrush semi-deserts. Ecology. 67(1): 269-272. [1103]

313. Hassan, Mohamed Ali. 1983. Effects of a wildfire on seed rain and soil seed reserve dynamics of a good condition sagebrush-grass rangeland in central Utah. Logan, UT: Utah State University. 127 p. Thesis. [92972]

314. Hemstrom, Miles A.; Wisdom, Michael J.; Hann, Wendel J.; Rowland, Mary M.; Wales, Barbara C.; Gravenmier, Rebecca A. 2002. Sagebrush-steppe vegetation dynamics and restoration potential in the interior Columbia Basin, U.S.A. Conservation Biology. 16(5): 1243-1255. [45072]

315. Herman-Brunson, Katie M.; Jensen, Kent C.; Kaczor, Nicholas W.; Swanson, Christopher C.; Rumble, Mark A.; Klaver, Robert W. 2009. Nesting ecology of greater sage-grouse Centrocercus urophasianus at the eastern edge of their historical distribution. Wildlife Biology. 15(4): 395-404. [90124]

316. Herriman, Kayla R.; Davis, Anthony S. 2016. Do container volume, site preparation, and field fertilization affect restoration potential of Wyoming big sagebrush? Natural Areas Journal. 36: 194-201. [93132]

317. Hess, Jennifer E. 2011. Greater sage-grouse (Centrocercus urophasianus) habitat response to mowing and prescribed burning Wyoming big sagebrush and the influence of disturbance factors on lek persistence in the Bighorn Basin, Wyoming. Laramie, WY: University of Wyoming. 141 p. Thesis. [90178]

318. Hess, Jennifer E.; Beck, Jeffrey L. 2012. Burning and mowing Wyoming big sagebrush: Do treated sites meet minimum guidelines for greater sage-grouse breeding habitats? Wildlife Society Bulletin. 36(1): 85-93. [86632]

319. Hess, Jennifer E.; Beck, Jeffrey L. 2012. Disturbance factors influencing greater sage-grouse lek abandonment in north-central Wyoming. The Journal of Wildlife Management. 76(8): 1625-1634. [86385]

320. Hess, Jennifer E.; Beck, Jeffrey L. 2014. Forb, insect, and soil response to burning and mowing Wyoming big sagebrush in greater sage-grouse breeding habitat. Environmental Management. 53(4): 813-822. [89211]

321. Hickman, James C., ed. 1993. The Jepson manual: Higher plants of California. Berkeley, CA: University of California Press. 1400 p. [21992]

322. Higgins, Kenneth F.; Kruse, Arnold D.; Piehl, James L. 1989. Effects of fire in the Northern Great Plains. Ext. Circ. EC-761. Brookings, SD: South Dakota State University, Cooperative Extension Service; South Dakota Cooperative Fish and Wildlife Research Unit. 47 p. [14749]

323. Hild, A. L.; Christensen, B.; Maier, A. 1999. Wyoming big sagebrush (Artemisia tridentata spp. wyomingensis) seedling growth and maternal plant stand position. In: McArthur, E. Durant; Ostler, W. Kent; Wambolt, Carl L., comps. Proceedings: Shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 287-289. [36102]

324. Hironaka, M. 1991. Vegetation of lower Snake River Plains. In: Abstracts, 64th annual meeting of the Northwest Scientific Association; 1991 March 20-22; Boise, ID. In: Northwest Science. 65(2): 64. Abstract. [17142]

325. Hironaka, M.; Fosberg, M. A.; Winward, A. H. 1983. Sagebrush-grass habitat types of southern Idaho. Bulletin Number 35. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 44 p. [1152]

326. Hironaka, Minoru. 1963. Plant-environment relations of major species in sagebrush-grass vegetation of southern Idaho. Madison, WI: University of Wisconsin. 124 p. Dissertation. [1154]

327. Hodgkinson, Harmon S. 1989. Big sagebrush subspecies and management implications. Rangelands. 11(1): 20-22. [6265]

328. Hoffman, Trista L.; Wambolt, Carl L. 1996. Growth response of Wyoming big sagebrush to heavy browsing by wild ungulates. In: Barrow, Jerry R.; McArthur, E. Durant; Sosebee, Ronald E.; Tausch, Robin J., comps. Proceedings: Shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 242-245. [27055]

329. Hoffman, Trista Lynn. 1996. An ecological investigation of mountain big sagebrush in the Gardiner Basin. Bozeman, MT: Montana State University. 84 p. Thesis. [46911]

330. Holechek, Jerry L. 1981. Brush control impacts on rangeland wildlife. Journal of Soil and Water Conservation. 36(5): 265-269. [1182]

331. Holland, Robert F. 1986. Preliminary descriptions of the terrestrial natural communities of California. Sacramento, CA: California Department of Fish and Game. 156 p. [12756]

332. Holloran, Matthew J. 1999. Sage-grouse (Centrocercus urophasianus) seasonal habitat use near Casper, Wyoming. Laramie, WY: University of Wyoming. 128 p. Thesis. [90161]

333. Holmes, Aaron L. 2007. Short-term effects of a prescribed burn on songbirds and vegetation in mountain big sagebrush. Western North American Naturalist. 67(2): 292-298. [67950]

334. Holmes, Aaron L. 2010. Small mammal and bird abundance in relation to post-fire habitat succession in mountain big sagebrush (Artemisia tridentata spp. vaseyana) communities. Corvallis, OR: Oregon State University. 128 p. Dissertation. [91212]

335. Holmes, Aaron L.; Maestas, Jeremy D.; Naugle, David E. 2017. Bird response to removal of western juniper in sagebrush-steppe. Rangeland Ecology and Management. 70(1): 87-94. [91612]

336. Holmes, Aaron L.; Miller, R. F. 2010. State-and-transition models for assessing grasshopper sparrow habitat us. Journal off Wildlife Management. 74(8): 1834-1840. [93142]

337. Holmes, Aaron L.; Robinson, W. Douglas. 2013. Fire mediated patterns of population densities in mountain big sagebrush bird communities. The Journal of Wildlife Management. 77(4): 737-748. [86949]

338. Holmes, Aaron L.; Robinson, W. Douglas. 2016. Small mammal abundance in mountain big sagebrush communities after fire and vegetation recovery. Western North American Naturalist. 76(3): 326-338. [91596]

339. Holmes, Jennifer A.; Johnson, Matthew J. 2005. Brewer's sparrow (Spizella breweri): A technical conservation assessment, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region (Producer). 51 p. Available: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5182053.pdf [2017, February 10]. [91428]

340. Holmes, Jennifer A.; Johnson, Matthew J. 2005. Sage sparrow (Amphispiza belli): A technical conservation assessment, [Online]. Durango, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region (Producer). Available: http://www.fs.fed.us/r2/projects/scp/assessments/sagesparrow.pdf [2017, February 1]. [91429]

341. Holthuijzen, Maike F. 2015. Grass-shrub spatial associations over precipitation and grazing gradients in the Great Basin, USA. Logan, UT: Utah State University. 70 p. Thesis. [93145]

342. Homer, Collin G.; Edwards, Thomas C., Jr.; Ramsey, R. Douglas; Price, Kevin P. 1993. Use of remote sensing methods in modelling sage grouse winter habitat. The Journal of Wildlife Management. 57(1): 78-84. [89960]

343. Hopkins, William E. 1979. Plant associations of South Chiloquin and Klamath Ranger Districts--Winema National Forest. R6-Ecol-79-005. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 96 p. [7339]

344. Horton, Jerome S.; Campbell, C. J. 1974. Management of phreatophyte and riparian vegetation for maximum multiple use values. Res. Pap. RM-117. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 23 p. [6318]

345. Hourihan, Erin; Schultz, Brad W.; Perryman, Barry L. 2018. Climatic influences on establishment pulses of four Artemisia species in Nevada. Rangeland Ecology & Management. 71(1): 77-86. [92677]

346. Houston, Kent E.; Hartung, Walter J.; Hartung, Carol J. 2001. A field guide for forest indicator plants, sensitive plants, and noxious weeds of the Shoshone National Forest, Wyoming. Gen. Tech. Rep. RMRS-

GTR-84. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 184 p. [40585]

347. Huber, Allen; Goodrich, Sherel. 1999. Big sagebrush, crested wheatgrass, and grazing on gravel-cobble pediments of the Duchesne River formation and Puaternary deposits in Uintah County, Utah. In: McArthur, E. Durant; Ostler, W. Kent; Wambolt, Carl L., compilers. Proceedings: shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 181-185. [36082]

348. Huber-Sannwald, Elizabeth; Pyke, David A. 2005. Establishing native grasses in a big sagebrush-dominated site: An intermediate restoration step. Restoration Ecology. 13(2): 292-301. [93150]

349. Hulbert, Lloyd C. 1955. Ecological studies of Bromus tectorum and other annual bromegrasses. Ecological Monographs. 25(2): 181-213. [1205]

350. Hull, A. C., Jr.; Hansen, W. Theron, Jr. 1974. Delayed germination of cheatgrass seed. Journal of Range Management. 27(5): 366-368. [43176]

351. Hull, A. C., Jr.; Pechanec, Joseph F. 1947. Cheatgrass--a challenge to range research. Journal of Forestry. 45(8): 555-564. [9930]

352. Humphrey, L. David. 1984. Patterns and mechanisms of plant succession after fire on Artemisia-grass sites in southeastern Idaho. Vegetatio. 57: 91-101. [1214]

353. Hungerford, R. D.; Harrington, M. G.; Frandsen, W. H.; Ryan, K. C.; Niehoff, G. J.. 1991. Influence of fire on factors that affect site productivity. In: Harvey, Alan E.; Neuenschwander, Leon F., comps. Proceedings--management and productivity of western-montane forest soils; 1990 April 10-April 12; Boise. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 32-50. [17438]

354. Hurley, C. A.; Wicklow-Howard, M. 1986. The occurrence of vesicular-arbuscular mycorrhizae associated with Artemisia tridentata var. wyomingensis within burned areas of the Idaho. Journal of the Idaho Academy of Science. 22(1): 7. Abstract. [1223]

355. Ingelfinger, Franz; Anderson, Stanley. 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. Western North American Naturalist. 64(3): 385-395. [92750]

356. Innes, Robin J. 2017. Artemisia tridentata subsp. vaseyana, mountain big sagebrush. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.fed.us/database/feis/plants/shrub/arttriv/all.html. [93331]

357. ITIS Database. 2019. Integrated taxonomic information system, [Online]. Available: http://www.itis.gov/index.html. [51763]

358. Jacobs, Jim; Scianna, Joseph D.; Winslow, Susan R. 2011. Big sagebrush establishment. Plant Materials Tech. Note, No. MT-68. Bozeman, MT: U.S. Department of Agriculture, Natural Resources Conservation Service. 9 p. [91211]

359. Jensen, M. E.; Peck, L. S.; Wilson, M. V. 1988. A sagebrush community type classification for mountainous northeastern Nevada rangelands. The Great Basin Naturalist. 48: 422-433. [27717]

360. Jensen, M. E.; Simonson, G. H.; Dosskey, M. 1990. Correlation between soils and sagebrush-dominated plant communities of northeastern Nevada. Soil Science Society of America Journal. 54: 902-910. [15502]

361. Jensen, Mark E. 1989. Soil characteristics of mountainous northeastern Nevada sagebrush community types. The Great Basin Naturalist. 49(4): 469-481. [9903]

362. Jensen, Mark E.; Simonson, G. H.; Keane, R. E. 1989. Soil temperature and moisture regime relationships within some rangelands of the Great Basin. Soil Science. 147(2): 134-139. [38661]

363. Johnson, Brittany G.; Johnson, Dale W.; Chambers, Jeanne C.; Blank, Robert R. 2011. Fire effects on the mobilization and uptake of nitrogen by cheatgrass (Bromus tectorum L.). Plant Soil. 341(1): 437-445. [82364]

364. Johnson, Charles Grier, Jr.; Swanson, David K. 2005. Bunchgrass plant communities of the Blue and Ochoco Mountains: A guide for managers. Gen. Tech. Rep. PNW-GTR-641. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 119 p. [63805]

365. Johnson, Donald E. 1951. Biology of the elk calf, Cervus canadensis Nelsoni. The Journal of Wildlife Management. 15(4): 396-410. [83301]

366. Johnson, Douglas H.; Holloran, Matthew J.; Connelly, John W.; Hanser, Steven E.; Amundson, Courtney L.; Knick, Steven T. 2011. Influences of environmental and anthropogenic features on greater sage-grouse populations, 1997-2007. Chapter 17. In: Knick, Steven T.; Connelly, John W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology, No. 38. Berkeley, CA: University of California Press: 407-450. [89723]

367. Johnson, Dustin D.; Miller, Richard F. 2006. Structure and development of expanding western juniper woodlands as influenced by two topographic variables. Forest Ecology and Management. 229(1-3): 7-15. [62648]

368. Johnson, James R.; Payne, Gene F. 1968. Sagebrush reinvasion as affected by some environmental influences. Journal of Range Management. 21: 209-213. [1280]

369. Johnson-Nistler, Carolyn M.; Sowell, Bok F.; Sherwood, Harrie W.; Wambolt, Carl L. 2004. Black-tailed prairie dog effects on Montana's mixed-grass prairie. Journal of Range Management. 57(6): 641-648. [38014]

370. Johnston, Aaron N.; Beever, Erik A.; Merkle, Jerod A.; Chong, Geneva. 2018. Vegetation responses to sagebrush-reduction treatments measured by satellites. Ecological Indicators. 87: 66-76. [92678]

371. Johnston, Barry C. 1987. Plant associations of Region 2: Potential plant communities of Wyoming, South Dakota, Nebraska, Colorado, and Kansas. 4th ed. R2-ECOL-87-2. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region. 429 p. [54304]

372. Jones, George P. 1991. Seedling survival and adult plant water relations of black sagebrush and big sagebrush in the Laramie Basin. Laramie, WY: University of Wyoming. 151 p. Dissertation. [92968]

373. Kaczor, Nicholas W.; Jensen, Kent C.; Klaver, Robert W.; Rumble, Mark A.; Herman-Brunson, Katie M; Swanson, Christopher C. 2011. Nesting success and resource selection of greater sage-grouse. Chapter 8. In: Sandercock, Brett; Martin, Kathy; Segelbacher, Gernot, eds. Ecology, conservation and management of grouse. Studies in Avian Biology, Number 39. Berkeley, California: University of California Press: 107-118. [90122]

374. Kaltenecker, J. H.; Wicklow-Howard, M. C.; Rosentreter, R. 1999. Biological soil crusts in three sagebrush communities recovering from a century of livestock trampling. In: McArthur, E. Durant; Ostler, W. Kent; Wambolt, Carl L., comps. Proceedings: Shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 222-226. [36091]

375. Kaltenecker, Julie; Wicklow-Howard, Marcia. 1994. Microbiotic soil crusts in sagebrush habitats of southern Idaho. Walla Walla, WA: Interior Columbia Basin Ecosystem Management Project. Unpublished report prepared for the Eastside Ecosystem Management Project on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 48 p. [26455]

376. Karrfalt, Robert P.; Shaw, Nancy. 2013. Banking Wyoming big sagebrush seeds. Native Plants. 14(1): 60-70. [93271]

377. Kartesz, J. T. The Biota of North America Program (BONAP). 2015. Taxonomic Data Center, [Online]. Chapel Hill, NC: The Biota of North America Program (Producer). Available: http://bonap.net/tdc [Maps generated from Kartesz, J. T. 2010. Floristic synthesis of North America, Version 1.0. Biota of North America Program (BONAP). [in press]. [84789]

378. Kartesz, John T. 1994. A synonymized checklist of the vascular flora of the United States, Canada, and Greenland. Volume I--checklist. 2nd ed. Portland, OR: Timber Press. 622 p. [23877]

379. Kasworm, Wayne F.; Irby, Lynn R.; Ihsle Pac, Helga B. 1984. Diets of ungulates using winter ranges in northcentral Montana. Journal of Range Management. 37(1): 67-71. [63610]

380. Katzner, Todd E.; Parker, Katherine L. 1997. Vegetative characteristics and size of home ranges used by pygmy rabbits (Brachylagus idahoensis) during winter. Journal of Mammalogy. 78(4): 1063-1072. [92738]

381. Keane, Robert E.; Agee, James K.; Fule, Peter; Keeley, Jon E.; Key, Carl; Kitchen, Stanley G.; Miller, Richard; Schulte, Lisa A. 2008. Ecological effects of large fires on US landscapes: Benefit or catastrophe? International Journal of Wildland Fire. 17(6): 696-712. [73387]

382. Keating, Kimberly A.; Irby, Lynn R.; Kasworm, Wayne F. 1985. Mountain sheep winter food habits in the upper Yellowstone Valley. The Journal of Wildlife Management. 49(1): 156-161. [15521]

383. Kelsey, Rick G. 1986. Emergence, seedling growth, and crude terpenoid concentrations in a sagebrush garden. In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 358-365. [1326]

384. Kelsey, Rick G.; Morris, Melvin S.; Shafizadeh, Fred. 1976. The use of sesquiterpene lactones as taxonomic markers in the shrubby species of Artemisia (section Tridentatae) in Montana. Journal of Range Management. 29(6): 502-505. [1329]

385. Kelsey, Rick G.; Wright, William E.; Sneva, Forrest; Winward, Al; Britton, Carlton. 1983. The concentration and composition of big sagebrush essential oils from Oregon. Biochemical Systematics and Ecology. 11(4): 353-360. [91447]

386. Kerley, Linda L.; Anderson, Stanley H. 1995. Songbird responses to sagebrush removal in a high elevation sagebrush steppe ecosystem. Prairie Naturalist. 27(3): 129-146. [27097]

387. Kerley, Linda. 1994. Bird response to habitat fragmentation caused by sagebrush management in a Wyoming sagebrush steppe system. Laramie, WY: University of Wyoming. 144 p. Dissertation. [90040]

388. Kindschy, Robert R. 1986. Rangeland vegetative succession--implications to wildlife. Rangelands. 8(4): 157-159. [22]

389. Kindschy, Robert R.; Sundstrom, Charles; Yoakum, James D. 1982. Wildlife habitats in managed rangelands--the Great Basin of southeastern Oregon: Pronghorns. Gen. Tech. Rep. PNW-145. Portland, OR: U.S. Department of Agriculture, Forest Service. 18 p. [9496]

390. Kirol, Christopher P.; Beck, Jeffrey L.; Dinkins, Jonathan B.; Conover, Michael R. 2012. Microhabitat selection for nesting and brood-rearing by the greater sage-grouse in xeric big sagebrush. The Condor. 114(1): 75-89. [93180]

391. Kirol, Christopher P.; Beck, Jeffrey L.; Huzurbazar, Snehalata V.; Holloran, Matthew J.; Miller, Scott N. 2015. Identifying greater sage-grouse source and sink habitats for conservation planning in an energy development landscape. Ecological Applications. 25(4): 968-990. [93181]

392. Kitchen, Stanley G.; McArthur, E. Durant. 2007. Big and black sagebrush landscapes. In: Hood, Sharon M.; Miller, Melanie, eds. Fire ecology and management of the major ecosystems of southern Utah. Gen. Tech. Rep. RMRS-GTR-202. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 73-95. [71081]

393. Kitchen, Stanley G.; Weisberg, Peter J. 2013. Historic fire frequency in mountain big sagebrush communities of the eastern Great Basin and Colorado Plateau: A comparison of estimates based upon proxy fire records and predictions derived from post-fire succession rates, [Online]. JFSP Research Project Reports, Paper 92, Project Number 06-3-1-17. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Joint Fire Science Program (Producer). 39 p. Available: http://digitalcommons.unl.edu/jfspresearch/92. [90808]

394. Klebenow, Donald A. 1985. Big game response to fire in sagebrush-grass rangelands. In: Saunders, Ken; Durham, Jack; [and others], eds. Rangeland fire effects: Proceedings of the symposium; 1984 November 27-29; Boise, ID. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 53-57. [1347]

395. Kleinhesselink, Andrew R.; Alder, Peter B. 2018. The response of big sagebrush (Artemisia tridentata) to interannual climate variation changes across its range. Ecology. 99(5): 1139-1149. [92728]

396. Klopatek, Carole Coe; DeBano, Leonard F.; Klopatek, Jeffrey M. 1988. Effects of simulated fire on vesicular-arbuscular mycorrhizae in pinyon- juniper woodland soil. Plant and Soil. 109: 245-249. [6576]

397. Knapp, Paul A. 1998. Spatio-temporal patterns of large grassland fires in the Intermountain West, U.S.A. Global Ecology and Biogeography Letters. 7(4): 259-273. [30109]

398. Knick, Steven T.; Dobkin, David S.; Rotenberry, John T.; Schroeder, Michael A.; Vander Haegen, W. Matthew; van Riper, Charles, III. 2003. Teetering on the edge or too late? Conservation issues for avifauna of sagebrush habitats. The Condor. 105(4): 611-634. [75524]

399. Knick, Steven T.; Holmes, Aaron L.; Miller, Richard F. 2005. The role of fire in structuring sagebrush habitats and bird communities. In: Saab, Victoria A.; Powell, Hugh D. W., eds. Fire and avian ecology in North America. Studies in Avian Biology No. 30. Ephrata, PA: Cooper Ornithological Society: 63-75. [65140]

400. Knick, Steven T.; Rotenberry, John T. 1997. Landscape characteristics of disturbed shrubsteppe habitats in southwestern Idaho (U.S.A.). Landscape Ecology. 12(5): 287-297. [43168]

401. Knight, D. H. 1994. Sagebrush steppe. In: Mountain and Plains. The Ecology of Wyoming Landscapes. New Haven, CT: Yale University: 90-107. [92942]

402. Knight, Dennis H.; Jones, George P.; Akashi, Yoshiko; Myers, Richard W. 1987. Vegetation ecology in the Bighorn Canyon National Recreation Area: Wyoming and Montana. Final Report. Laramie, WY: University of Wyoming; National Park Service Research Center. 114 p. [12498]

403. Koniak, Susan. 1985. Succession in pinyon-juniper woodlands following wildfire in the Great Basin. The Great Basin Naturalist. 45(3): 556-566. [1371]

404. Korfmacher, John L.; Chambers, Jeanne C.; Tausch, Robin J.; Roundy, Bruce A.; Meyer, Susan E.; Kitchen, Stanley. 2003. Tech. Note: A technique for conducting small-plot burn treatments. Journal of Range Management. 56(3): 251-254. [47097]

405. Krausman, Paul R.; Bowyer, R. Terry. 2003. Mountain sheep (Ovis canadensis and O. dalli). In: Feldhamer, George A.; Thompson, Bruce C.; Chapman, Joseph A., eds. Wild mammals of North America: Biology, management, and conservation. 2nd ed. Baltimore, MD: Johns Hopkins University Press: 1095-1115. [82128]

406. Kuchler, A. W. 1975. United States [Potential natural vegetation of the conterminous United States]. Special Publication No. 36. New York: American Geographical Society. 1:3,168,000; colored. 2nd edition.

[28322]

407. Kufeld, Roland C. 1973. Foods eaten by the Rocky Mountain elk. Journal of Range Management. 26(2): 106-113. [1385]

408. Kufeld, Roland C.; Wallmo, O. C.; Feddema, Charles. 1973. Foods of the Rocky Mountain mule deer. Res. Pap. RM-111. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 31 p. [1387]

409. La Tourrette, Jospeh E.; Young, James A.; Evans, Raymond A. 1971. Seed dispersal in relation to rodent activities in seral big sagebrush communities. Journal of Range Management. 24(2): 118-120. [90620]

410. Lambert, Scott M. 2005. Seeding considerations in restoring big sagebrush habitat. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 75-80. [63186]

411. Landeen, Melissa L. 2015. Mountain big sagebrush (Artemisia tridentata ssp vaseyana) seed production. Provo, UT: Brigham Young University. 72 p. Thesis. [91499]

412. LANDFIRE Biophysical Settings. 2014n. Inter-Mountain Basins Big Sagebrush Shrubland: Biophysical setting 10800. Review guidance for LANDFIRE Biophysical Settings Models and Descriptions. In: LANDFIRE Biophysical Setting Model: Map zone 18, [Online]. In: Vegetation Dynamics Models. In: LANDFIRE. Washington, DC: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Geological Survey; Arlington, VA: The Nature Conservancy (Producers). Available: http://www.landfirereview.org/individual-review.html [2018, January 18]. [92634]

413. LANDFIRE Biophysical Settings. 2014q. Inter-Mountain Basins Big Sagebrush Shrubland - Wyoming Big Sagebrush: Biophysical setting 10802. Review guidance for LANDFIRE Biophysical Settings Models and Descriptions. In: LANDFIRE Biophysical Setting Model: Map zone 21, [Online]. In: Vegetation Dynamics Models. In: LANDFIRE. Washington, DC: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Geological Survey; Arlington, VA: The Nature Conservancy (Producers). Available: http://www.landfirereview.org/individual-review.html [2018, January 18]. [92637]

414. LANDFIRE Biophysical Settings. 2014r. Inter-Mountain Basins Big Sagebrush Shrubland - Wyoming Big Sagebrush: Biophysical setting 10802. Review guidance for LANDFIRE Biophysical Settings Models and Descriptions. In: LANDFIRE Biophysical Setting Model: Map zone 22, [Online]. In: Vegetation Dynamics Models. In: LANDFIRE. Washington, DC: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory; U.S. Geological Survey; Arlington, VA: The Nature Conservancy (Producers). Available: http://www.landfirereview.org/individual-review.html [2018, January 18]. [92638]

415. LANDFIRE. 2008. Alaska refresh (LANDFIRE 1.1.0). Biophysical settings layer. In: LANDFIRE data distribution site, [Online]. In: LANDFIRE. U.S. Department of the Interior, Geological Survey (Producer). Available: https://landfire.cr.usgs.gov/viewer/ [2017, January 10]. [86808]

416. LANDFIRE. 2008. CONUS refresh (LANDFIRE 1.1.0). Biophysical settings layer, LANDFIRE data distribution site, [Online]. In: LANDFIRE. U.S. Department of the Interior, Geological Survey (Producer). Available: https://landfire.cr.usgs.gov/viewer/ [2017, January 10]. [89416]

417. Larrucea, E. S.; Brussard, P. F. 2008. Shift in location of pygmy rabbit (Brachylagus idahoensis) habitat in response to changing environments. Journal of Arid Environments. 72(9): 1636-1643. [91522]

418. Larrucea, Eveline; S.; Brussard, P. F. 2008. Habitat selection and current distribution of the pygmy rabbit in Nevada and California, USA. Journal of Mammalogy. 89(3): 691-699. [91443]

419. Laycock, W. A. 1991. Stable states and thresholds of range condition on North American rangelands: A viewpoint. Journal of Range Management. 44(5): 427-433. [43349]

420. Laycock, W. A.; Bartos, D. L.; Klement, K. D. 2004. Species richness inside and outside long-term exclosures. In: Hild, Ann L.; Shaw, Nancy L.; Meyer, Susan E.; Booth, D. Terrance; McArthur, E. Durant, comps. Seed and soil dynamics in shrubland ecosystems: Proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 183-188. [49239]

421. Laycock, William A. 1979. Management of sagebrush. Rangelands. 1(5): 207-210. [1423]

422. Leaf, Charles F. 1975. Watershed management in the central and southern Rocky Mountains: A summary of the status of our knowledge by vegetation types. Res. Pap. RM-142. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 28 p. [8422]

423. Lesica, Peter. 2017. Unpublished data on mountain big sagebrush, Wyoming big sagebrush, and basin big sagebrush postfire recovery. Documents on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. 3 p. [93112]

424. Lesica, Peter; Cooper, Stephen V.; Kudray, Greg. 2005. Big sagebrush shrub-steppe postfire succession in southwest Montana. Report to Bureau of Land Management, Dillon Field Office. Helena, MT: Montana Natural Heritage Program, Natural Resource Information System. 29 p. [91595]

425. Lesica, Peter; Cooper, Stephen V.; Kudray, Greg. 2007. Recovery of big sagebrush following fire in southwest Montana. Rangeland Ecology & Management. 60(3): 261-269. [68272]

426. Lesica, Peter; Cooper, Stephen. 2018. Personal communication [Email to Robin Innes]. 9 November. Regarding unpublished data on Wyoming big sagebrush postfire recovery at Steele Creek. Missoula, MT. Documents on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [93116]

427. Levitt, Jacob. 1980. 2nd ed. Responses of plants to environmental stresses. Volume I: Chilling, freezing, and high temperature stresses. Physiological Ecology Series. New York: Academic Press. 497 p. [79587]

428. Link, Steven O.; Keeler, Carson W.; Hill, Randal W.; Hagan, Eric. 2006. Bromus tectorum cover mapping and fire risk. International Journal of Wildland Fire. 15: 113-119. [91583]

429. Littell, Jeremy S.; McKenzie, Donald; Peterson, David L.; Westerling, Anthony L. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003. Ecological Applications. 19(4): 1003-1021. [81459]

430. Lommasson, T. 1948. Succession in sagebrush. Journal of Range Management. 1: 19-21. [1468]

431. Long, Lynn E. 1986. Container nursery production of Artemisia and Chrysothamnus species. In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 395-396. [1469]

432. Long, Ryan A.; Rachlow, Janet L.; Kie, John G. 2008. Effects of season and scale on response of elk and mule deer to habitat manipulation. The Journal of Wildlife Management. 72(5): 1133-1142. [82412]

433. Long, Ryan A.; Rachlow, Janet L.; Kie, John G.; Vavra, Martin. 2008. Fuels reduction in a western coniferous forest: Effects on quantity and quality of forage for elk. Rangeland Ecology and Management. 61: 302-313. [70956]

434. Lyford, Mark E. 1995. Shrub establishment on drastically disturbed lands. Laramie, WY: University of Wyoming. 84 p. Thesis. [93087]

435. Lyon, L. Jack; Crawford, Hewlette S.; Czuhai, Eugene; Fredriksen, Richard L.; Harlow, Richard F.; Metz, Louis J.; Pearson, Henry A. 1978. Effects of fire on fauna: A state-of-knowledge review--National fire effects workshop; 1978 April 10-14; Denver, CO. Gen. Tech. Rep. WO-6. Washington, DC: U.S. Department of Agriculture, Forest Service. 41 p. [25066]

436. Lyon, L. Jack; Telfer, Edmund S.; Schreiner, David Scott. 2000. Direct effects of fire and animal responses. In: Smith, Jane Kapler, ed. Wildland fire in ecosystems: Effects of fire on fauna. Gen. Tech. Rep. RMRS-GTR-42-Vol. 1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 17-23. [44435]

437. Lysne, Cindy R. 2005. Restoring Wyoming big sagebrush. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 93-98. [63188]

438. MacDonald, Linda. 1999. Wildfire rehabilitation in Utah. In: Monsen, Stephen B.; Stevens, Richard, comps. Proceedings: Ecology and management of pinyon-juniper communities within the Interior West: Sustaining and restoring a diverse ecosystem; 1997 September 15-18; Provo, UT. Proceedings RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 410-411. [30590]

439. Mackie, Richard J.; Hamlin, Kenneth L.; Pac, David F. 1987. Mule-deer. In: Chapman, Joseph A.; Feldhamer, George A., eds. Wild mammals of North America. Baltimore, MD: Johns Hopkins University Press: 862-877. [14400]

440. Mackie, Richard J.; Kie, John G.; Pac, David F.; Hamlin, Kenneth L. 2003. Mule deer (Odocoileus hemionus). In: Feldhamer, George A.; Thompson, Bruce C.; Chapman, Joseph A., eds. Wild mammals of North America: Biology, management, and conservation. 2nd ed. Baltimore, MD: Johns Hopkins University Press: 889-905. [82121]

441. Mahalovich, Mary F.; McArthur, E. Durant. 2004 (revised 2016). Sagebrush (Artemisia spp.): Seed and plant transfer guidelines. Native Plants Journal. Fall 2004: 141-148. [90903]

442. Mahood, Adam Lee. 2017. Long-term effects of repeated fires on the diversity and composition of Great Basin sagebrush plant communities. Boulder, CO: University of Colorado. 37 p. Thesis. [92388]

443. Maier, Aaron M.; Perryman, Barry L.; Olson, Richard A.; Hild, Ann L. 2001. Climatic influences on recruitment of 3 subspecies of Artemisia tridentata. Journal of Range Management. 54(6): 699-703. [40189]

444. Mangan, Larry; Autenrieth, R. 1985. Vegetation changes following 2,4-D application and fire in a mountain big sagebrush habitat type. In: Saunders, Ken; Durham, Jack; [and others], eds. Rangeland fire effects: Proceedings of the symposium; 1984 November 27-29; Boise, ID. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 61-65. [1519]

445. Manier, D. J.; Wood, D. J. A.; Bowen, Z. H.; Donovan, R. M.; Holloran, M. J.; Juliusson, L. M.; Mayne, K. S.; Oyler-McCance, S. J.; Quamen, F. R.; Saher, D. J.; Titolo, A. J. 2013. Summary of science, activities, programs, and policies that influence the rangewide conservation of greater sage-grouse (Centrocercus urophasianus), [Online]. Open-File Rep. 2013-1098. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey (Producer). 151 p. Available: http://pubs.usgs.gov/of/2013/1098/ [2016, March 21]. [90148]

446. Manier, Daniel J.; Hobbs, N. Thompson; Theobald, David M.; Reich, Robin M.; Kalkhan, Mohammed A.; Campbell, Mark R. 2005. Canopy dynamics and human caused disturbance on a semi-arid landscape in the Rocky Mountains, USA. Landscape Ecology. 20(1): 1-17. [91631]

447. Marlette, Guy M.; Anderson, Jay E. 1986. Seed banks and propagule dispersal in crested-wheatgrass stands. Journal of Applied Ecology. 23: 161-175. [1526]

448. Martin, Alexander C.; Zim, Herbert S.; Nelson, Arnold L. 1951. American wildlife and plants. New York: McGraw-Hill. 500 p. [4021]

449. Maser, Chris; Gashwiler, Jay S. 1978. Interrelationships of wildlife and western juniper. In: Martin, Robert E.; Dealy, J. Edward; Caraher, David L., eds. Proceedings of the western juniper ecology and management workshop; 1977 January; Bend, OR. Gen. Tech. Rep. PNW-74. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 37-82. [1541]

450. Maser, Chris; Strickler, Gerald S. 1978. The sage vole, Lagurus curtatus, as an inhabitant of subalpine sheep fescue, Festuca ovina, communities on Steens Mountain--an observation and interpretation. Northwest Science. 52(3): 276-284. [15507]

451. Mata-Gonzalez, R.; Hunter, R. G.; Coldren, C. L.; McLendon, T.; Paschke, M. W. 2008. A comparison of modeled and measured impacts of resource manipulations for control of Bromus tectorum in sagebrush steppe. Journal of Arid Environments. 72(5): 643-651. [70396]

452. Mata-Gonzalez, Ricardo; Reed-Dustin, Claire M.; Rodhouse, Thomas J. 2018. Contrasting effects of long-term fire on sagebrush steppe shrubs mediated by topography and plant community. Rangeland Ecology and Management. 71(3): 336-344. [92755]

453. Mattise, Samuel N. 1995. Sage grouse in Idaho: Forum '94. Tech. Bull. No. 95-15. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office. 10 p. [26119]

454. McAdoo, J. Kent; Barrington, Mack R.; Ports, Mark A. 2006. Habitat affinities of rodents in northeastern Nevada rangeland communities. Western North American Naturalist. 66(3): 321-331. [65155]

455. McAdoo, J. Kent; Longland, William S.; Cluff, Greg J.; Klebenow, Donald A. 1987. Use of new rangeland seedings by black-tailed jackrabbits. Journal of Range Management. 40(6): 520-524. [135]

456. McArthur, E. D.; Welch, B. L.; Sanderson, S. C. 1988. Natural and artificial hybridization between big sagebrush (Artemisia tridentata) subspecies. Journal of Heredity. 79: 268-276. [76195]

457. McArthur, E. Durant. 1994. Ecology, distribution, and values of sagebrush within the Intermountain region. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 347-351. [24308]

458. McArthur, E. Durant. 2000. Sagebrush systematics and distribution. In: Entwistle, P. G.; DeBolt, A. M.; Kaltenecker, J. H.; Steenhof, K., comps. Sagebrush steppe ecosystems symposium: Proceedings; 1999 June 21-23; Boise, ID. Publ. No. BLM/ID/PT-001001+1150. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Boise State Office: 9-14. [41811]

459. McArthur, E. Durant. 2005. Sagebrush, common and uncommon, palatable and unpalatable. Rangelands. 27(4): 47-51. [60405]

460. McArthur, E. Durant; Blauer, A. Clyde; Plummer, A. Perry; Stevens, Richard. 1979. Characteristics and hybridization of important Intermountain shrubs. III. Sunflower family. Res. Pap. INT-220. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 82 p. [1571]

461. McArthur, E. Durant; Freeman, D. Carl; Graham, John H.; Wang, Han; Sanderson, Stewart C.; Monaco, Thomas A.; Smith, Bruce N. 1998. Narrow hybrid zone between two subspecies of big sagebrush (Artemisia tridentata: Asteraceae). VI. Respiration and water potential. Canadian Journal of Botany. 76(4): 567-574. [29357]

462. McArthur, E. Durant; Giunta, Bruce C.; Plummer, A. Perry. 1977. Shrubs for restoration of depleted range and disturbed areas. Utah Science. 35: 28-33. [25035]

463. McArthur, E. Durant; Plummer, A. Perry. 1978. Biogeography and management of native western shrubs: A case study, section Tridentatae of Artemisia. The Great Basin Naturalist Memoirs. 2: 229-243. [1574]

464. McArthur, E. Durant; Sanderson, Stewart C. 1999. Cytogeography and chromosome evolution of subgenus Tridentatae of Artemisia (Asteraceae). American Journal of Botany. 86(12): 1754-1775. [34931]

465. McArthur, E. Durant; Sanderson, Stewart C. 1999. Ecotones: Introduction, scale, and big sagebrush example. In: McArthur, E. Durant; Ostler, W. Kent; Wambolt, Carl L., comps. Proceedings: Shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 3-8. [36053]

466. McArthur, E. Durant; Welch, Bruce L. 1982. Growth rate differences among big sagebrush [Artemisia tridentata] accessions and subspecies. Journal of Range Management. 35(3): 396-401. [91233]

467. McCorquodale, Scott M.; Raedeke, Kenneth J.; Taber, Richard D. 1986. Elk habitat use patterns in the shrub-steppe of Washington. The Journal of Wildlife Management. 50(4): 664-669. [1593]

468. McDonough, W. T.; Harniss, R. O. 1974. Effects of temperature on germination in three subspecies of big sagebrush. Journal of Range Management. 27(3): 204-205. [1597]

469. McDonough, W. T.; Harniss, R. O. 1974. Seed dormancy in Artemisia tridentata Nutt. subspecies vaseyana Rydb. Northwest Science. 48(1): 17-20. [1598]

470. McGee, John M. 1982. Small mammal populations in an unburned and early fire successional sagebrush community. Journal of Range Management. 35(2): 177-180. [1601]

471. McIntyre, Kristian K. 2003. Species composition and beta diversity of avian communities along a burned/unburned gradient in sagebrush steppe habitat at Sheldon National Wildlife Refuge, Nevada. Alpine, TX: Sul Ross State University. 86 p. Thesis. [91471]

472. McIver, J. D.; Brunson, M.; Bunting, S.; Chambers, J.; Devoe, N.; Doescher, P.; Grace, J.; Johnson, D.; Knick, S.; Miller, R.; Pellant, M.; Pierson, F.; Pyke, D.; Rollins, K.; Roundy, B.; Schupp, E.; Tausch, R.; Turner, D. 2010. The Sagebrush Steppe Treatment Evaluation Project (SageSTEP): A test of state-and-transition theory. RMRS-GTR-237. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 p. [91518]

473. Medin, Dean E.; Welch, Bruce L.; Clary, Warren P. 2000. Bird habitat relationships along a Great Basin elevational gradient. Res. Pap. RMRS-RP-23. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 22 p. [38470]

474. Mehus, Chris Allen. 1995. Influences of browsing and fire on sagebrush taxa of the northern Yellowstone winter range. Bozeman, MT: Montana State University. 70 p. Thesis. [46920]

475. Menakis, James P.; Osborne, Dianne; Miller, Melanie. 2003. Mapping the cheatgrass-caused departure from historical natural fire regimes in the Great Basin, USA. In: Omi, Philip N.; Joyce, Linda A., tech. eds. Fire, fuel treatments, and ecological restoration: Conference proceedings; 2002 April 16-18; Fort Collins, CO. Proceedings RMRS-P-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 281-287. [45333]

476. Mensing, Scott; Livingston, Stephanie; Barker, Pat. 2006. Long-term fire history in Great Basin sagebrush reconstructed from macroscopic charcoal in spring sediments, Newark Valley, Nevada. Western North American Naturalist. 66(1): 64-77. [62274]

477. Messina, Frank J.; Durham, Susan L.; Richards, James H.; McArthur, E. Durant. 2002. Trade-off between plant growth and defense? A comparison of sagebrush populations. Oecologia. 131(1): 43-51. [91234]

478. Meyer, S. E. 1990. Seed source differences in germination under snowpack in northern Utah. In: Proceedings, 5th Billings symposium on disturbed land rehabilitation: Volume I; 1990 March 25-30; Billings, MT. Reclamation Research Unit Publication No. 9003. 184-191. [19829]

479. Meyer, S. E. 2012. Restoring and managing cold desert shrublands for climate change mitigation, Chapter 2. In: Finch, Deborah M., ed. Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Gen. Tech. Rep. RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 21-34. [91463]

480. Meyer, S. E.; McArthur, E. D.; Monsen, S. B. 1987. Infraspecific variation in germination patterns of rangeland shrubs and its relationship to seeding success. In: Frasier, Gary W.; Evans, Raymond A., eds. Seed and seedbed ecology of rangeland plants: proceedings of symposium; 1987 April 21-23; Tucson, AZ. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service: 82-92. [3898]

481. Meyer, Susan E. 1994. Germination and establishment ecology of big sagebrush: Implications for community restoration. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 244-251. [24290]

482. Meyer, Susan E. 2008. Artemisia L., sagebrush. In: Bonner, Franklin T.; Karrfalt, Robert P., eds. Woody plant seed manual. Agric. Handbook No. 727. Washington, DC: U.S. Department of Agriculture, Forest Service: 274-282. [45115]

483. Meyer, Susan E.; Monsen, Stephen B. 1990. Seed-source differences in initial establishment for big sagebrush and rubber rabbitbrush. In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings--symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 200-208. [12852]

484. Meyer, Susan E.; Monsen, Stephen B. 1992. Big sagebrush germination patterns: Subspecies and population differences. Journal of Range Management. 45(1): 87-93. [17776]

485. Meyer, Susan E.; Monsen, Stephen B.; McArthur, E. Durant. 1990. Germination response of Artemisia tridentata (Asteraceae) to light and chill: Patterns of between-population variation. Botanical Gazette. 151(2): 176-183. [15525]

486. Miglia, Kathleen J. 2004. Importance of genotype, soil type, and location on the performance of parental and hybrid big sagebrush reciprocal transplants in the gardens of Salt Creek Canyon. In: Hild, Ann L.; Shaw, Nancy L.; Meyer, Susan E.; Booth, D. Terrance; McArthur, E. Durant, comps. Seed and soil dynamics in shrubland ecosystems: Proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 30-36. [49082]

487. Miller, R. F.; Bates, J. D.; Svejcar, T. J.; Pierson, F. B.; Eddleman, L. E. 2007. Western juniper field guide: Asking the right questions to select appropriate management actions. U.S. Geological Survey Circular 1321. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 61 p. [88757]

488. Miller, R. F.; Doescher P. S.; Swanson, S. R.; Svejcar, T. J.; Buckhouse, J. C.; Sneva, F. A.; Winward, A. H. 1982. Soil-plant relationships among three big sagebrush subspecies. In: Special Report 663. 1982 Progress report--research in rangeland management. Corvallis, OR: Oregon State University, Agricultural Experiment Station: 5-9. In cooperation with: U.S. Department of Agriculture, Agricultural Research Service. [3643]

489. Miller, Richard F. 1989. Plant competition in Oregon's high desert. In: Oregon's high desert: the last 100 years. Special Report 841. Corvallis, OR: Oregon State University, Agricultural Experiment Station: 7-14. In cooperation with: U.S. Department of Agriculture, Agricultural Research Service. [15513]

490. Miller, Richard F.; Bates, Jon D.; Svejcar, Tony J.; Pierson, Fred B.; Eddleman, Lee E. 2005. Biology, ecology, and management of western juniper, [Online]. Tech. Bull. 152. Corvallis, OR: Oregon State

University, Agricultural Experiment Station (Producer). 77 p. Available: http://juniper.oregonstate.edu/bibliography/documents/phpQ65pOk_tb152.pdf [2016, April 6]. [64176]

491. Miller, Richard F.; Chambers, Jeanne C.; Pellant, Mike. 2014. A field guide for selecting the most appropriate treatment in sagebrush and pinon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses, and predicting vegetation response. RMRS-GTR-322-rev. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 68 p. [90440]

492. Miller, Richard F.; Chambers, Jeanne C.; Pellant, Mike. 2015. A field guide for rapid assessment of post-wildfire recovery potential in sagebrush and pinon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses and predicting vegetation response. Gen. Tech. Rep. RMRS-GTR-338. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 70 p. [90443]

493. Miller, Richard F.; Chambers, Jeanne C.; Pyke, David A.; Pierson, Fred B.; Williams, C. Jason. 2013. A review of fire effects on vegetation and soils in the Great Basin Region: Response and ecological site characteristics. Gen. Tech. Rep. RMRS-GTR-308. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 126 p. [87889]

494. Miller, Richard F.; Doescher, Paul; Purrington, Teal. 1991. Dry-wet cycles and sagebrush in the Great Basin. In: Miller, Richard F., ed. Management in the sagebrush steppe. Special Report 880. Corvallis, OR: Oregon State University, Agricultural Experiment Station: 8-15. [92799]

495. Miller, Richard F.; Eddleman, Lee L. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Tech. Bull. 151. Corvallis, OR: Oregon State University, Agricultural Experiment Station. 35 p. [40586]

496. Miller, Richard F.; Knick, Steven T.; Pyke, David A.; Meinke, Cara W.; Hanser, Steven E.; Wisdom, Michael J.; Hild, Ann L. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. In: Knick, Steven T.; Connelly, John W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology, No. 38. Berkeley, CA: University of California Press: 145-184. [89659]

497. Miller, Richard F.; Ratchford, Jaime; Roundy, Bruce A.; Tausch, Robin J.; Hulet, April; Chambers, Jeanne. 2014. Response of conifer-encroached shrublands in the Great Basin to prescribed fire and mechanical treatments. Rangeland Ecology and Management. 67(5): 468-481. [89200]

498. Miller, Richard F.; Rose, Jeffery A. 1995. Historic expansion of Juniperus occidentalis (western juniper) in southeastern Oregon. The Great Basin Naturalist. 55(1): 37-45. [25666]

499. Miller, Richard F.; Rose, Jeffrey A. 1999. Fire history and western juniper encroachment in sagebrush steppe. Journal of Range Management. 52(6): 550-559. [28671]

500. Miller, Richard F.; Seufert, Jamie M.; Hauferkamp, Marshall R. 1986. The ecology and management of bluebunch wheatgrass (Agropyron spicatum): a review. Station Bulletin 669. Corvallis, OR: Oregon State University, Agriculture Experiment Station. 39 p. [6666]

501. Miller, Richard F.; Shultz, Leila M. 1987. Development and longevity of ephemeral and perennial leaves on Artemisia tridentata Nutt. ssp. wyomingensis. The Great Basin Naturalist. 47(2): 227-230. [1655]

502. Miller, Richard F.; Svejcar, Tony J.; Rose, Jeffrey A. 2000. Impacts of western juniper on plant community composition and structure. Journal of Range Management. 53(6): 574-585. [36578]

503. Miller, Richard F.; Svejcar, Tony J.; West, Neil E. 1994. Implications of livestock grazing in the Intermountain sagebrush region: Plant composition. In: Vavra, Martin; Laycock, William A.; Pieper, Rex D., eds. Ecological implications of livestock herbivory in the West. Denver, CO: Society for Range Management: 101-146. [91614]

504. Miller, Richard F.; Tausch, Robin J. 2001. The role of fire in juniper and pinyon woodlands: A descriptive analysis. In: Galley, Krista E. M.; Wilson, Tyrone P., eds. Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species; Fire conference 2000: The first national congress on fire ecology, prevention, and management; 2000 November 27 - December 1; San Diego, CA. Misc. Publ. No. 11. Tallahassee, FL: Tall Timbers Research Station: 15-30. [40675]

505. Miller, Richard F.; Tausch, Robin J.; McArthur, E. Durant; Johnson, Dustin D.; Sanderson, Stewart C. 2008. Age structure and expansion of pinyon-juniper woodlands: A regional perspective in the Intermountain West. Research Paper RMRS-RP-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p. [91332]

506. Miller, Richard F.; Wigand, Peter E. 1994. Holocene changes in semiarid pinyon-juniper woodlands. Bioscience. 44(7): 465-474. [23563]

507. Miller, Rick; Rose, Jeff. 1998. Pre- and post-settlement fire return intervals on Intermountain sagebrush steppe. In: Annual report: Eastern Oregon Agricultural Research Center. Corvallis, OR: Oregon State University, Agricultural Experiment Station: 16-17. [29194]

508. Miller, Rick; Svejcar, Tony; Rose, Jeff. 1999. Conversion of shrub steppe to juniper woodland. In: Monsen, Stephen B.; Stevens, Richard, comps. Proceedings: Ecology and management of pinyon-juniper communities within the Interior West: Sustaining and restoring a diverse ecosystem; 1997 September 15-18; Provo, UT. Proceedings RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 385-390. [30583]

509. Minnick, Tamera J.; Alward, Richard D. 2012. Soil moisture enhancement techniques aid shrub transplant success in an arid shrubland restoration. Rangeland Ecology and Management. 65(3): 232-240. [93131]

510. Monsen, S. B.; Meyer, S. E. 1990. Planning, rehabilitation, and treatment of disturbed lands: Seeding equipment effects on establishment of big sagebrush on mine disturbances. In: Munshower, Frank F.; Fisher, Scott E., Jr., co-chairmen. Proceedings: Fifth Billings Symposium on Disturbed Land Rehabilitation: 1990 March 25-30; Billings, MT. Volume 1: Hardrock waste, analytical and revegetation. Helena, MT: Montana State University: 192-199. [91229]

511. Monsen, S. B.; Shaw, N. L. 1997. Persistence of cheatgrass (Bromus tectorum) amid bunchgrass/shrubsteppe communities. In: Grasslands 2000: Proceedings, 18th international grassland congress; 1997 June 8-18; Winnipeg, MB. Saskatoon, SK: International Grasslands Congress. Session 21.2: 27-28. [33480]

512. Monsen, Stephen B. 1994. Selection of plants for fire suppression on semiarid sites. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 363-373. [24310]

513. Monsen, Stephen B. 1994. The competitive influences of cheatgrass (Bromus tectorum) on site restoration. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-50. [24251]

514. Monsen, Stephen B. 2000. Establishment of big sagebrush (Artemisia tridentata) in semiarid environments. In: Entwistle, P. G.; DeBolt, J. H.; Kaltenecker, J. H.; Steenhof, K., comps. Sagebrush steppe ecosystems symposium: Proceedings; 1999 June 21-23; Boise, ID. Publication No. PLM/ID/PT-001001+1150. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 81-86. [41931]

515. Monsen, Stephen B.; McArthur, E. Durant. 1985. Factors influencing establishment of seeded broadleaf herbs and shrubs following fire. In: Saunders, Ken; Durham, Jack; et al., eds. Rangeland fire effects: Proceedings of the symposium; 1984 November 27-29; Boise, ID. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 112-124. [1682]

516. Monsen, Stephen B.; Meyer, Susan E.; Carlson, Stephanie L. 1992. Sagebrush establishment enhanced by snowfencing. In: Rangeland Technology Equipment Council: 1992 annual report. 2200-Range, 922-2842-MTDC. Washington, DC: U.S. Department of Agriculture, Forest Service, Technology and Development Program: 6-8. [91046]

517. Monsen, Stephen B.; Motley, Pam; Welch, Bob. 2004. Restoration of sagebrush communities following mechanical treatments of pinyon-juniper woodlands. In: Schroeder, Michael A.; Berger, Matt; Robb, Leslie A., tech. comm. 24th meeting of the western agencies sage and Columbian sharp-tailed grouse technical committee. 2004 28 Juneâ€“1 July, Wenatchee, WA; Boise, ID: Western Association of Fish & Wildlife Agencies: 19. Abstract. [93097]

518. Monsen, Stephen B.; Shaw, Nancy L. 2000. Big sagebrush (Artemisia tridentata) communities--ecology, importance and restoration potential. In: Schuman, Gerald E.; Richmond, Timothy C.; Neuman, Dennis R., eds. Sagebrush establishment on mined lands: Ecology and research: Proceedings of the symposium; 2000 March 20-24; Billings, MT. Bozeman, MT: Montana State University, Reclamation Research Unit: 1-15. [42417]

519. Monsen, Stephen B.; Stevens, Richard. 2004. Seedbed preparation and seeding practices. In: Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol. 1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 121-154. [52825]

520. Moritz, William E. 1988. Wildlife use of fire-disturbed areas in sagebrush steppe on the Idaho National Engineering Laboratory. Bozeman, MT: Montana State University. 95 p. Thesis. [90043]

521. Morris, Amy N. 2001. The effects of changes in timing and amounts of precipitation on vegetation dynamics and nitrogen mineralization in a sagebrush-steppe ecosystem. Pocatello, ID: Idaho State University. 98 p. Thesis. [93134]

522. Morris, Lesley R.; Leger, Elizabeth A. 2016. Secondary succession in the sagebrush semidesert 66 Years after fire in the Great Basin, USA. Natural Areas Journal. 36(2): 187-193. [90908]

523. Morris, Melvin S.; Kelsey, Rick G.; Griggs, Dave. 1976. The geographic and ecological distribution of big sagebrush and other woody Artemisias in Montana. Proceedings of the Montana Academy of Sciences. 36: 56-79. [1695]

524. Moseley, Robert K. 1998. Riparian and wetland community inventory of 14 reference areas in southwestern Idaho. Tech. Bull. No. 98-5. Boise, Idaho: U.S. Department of the Interior, Bureau of Land Management, Boise State Office. 52 p. [75569]

525. Mosely, Jeffrey C.; Bunting, Stephen C.; Manoukian, Mark E. 1999. Cheatgrass. In: Sheley, Roger L.; Petroff, Janet K., eds. Biology and management of noxious rangeland weeds. Corvallis, OR: Oregon State University Press: 175-188. [35720]

526. Mosley, Jeffrey C. 1996. Prescribed sheep grazing to suppress cheatgrass: A review. Sheep & Goat Research Journal. 12(2): 74-81. [30475]

527. Mozingo, Hugh N. 1987. Shrubs of the Great Basin: A natural history. Reno, NV: University of Nevada Press. 342 p. [1702]

528. Mueggler, W. F. 1967. Voles damage big sagebrush in southwestern Montana. Journal of Range Management. 20(2): 88-91. [91417]

529. Mueggler, Walter F. 1956. Is sagebrush seed residual in the soil of burns or is it wind-borne? Research Note No. 35. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p. [1704]

530. Mueggler, Walter F. 1976. Ecological role of fire in western woodland and range ecosystems. In: Use of prescribed burning in western woodland and range ecosystems: Proceedings of the symposium; 1976

March 18-19; Logan, UT. Logan, UT: Utah State University, Utah Agricultural Experiment Station: 1-9. [1709]

531. Muscha, Jennifer M.; Hild, Ann L.; Munn, Larry C.; Stahl, Peter D. 2004. Impacts of livestock exclusion from Wyoming big sagebrush communities. In: Hild, Ann L.; Shaw, Nancy L.; Meyer, Susan E.; Booth, D. Terrance; McArthur, E. Durant, comps. Seed and soil dynamics in shrubland ecosystems: proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 176-182. [49238]

532. Nafus, Aleta M.; Svejcar, Tony J.; Davies, Kirk W. 2016. Disturbance history, management, and seeding year precipitation influences vegetation characteristics of crested wheatgrass stands. Rangeland Ecology and Management. 69(4): 248-256. [93144]

533. Nagy, Julius G. 1979. Wildlife nutrition and the sagebrush ecosystem. In: The sagebrush ecosystem: A symposium: Proceedings; 1978 April; Logan, UT. Logan, UT: Utah State University, College of Natural Resources: 164-168. [1729]

534. NatureServe. 2016. International ecological classification standard: Terrestrial ecological classifications, [Online]. In: NatureServe Central Databases. Arlington, VA: NatureServe (Producer). Available: http://explorer.natureserve.org/servlet/NatureServe?init=Ecol [2019, January 30]. [87721]

535. Neilson, Ronald P.; Lenihan, James M.; Bachelet, Dominique; Drapek, Raymond J. 2005. Climate change implications for sagebrush ecosystems. In: Sparrowe, Rollin D., chair; Carpenter, Len H., cochair. The sage-grouse dilemma: A case study of long-term landscape use and abuse; 2005 March 16-19; Arlington, VA. Transactions of the 70th North American Wildlife and Natural Resources Conference. Washington, D.C.: Wildlife Management Institute: 145-159. [91458]

536. Nelle, Pamela J.; Reese, Kerry P.; Connelly, John W. 2000. Long-term effects of fire on sage grouse habitat. Journal of Range Management. 53(6): 586-591. [37079]

537. Nelson, David L.; Harper, Kimball T.; Boyer, Kenneth C.; Weber, Darrell J.; Haws, B. Austin; Marble, James R. 1989. Wildland shrub dieoffs in Utah: An approach to understanding the cause. In: Wallace, Arthur; McArthur, E. Durant; Haferkamp, Marshall R., comps. Proceedings--symposium on shrub ecophysiology and biotechnology; 1987 June 30 - July 2; Logan, UT. Gen. Tech. Rep. INT-256. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 119-135. [5942]

538. Neuenschwander, L. F. 1978. The fire induced autecology of selected shrubs of the cold desert and surrounding forests: A-state-of-the-art review. Unpublished manuscript on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 31 p. [1747]

539. Neuenschwander, L. F. 1980. Broadcast burning of sagebrush in the winter. Journal of Range Management. (33)3: 233-236. [1746]

540. Newsome, Heidi. 2016. Personal communication [Email to Robin Innes]. 1 December. Regarding use of Rx fire in big sagebrush communities within the Mid-Columbia River National Wildlife Refuge Complex. Burbank, WA: U.S. Department of the Interior, US Fish and Wildlife Service, Mid-Columbia River National Wildlife Refuge Complex. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [91634]

541. Ngugi, Kinuthia R.; Powell, Jeff; Hinds, Frank C.; Olson, Richard A. 1992. Range animal diet composition in southcentral Wyoming. Journal of Range Management. 45(6): 542-545. [19781]

542. Noson, Anna C. 2002. Avian communities in relation to habitat influenced by fire in a sagebrush steppe landscape. Corvallis, OR: Oregon State University. 77 p. Thesis. [91597]

543. Noson, Anna C.; Schmitz, Richard A.; Miller, Richard F. 2006. Influence of fire and juniper encroachment on birds in high-elevation sagebrush steppe. Western North American Naturalist. 66(3): 343-

353. [65137]

544. Noste, Nonan V.; Bushey, Charles L. 1987. Fire response of shrubs of dry forest habitat types in Montana and Idaho. Gen. Tech. Rep. INT-239. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 22 p. [255]

545. Nydegger, Nicholas C.; Smith, Graham W. 1986. Prey populations in relation to Artemisia vegetation types in southwestern Idaho. In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 152-156. [1787]

546. O'Farrell, Thomas. 1972. Ecological distribution of sagebrush voles, Lagurus curtatus, in south-central Washington. Journal of Mammalogy. 53(3): 632-636. [92740]

547. Oldemeyer, John L.; Martin, Stephen J.; Woodis, Steven G. 1983. A preliminary report on the effects of a deferred-rotation grazing system on wildlife at the Sheldon National Wildlife Refuge. Cal-Neva Wildlife Transactions 1983: 26-42. [91437]

548. Olson, Rich. 1992. Mule deer habitat requirements and management in Wyoming. B-965. Laramie, WY: University of Wyoming, Cooperative Extension Service. 15 p. [20679]

549. Omernik, James M.; Griffith, Glenn E. 2014. Ecoregions of the conterminous United States: Evolution of a hierarchical spatial framework. Environmental Management. 54(6): 1249-1266. [92352]

550. Onsager, Jerome A., ed. 1987. Integrated pest management on rangeland: State of the art in the sagebrush ecosystem. ARS-50. [Place of publication unknown]: United States Department of Agriculture, Agricultural Research Service. 85 p. [2836]

551. Ostoja, Steven M.; Schupp, Eugene W. 2009. Conversion of sagebrush shrublands to exotic annual grasslands negatively impacts small mammal communities. Diversity and Distributions. 15(5): 863-870. [91523]

552. Ott, Jeffrey; Cox, Robert D.; Shaw, Nancy L. 2017. Comparison of postfire seeding practices for Wyoming big sagebrush. Rangeland Ecology and Management. 70(5): 625-632. [92427]

553. Ottmar, Roger D.; Vihnanek, Robert E.; Wright, Clinton S. 2007. Stereo photo series for quantifying natural fuels. Volume X: Sagebrush with grass and ponderosa pine-juniper types in central Montana. Gen. Tech. Rep. PNW-GTR-719. Seattle, WA: U.S. Department of Agriculture, Pacific Northwest Research Station. 59 p. [91260]

554. Paige, Christine; Ritter, Sharon A. 1999. Birds in a sagebrush sea: Managing sagebrush habitats for bird communities. Boise, ID: Partners in Flight Western Working Group. 47 p. [65948]

555. Palmquist, Kyle A.; Schlaepfer, Daniel R.; Bradford, John B.; Lauenroth, William K. 2016. Spatial and ecological variation in dryland ecohydrological responses to climate change: Implications for management. Ecosphere. 7(11): 1-20. [91505]

556. Parish, Roberta; Coupe, Ray; Lloyd, Dennis, eds. 1996. Plants of southern interior British Columbia. Vancouver, BC: Lone Pine Publishing. 450 p. [35949]

557. Partlow, Kristene A.; Olson, Richard A.; Schuman, Gerald E. 2004. Effects of wildlife utilization and grass seeding rates on big sagebrush growth and survival on reclaimed mined lands. In: Hild, Ann L.; Shaw, Nancy L.; Meyer, Susan E.; Booth, D. Terrance; McArthur, E. Durant, comps. Seed and soil dynamics in shrubland ecosystems: Proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 198-205. [49139]

558. Passey, H. B.; Hugie, Vern K.; Williams, E. W.; Ball, D. E. 1982. Relationships between soil, plant community, and climate on rangelands of the Intermountain West. Tech. Bull. 1669. Washington, DC: U.S.

Department of Agriculture, Soil Conservation Service. 123 p. [1834]

559. Paysen, Timothy E.; Ansley, R. James; Brown, James K.; Gottfried, Gerald J.; Haase, Sally M.; Harrington, Michael G.; Narog, Marcia G.; Sackett, Stephen S.; Wilson, Ruth C. 2000. Fire in western shrubland, woodland, and grassland ecosystems. In: Brown, James K.; Smith, Jane Kapler, eds. Wildland fire in ecosystems: Effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol. 2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 121-159. [36978]

560. Pearson, Scott M.; Turner, Monica G.; Wallace, Linda L.; Romme, William H. 1995. Winter habitat use by large ungulates following fire in northern Yellowstone National Park. Ecological Applications. 5(3): 744-755. [26077]

561. Pechanec, J. F.; Pickford, G. D.; Stewart, George. 1937. Effects of the 1934 drought on native vegetation of the Upper Snake River Plains, Idaho. Ecology. 18(4): 490-505. [91047]

562. Pechanec, Joseph F.; Plummer, A. Perry; Robertson, Joseph H.; Hull, A. C., Jr. 1965. Sagebrush control on rangelands. Agriculture Handbook No. 277. Washington, DC: U.S. Department of Agriculture. 40 p. [1858]

563. Pechanec, Joseph F.; Stewart, George; Blaisdell, James P. 1954. Sagebrush burning--good and bad. Farmers' Bulletin No. 1948. Washington, DC: U.S. Department of Agriculture. 34 p. [1859]

564. Pedersen, E. K.; Connelly, J. W.; Hendrickson, J. R.; Grant, W. E. 2003. Effect of sheep grazing and fire on sage grouse populations in southeastern Idaho. Ecological Modelling. 165(1): 23-47. [90036]

565. Peek, James M. 1987. Elk. In: Chapman, Joseph A.; Feldhamer, George A., eds. Wild mammals of North America. Baltimore, MD: Johns Hopkins Press: 851-861. [14655]

566. Peek, James M. 2003. Wapiti (Cervus elaphus). In: Feldhamer, George A.; Thompson, Bruce C.; Chapman, Joseph A., eds. Wild mammals of North America: Biology, management, and conservation. 2nd ed. Baltimore, MD: The Johns Hopkins University Press: 877-888. [82099]

567. Peek, James M.; Riggs, Robert A.; Lauer, Jerry L. 1979. Evaluation of fall burning on bighorn sheep winter range. Journal of Range Management. 32(6): 430-432. [1863]

568. Peek, James, M.; Demarchi, Dennis A.; Demarchi, Raymond A.; Stucker, Donald E. 1985. Bighorn sheep and fire: Seven case histories. In: Lotan, James E.; Brown, James K., comps. Fire's effect on wildlife habitat--symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 36-43. [1864]

569. Pellant, Mike. 1990. The cheatgrass-wildfire cycle--are there any solutions? In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings--symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 11-18. [12730]

570. Pellant, Mike. 1994. History and applications of the Intermountain greenstripping program. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 63-68. [24254]

571. Pellant, Mike; Lysne, Cindy R. 2005. Strategies to enhance plant structure and diversity in crested wheatgrass seedings. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 81-92. [63187]

572. Pendleton, Rosemary L.; Pendleton, Burton K.; Harper, Kimball T. 1989. Breeding systems of woody plant species in Utah. In: Wallace, Arthur; McArthur, E. Durant; Haferkamp, Marshall R., comps.

Proceedings--symposium on shrub ecophysiology and biotechnology; 1987 June 30 - July 2; Logan, UT. Gen. Tech. Rep. INT-256. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 5-22. [5918]

573. Perryman, B. L.; Maier, A. M.; Hild, A. L.; Olson, R. A. 2000. Demographic characteristics of three Artemisia tridentata subspecies. In: Schuman, Gerald E.; Richmond, Timothy C.; Neuman, Dennis R., eds. Sagebrush establishment on mined lands: Ecology and research: Proceedings of symposium; 2000 March 20; Billings, MT. [Part of: 2000 Billings land reclamation symposium; 2000 March 20-24; Billings, MT]. Bozeman, MT: Montana State University, Reclamation Research Unit: 56-64. [42422]

574. Perryman, Barry L.; Maier, Aaron M. ; Hild, Ann L.; Olson, Richard A. 2001. Demographic characteristics of 3 Artemisia tridentata Nutt. subspecies. Journal of Range Management. 54(2): 166-170. [39049]

575. Perryman, Barry L.; Olson, Richard A. 2000. Age-stem diameter relationships of big sagebrush and their management implications. Journal of Range Management. 53(3): 342-346. [35851]

576. Perryman, Barry L.; Olson, Richard A.; Petersburg, Stephen; Naumann, Tamara. 2002. Vegetation response to prescribed fire in Dinosaur National Monument. Western North American Naturalist. 62(4): 414-422. [43906]

577. Personius, Timothy L.; Wambolt, Carl L.; Stephens, Jeffrey R.; Kelsey, Rick G. 1987. Crude terpenoid influence on mule deer preference for sagebrush. Journal of Range Management. 40(1): 84-88. [1872]

578. Peters, Erin F.; Bunting, Stephen C. 1994. Fire conditions pre-and post-occurrence of annual grasses on the Snake River Plain. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 31-36. [24249]

579. Petersen, Charles A.; Villalba, Juan J.; Provenza, Frederick D. 2014. Influence of experience on browsing sagebrush by cattle and its impacts on plant community structure. Rangeland Ecology and Management. 67: 78-87. [93124]

580. Petersen, Kenneth L.; Best, Louis B. 1987. Effects of prescribed burning on nongame birds in a sagebrush community. Wildlife Society Bulletin. 15: 317-329. [173]

581. Petersen, Steven L.; Stringham, Tamzen K.; Roundy, Bruce A. 2009. A process-based application of state-and-transition models: A case study of western juniper (Juniperus occidentalis) encroachment. Rangeland Ecology & Management. 62(2): 186-192. [75456]

582. Peterson, Eric B. 2008. International vegetation classification alliances and associations occurring in Nevada with proposed additions. Carson City, NV: Nevada Natural Heritage Program. 347 p. [77864]

583. Peterson, Joel G. 1995. Ecological implications of sagebrush manipulation: A literature review. Project W-101-R-2. Helena, MT: Montana Department of Fish, Wildlife and Parks. 48 p. [91444]

584. Pierson, Frederick B.; Williams, C. Jason; Hardegree, Stuart P.; Clark, Patrick E.; Kormos, Patrick R.; Al-Hamdan, Osama Z. 2013. Hydrologic and erosion responses of sagebrush steppe following juniper encroachment, wildfire, and tree cutting. Rangeland Ecology & Management. 66(3): 274-289. [87374]

585. Pietruszka, Brad. 2016. Personal communication [Email to Robin Innes]. 18 May. Regarding use of Rx fire in Gunnison sage-grouse habitats in the Tres Rios field office. Montrose, CA: U.S. Department of the Interior, Bureau of Land Management, Southwest District. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [90477]

586. Popham, Gail P.; Gutierrez, R. J. 2003. Greater sage grouse Centrocercus urophasianus nesting success and habit use in northeastern California. Wildlife Biology. 9(4): 327-334. [89940]

587. Prenzlow, E. J.; Gilbert, D. L.; Glover, F. A. 1968. Some behavior patterns of the pronghorn. Special Report No. 17/GFP-R-S 17. Denver, CO: Colorado Department of Game, Fish and Parks. 16 p. [25691]

588. Pyke, D. A.; Chambers, J. C.; Pellant, M.; Miller, R. F.; Beck, J. L.; Doescher, P. S.; Roundy, B. A.; Schupp, E. W.; Knick, S. T.; Brunson, M.; and McIver, J. D. 2017. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat--Part 3. Site level restoration decisions. Circular 1426. Washington, DC: U.S. Department of the Interior, Geological Survey. 62 p. doi: 10.3133/cir1426. [93195]

589. Pyke, D. A.; Knick, S. T.; Chambers, J. C.; Pellant, M.; Miller, R. F.; Beck, J. L.; Doescher, P. S.; Schupp, E. W.; Roundy, B. A.; Brunson, M.; McIver, J. D. 2015. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat--Part 2. Landscape level restoration decisions. Circular 1418. Washington, DC: U.S. Department of the Interior, Geological Survey. 21 p. doi: 10.3133/cir1418. [93197]

590. Pyke, David A.; Chambers, Jeanne C.; Pellant, Mike; Knick, Steven T.; Miller, Richard F.; Beck, Jeffrey L.; Doescher, Paul S.; Schupp, Eugene W.; Roundy, Bruce A.; Brunson, Mark; McIver, James D. 2015. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat, Part 1. Concepts for understanding and applying restoration. Circular 1416. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 44 p. [91555]

591. Pyke, David A.; Shaff, Scott E.; Lindgreen, Andrew I.; Schupp, Eugene W.; Doescher, Paul S.; Chambers, Jeanne C.; Burnham, Jeffrey S.; Huso, Manuela M. 2014. Region-wide ecological responses of arid Wyoming big sagebrush communities to fuel treatments. Rangeland Ecology and Management. 67(5): 455-467. [89201]

592. Pyke, David A.; Wirth, Troy A.; Beyers, Jan L. 2013. Does seeding after wildfires in rangelands reduce erosion or invasive species? Restoration Ecology. 21(4): 415-421. [87983]

593. Qi, Yi; Jolly, W. Matt; Dennison, Philip E.; Kropp, Rachael C. 2016. Seasonal relationships between foliar moisture content, heat content and biochemistry of lodgepole pine and big sagebrush foliage. International Journal of Wildland Fire. 25(5): 574-578. [90925]

594. Rachlow, Janet L.; Svancara, Leona K. 2006. Prioritizing habitat for surveys of an uncommon mammal: A modeling approach applied to pygmy rabbits. Journal of Mammalogy. 87(5): 827-833. [92739]

595. Rau, Benjamin M.; Chambers, Jeanne C.; Pyke, David A.; Roundy, Bruce A.; Schupp, Eugene W.; Doescher, Paul; Caldwell, Todd G. 2014. Soil resources influence vegetation and response to fire and fire-surrogate treatments in sagebrush-steppe ecosystems. Rangeland Ecology and Management. 67(5): 506-521. [89199]

596. Raunkiaer, C. 1934. The life forms of plants and statistical plant geography. Oxford, England: Clarendon Press. 632 p. [2843]

597. Reed-Dustin, Claire M., Mata-Gonzalez, Ricardo; Rodhouse, Thomas J. 2016. Long-term fire effects on native and invasive grasses in protected area sagebrush steppe. Rangeland Ecology and Management. 69(4): 257-264. [90881]

598. Reeves, Matt C.; Manning, Mary E.; DiBenedetto, Jeff P.; Palmquist, Kyle A.; Lauenroth, William K.; Bradford, John B.; Schlaepfer, Daniel R. 2018. Effects of climate change on rangeland vegetation in the Northern Rockies region. In: Halofsky, Jessica E.; Peterson, David L.; Dante-Wood, S. Karen; Hoang, Linh; Ho, Joanne J.; Joyce, Linda A., eds. Climate change vulnerability and adaptation in the Northern Rocky Mountains. Part 2. Gen. Tech. Rep. RMRS-GTR-374. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 275-316. [92842]

599. Reichenberger, Gunther; Pyke, David A. 1990. Impact of early root competition on fitness components of four semiarid species. Oecologia. 85(2): 159-166. [91230]

600. Reid, Angela M.; Fuhlendorf, Samuel D. 2011. Fire management in the National Wildlife Refuge system: A case study of the Charles M. Russell National Wildlife Refuge, Montana. Rangelands. 33(2): 17-23. [82936]

601. Reiner, Alicia L. 2004. Fuel load and understory community changes associated with varying elevation and pinyon-juniper dominance. Reno, NV: University of Nevada. 63 p. Thesis. [91569]

602. Reiner, Alicia L.; Tausch, Robin J.; Walker, Roger F. 2010. Estimation procedures for understory biomass and fuel loads in sagebrush steppe invaded by woodlands. Western North American Naturalist. 70(3): 312-322. [82208]

603. Reinkensmeyer, Daniel P.; Miller, Richard F.; Anthony, Robert G.; Marr, Vern E. 2000. Avian community structure along a mountain big sagebrush successional gradient. Journal of Wildlife Management. 71(4): 1057-1066. [91436]

604. Reis, Schyler A.; Ellsworth, Lisa M.; Kauffman, J. Boone; Wrobleski, David W. 2018. Long-term effects of fire on vegetation structure and predicted fire behavior in Wyoming big sagebrush ecosystems. Ecosystems. 1-9: doi: 10.1007/s10021-018-0268-7. [92881]

605. Reisner, Michael D.; Grace, James B.; Pyke, David A.; Doescher, Paul S. 2013. Conditions favouring Bromus tectorum dominance of endangered sagebrush steppe ecosystems. Journal of Applied Ecology. 50(4): 1039-1049. [91615]

606. Remington, Thomas E.; Braun, Clait E. 1985. Sage grouse food selection in winter, North Park, Colorado. The Journal of Wildlife Management. 49(4): 1055-1061. [1955]

607. Rens, Reyer Jan. 2001. Elk effects on sagebrush-grassland after fire on Yellowstone's Northern Range. Bozeman, MT: Montana State University. 61 p. Thesis. [46927]

608. Renwick, Katherine M.; Curtis, Caroline; Kleinhesselink, Andrew R.; Schlaepfer, Daniel; Bradley, Bethany A.; Aldridge, Cameron L.; Poulter, Benjamin; Adler, Peter B. 2018. Multi-model comparison highlights consistency in predicted effect of warming on a semi-arid shrub. Global Change Biology. 24(1): 424-438. doi: 10.1111/gcb.13900. [93300]

609. Rhodes, Edward C.; Bates, Jonathan D.; Sharp, Robert N.; Davies, Kirk W. 2010. Fire effects on cover and dietary resources of sage-grouse habitat. The Journal of Wildlife Management. 74(4): 755-764. [82357]

610. Rice, Barry Meyers; Randall, John, comps. 1999. Weed report: Bromus tectorum--cheatgrass. In: Wildland weeds management and research: 1998-1999 weed survey. Davis, CA: The Nature Conservancy, Wildland Invasive Species Program. 8 p. On file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT, FEIS files. [43180]

611. Richardson, Bryce A.; Boyd, Alicia A.; Tobiasson, Tanner; Germino, Matthew J. 2017. Spectrophotometry of Artemisia tridentata to quantitatively determine subspecies. Rangeland Ecology and Management. 71(1): 87-90. [92806]

612. Richardson, Bryce A.; Chaney, Lindsay; Shaw, Nancy L.; Still, Shannon M. 2016. Will phenotypic plasticity affecting flowering phenology keep pace with climate change? Global Change Biology: 1-10. doi: 10.1111/gcb.13532. [91682]

613. Richardson, Bryce A.; Page, Justin T.; Bajgain, Prabin; Sanderson, Stewart C.; Udall, Joshua A. 2012. Deep sequencing of amplicons reveals widespread intraspecific hybridization and multiple origins of polyploidy in big sagebrush (Artemisia tridentata; Asteraceae). American Journal of Botany. 99(12): 1962-1975. [91016]

614. Riegel, Gregg M.; Miller, Richard F.; Skinner, Carl N.; Smith, Sydney E. 2006. Northeastern Plateaus bioregion. In: Sugihara, Neil G.; van Wagtendonk, Jan W.; Shaffer, Kevin E.; Fites-Kaufman, Joann; Thode, Andrea E., eds. Fire in California's ecosystems. Berkeley, CA: University of California Press: 225-263. [65541]

615. Riggs, Robert A.; Urness, Philip J. 1989. Effects of goat browsing on Gambel oak communities in northern Utah. Journal of Range Management. 42(5): 354-360. [9299]

616. Ripplinger, Julie; Franklin, Janet; Edwards, Thomas C., Jr. 2015. Legacy effects of no-analogue disturbances alter plant community diversity and composition in semi-arid sagebrush steppe. Journal of Vegetation Science. 26(5): 923-933. [91611]

617. Rittenhouse, L. R.; Sneva, F. A. 1976. Expressing the competitive relationship between Wyoming big sagebrush and crested wheatgrass. Journal of Range Management. 29(4): 326-327. [1997]

618. Rittenhouse, L. R.; Sneva, F. A. 1977. A technique for estimating big sagebrush production. Journal of Range Management. 30(1): 68-70. [92737]

619. Roberson, Jay A. 1986. Sage grouse-sagebrush relationships: A review. In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT; U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 157-167. [2006]

620. Roberts, Thomas C., Jr. 1999. The budgetary, ecological, and managerial impacts of pinyon-juniper and cheatgrass fires. In: Monsen, Stephen B.; Stevens, Richard, comps. Proceedings: Ecology and management of pinyon-juniper communities within the Interior West: Sustaining and restoring a diverse ecosystem; 1997 September 15-18; Provo, UT. Proceedings RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 400-402. [30587]

621. Robinson, Jason D.; Messmer, Terry A. 2013. Vital rates and seasonal movements of two isolated greater sage-grouse populations in Utah's West Desert. Human-Wildlife Interactions. 7(2): 182-194. [93185]

622. Rodhouse, Thomas J.; Irvine, Kathryn M.; Sheley, Roger L.; Smith, Brenda S.; Hoh, Shirley; Esposito, Daniel M.; Mata-Gonzalez, Ricardo. 2014. Predicting foundation bunchgrass species abundances: Model-assisted decision-making in protected-area sagebrush steppe. Ecosphere. 5(9): 16 p. [92793]

623. Romme, William H.; Allen, Craig D.; Bailey, John D.; Baker, William L.; Bestelmeyer, Brandon T.; Brown, Peter M.; Eisenhart, Karen S.; Floyd, M. Lisa; Huffman, David W.; Jacobs, Brian F.; Miller, Richard F.; Muldavin, Esteban H.; Swetnam, Thomas W.; Tausch, Robin J.; Weisberg, Peter J. 2009. Historical and modern disturbance regimes, stand structures, and landscape dynamics in pinon-juniper vegetation of the western United States. Rangeland Ecology & Management. 62(3): 203-222. [75419]

624. Rose, Jeffrey A.; Eddleman, Lee E. 1994. Ponderosa pine and understory growth following western juniper removal. Northwest Science. 68(2): 79-85. [23145]

625. Rosentreter, Roger. 2005. Sagebrush identification, ecology, and palatability relative to sage-grouse. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 3-16. [63178]

626. Rothleutner, Andy. 2016. Personal communication [Email with Robin Innes]. 20 May. Regarding use of Rx fire in greater sage-grouse habitats within the Worland field office. Worland, WY: U.S. Department of the Interior, Bureau of Land Management, Wind River/Bighorn Basin District, Worland Field Office. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [90499]

627. Rottler, Caitlin M.; Noseworthy, Cara E.; Fowers, Beth; Beck, Jeffrey L. 2015. Effects of conversion from sagebrush to non-native grasslands on sagebrush-associated species. Rangelands. 37(1): 1-6. [90402]

628. Roundy, Bruce A. 2005. Plant succession and approaches to community restoration. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 43-48. [63181]

629. Runyon, Justin B.; Butler, Jack L.; Friggens, Megan M.; Meyer, Susan E.; Sing, Sharlene E. 2012. Invasive species and climate change. In: Finch, Deborah M., ed. Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Gen. Tech. Rep. RMRS-GTR-285. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 97-115. [92787]

630. Sandberg, David V.; Barrows, Jack S.; Gibson, James C. 1976. Prescribed burning in pine forests of the Black Hills. Final Report. Cooperative Agreement No. 16-471-CA. Fort Collins, CO: Colorado State University, College of Forestry and Natural Resource, Forest and Wood Sciences Department. 184 p. [2054]

631. Sandford, Charles P.; Kohl, Michel T.; Messmer, Terry A.; Dahlgren, David K.; Cook, Avery; Wing, Brian R. 2017. Greater sage-grouse resource selection drives reproductive fitness under a conifer removal strategy. Rangeland Ecology and Management. 70: 59-67. [93182]

632. Sankey, Joel B.; Wallace, Cynthia S. A.; Ravi, Sujith. 2013. Phenology-based, remote sensing of post-burn disturbance windows in rangelands. Ecological Indicators. 30: 35-44. [88824]

633. Sawyer, Hall; Nielson, Ryan M.; Lindzey, Fred G.; Keith, Lorraine; Powell, Jake H.; Abraham, Anu A. 2007. Habitat selection of Rocky Mountain elk in a nonforested environment. The Journal of Wildlife Management. 71(3): 868-874. [83401]

634. Schachtschneider, Christopher L. 2016. Targeted grazing applied to reduce fire behavior metrics and wildfire spread. Moscow, ID: University of Idaho. 33 p. Thesis. [92402]

635. Schell, Andrew. 2017. Personal communication [Email to Robin Innes]. 24 January. Regarding use of Rx fire in big sagebrush communities within the Charles M. Russell NWR. Spokane, WA: U.S. Department of the Interior, U.S. Department of the Interior, US Fish and Wildlife Service, Charles M. Russell National Wildlife Refuge. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [91637]

636. Schlaepfer, Daniel R., Lauenroth, William K.; Bradford, John B. 2012. Ecohydrological niche of sagebrush ecosystems. Ecohydrology. 5(4): 453-466. [91550]

637. Schlaepfer, Daniel R.; Lauenroth, William K.; Bradford, John B. 2012. Effects of ecohydrological variables on current and future ranges, local suitability patterns, and model accuracy in big sagebrush. Ecography. 35(4): 374-384. [90149]

638. Schlaepfer, Daniel R.; Taylor, Kyle A.; Pennington, Victoria E.; Nelson, Kellen N.; Martyn, Trace E.; Rottler, Caitlin M.; Lauenroth, William K.; Bradford, John B. 2015. Simulated big sagebrush regeneration supports predicted changes at the trailing and leading edges of distribution shifts. Ecosphere. 6(1): 1-31. [91461]

639. Schlatterer, E. F. 1973. Sagebrush species and subspecies. Range Improvement Notes. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 18(2): 1-11. [2077]

640. Schlatterer, Edward F. 1972. A preliminary description of plant communities found on the Sawtooth, White Cloud, Boulder and Pioneer Mountains. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. Unpublished paper on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 111 p. [2076]

641. Scholl, Jackson P.; Kelsey, Rick G.; Shafizadeh, Fred. 1977. Involvement of volatile compounds of Artemisia in browse preference by mule deer. Biochemical Systematics and Ecology. 5: 291-295. [2086]

642. Schrag, Anne; Konrad, Sarah; Miller, Scott; Walker, Brett; Forrest, Steve. 2011. Climate-change impacts on sagebrush habitat and West Nile virus transmission risk and conservation implications for greater sage-grouse. GeoJournal. 76(5): 561-575. doi: 10.1007/s10708-010-9369-3. [93301]

643. Schroeder, Michael A.; Connelly, John W.; Wambolt, Carl L.; Braun, Clait E.; Hagen, Christian A.; Frisina, Michael R. 2006. View points: Society for range management issue paper: Ecology and

management of sage-grouse and sage-grouse habitat: A reply. Rangelands. 28(3): 3-7. [89733]

644. Schuman, G. E.; Booth, D. T.; Cockrell, J. R. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. Journal of Range Management. 51(2): 223-230. [92622]

645. Schuman, G. E.; Booth, D. T.; Olson, R. A. 2000. Enhancing Wyoming big sagebrush establishment with cultural practices. In: Schuman, Gerald E.; Richmond, Timothy C.; Neuman, Dennis R., eds. Sagebrush establishment on mined lands: Ecology and research: Proceedings of symposium; 2000 March 20; Billings, MT. [Part of the 2000 Billings land reclamation symposium; 2000 March 20-24; Billings, MT]. Bozeman, MT: Montana State University, Reclamation Research Unit: 32-36. [42420]

646. Schupp, Eugene W.; Gomez, Jose M.; Jimenez, Jaime E.; Fuentes, Marcelino. 1997. Dispersal of Juniperus occidentalis (western juniper) seeds by frugivorous mammals on Juniper Mountain, southeastern Oregon. The Great Basin Naturalist. 57(1): 74-78. [27379]

647. Scott, M. Douglas; Geisser, Hannes. 1996. Pronghorn migration and habitat use following the 1988 Yellowstone fires. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 123-132. [27837]

648. Severson, John Paul. 2016. Greater sage-grouse response to conifer encroachment and removal. Moscow, Idaho: University of Idaho. 146 p. Dissertation. [93175]

649. Severson, Kieth E.; Medina, Alvin L. 1983. Deer and elk habitat management in the Southwest. Journal of Range Management. Monograph No. 2. Denver, CO: Society for Range Management. 64 p. [2110]

650. Shafizadeh, F.; Bhadane, N. R.; Morris, M. S.; Kelsey, R. G.; Khanna, S. N. 1971. Sesquiterpene lactones of big sagebrush. Phytochemistry. 10: 2745-2754. [2115]

651. Shantz, H. L. 1947. The use of fire as a tool in the management of the brush ranges of California. Sacramento, CA: State of California, Department of Natural Resources, Division of Forestry. 156 p. [36305]

652. Shaw, Nancy L.; DeBolt, Ann M.; Rosentreter, Roger. 2005. Reseeding big sagebrush: techniques and issues. In: Shaw, Nancy L.; Pellant, Mike; Monsen, Stephen B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4-7; Boise, ID. Proc. RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 99-108. [63189]

653. Shaw, Nancy L.; Monsen, Stephen B. 1990. Use of sagebrush for improvement of wildlife habitat. In: Fisser, Herbert G., ed. Wyoming shrublands: Aspen, sagebrush and wildlife management: Proceedings, 17th Wyoming shrub ecology workshop; 1988 June 21-22; Jackson, WY. Laramie, WY: University of Wyoming, Department of Range Management; Shrub Ecology Workshop: 19-35. [22929]

654. Sheehy, Dennis P.; Winward, A. H. 1981. Relative palatability of seven Artemisia taxa to mule deer and sheep. Journal of Range Management. 34(5): 397-399. [2128]

655. Sheehy, Dennis Patrick. 1975. Relative palatability of seven Artemisia taxa to mule deer and sheep. Corvalis, OR: Oregon State University. 132 p. Thesis. [91427]

656. Shepherd, James F., III. 2006. Landscape-scale habitat use by greater sage-grouse in southern Idaho. Moscow, ID: University of Idaho. 180 p. Dissertation. [90164]

657. Shepperd, Wayne D.; Battaglia, Michael A. 2002. Ecology, silviculture, and management of Black Hills ponderosa pine. Gen. Tech. Rep. RMRS-GTR-97. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 112 p. [44794]

658. Sheridan, Chris. 2016. Personal communication [Email to Robin Innes]. 2 December. Regarding use of Rx fire in big sagebrush communities within the Spokane District. Spokane, WA: U.S. Department of the

Interior, U.S. Department of the Interior, Bureau of Land Management, Spokane District. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [91636]

659. Shiflet, Thomas N., ed. 1994. Rangeland cover types of the United States. Denver, CO: Society for Range Management. 152 p. [23362]

660. Shinn, Dean A. 1980. Historical perspectives on range burning in the inland Pacific Northwest. Journal of Range Management. 33(6): 415-423. [2136]

661. Shinneman, Douglas J.; Baker, William L. 2009. Environmental and climatic variables as potential drivers of post-fire cover of cheatgrass (Bromus tectorum) in seeded and unseeded semiarid ecosystems. International Journal of Wildland Fire. 18: 191-202. [75452]

662. Shinneman, Douglas J.; McIlroy, Susan K. 2016. Identifying key climate and environmental factors affecting rates of post-fire big sagebrush (Artemisia tridentata) recovery in the northern Columbia Basin, USA. International Journal of Wildland Fire. 25(9): 933-945. [91224]

663. Shive, Kristen L.; Sieg, Carolyn H.; Fule, Peter Z. 2013. Pre-wildfire management treatments interact with fire severity to have lasting effects on post-wildfire vegetation response. Forest Ecology and Management. 297: 75-83. [86959]

664. Shultz, Leila M. 2009. Monograph of Artemisia subgenus Tridentatae (Asteraceae-Anthemideae). Systematic Botany Monographs. Laramie, WY: American Society of Plant Taxonomists. 89: 1-131. [90844]

665. Shuman, Gerald E.; Vicklund, Laurel E.; Belden, Scott E. 2005. Establishing Artemisia tridentata spp. wyomingensis on mined lands: Science and economics. Arid Land Research and Management. 19(4): 353-362. [92805]

666. Shumar, Mark L.; Anderson, Jay E. 1986. Gradient analysis of vegetation dominated by two subspecies of big sagebrush. Journal of Range Management. 39(2): 156-159. [2142]

667. Shumar, Mark L.; Anderson, Jay E. 1987. Research note: Transplanting wildings in small revegetation projects. Arid Soil Research and Rehabilitation. 1: 253-256. [3005]

668. Shumar, Mark L.; Anderson, Jay E.; Reynolds, Timothy D. 1982. Identification of subspecies of big sagebrush by ultraviolet spectrophotometry. Journal of Range Management. 35(1): 60-62. [30181]

669. Sime, Carolyn Anne. 1991. Sage grouse use of burned, non-burned, and seeded vegetation communities on the Idaho National Engineering Laboratory, Idaho. Bozeman, MT: Montana State University. 72 p. Thesis. [24908]

670. Singer, Francis J.; Coughenour, Michael B.; Norland, Jack E. 2004. Elk biology and ecology before and after the Yellowstone fires of 1988. In: Wallace, Linda L., ed. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press: 117-139. [81963]

671. Singer, Francis J.; Renkin, Roy A. 1995. Effects of browsing by native ungulates on the shrubs in big sagebrush communities in Yellowstone National Park. Great Basin Naturalist. 55(3): 201-212. [35476]

672. Singer, Francis J.; Swift, David M.; Coughenour, Michael B.; Varley, John D. 1998. Thunder on the Yellowstone revisited: An assessment of management of native ungulates by natural regulation. Wildlife Society Bulletin. 26(3): 375-390. [83718]

673. Sipes, Douglas R. 1978. Wyoming big sagebrush production yields through measurements. Laramie, WY: University of Wyoming. 104 p. Thesis. [93125]

674. Skovlin, Jon M.; Zager, Peter; Johnson, Bruce K. 2002. Elk habitat selection and evaluation. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: Ecology and management. Washington, DC: Smithsonian Institution Press: 531-556. [81803]

675. Smith, Bruce N.; Lytle, C. Mel; Hansen, Lee D.; Lipp, Josef; Ziegler, Hubert. 1992. Respiration and growth in seedlings of cold-desert shrubs. In: Clary, Warren P.; McArthur, E. Durant; Bedunah, Don; Wambolt, Carl L., comps. Proceedings--symposium on ecology and management of riparian shrub communities; 1991 May 29-31; Sun Valley, ID. Gen. Tech. Rep. INT-289. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 190-193. [19119]

676. Smith, Scott G. 1988. Diet quality of wintering bighorn sheep on burned and unburned vegetation types of the South Fork Shoshone River, Wyoming. Laramie, WY: University of Wyoming. 95 p. Thesis. [93248]

677. Smith, Tom S.; Hardin, Perry J.; Flinders, Jerran T. 1999. Response of bighorn sheep to clear-cut logging and prescribed burning. Wildlife Society Bulletin. 27(3): 840-845. [36492]

678. Sneva, Forrest A.; Rittenhouse, L. R.; Tueller, P. T.; Reece, P. 1984. Changes in protected and grazed sagebrush-grass in eastern Oregon, 1937 to 1974. Station Bulletin 663. Corvallis, OR: Oregon State University, Agricultural Experiment Station. 11 p. [2195]

679. Soehn, George. 2016. Personal communication [Email to Robin Innes]. 19 May. Regarding use of Rx fire in greater sage-grouse habitats within the Casper field office. Casper, WY: U.S. Department of the Interior, Bureau of Land Management, Wind River/Bighorn Basin District, Casper Field Office. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [90482]

680. Soule, Peter T.; Knapp, Paul A. 2000. Juniperus occidentalis (western juniper) establishment history on two minimally disturbed Research Natural Areas in central Oregon. Western North American Naturalist. 60(1): 26-33. [36425]

681. Spomer, George G.; Henderson, Douglass M. 1988. Use of UV absorption for identifying subspecies of Artemisia tridentata. Journal of Range Management. 41(5): 395-398. [6260]

682. Stahl, Peter D.; Schuman, Gerald E.; Frost, Sandra M.; Williams., Stephen E. 1998. Arbuscular mycorrhizae and water stress tolerance of Wyoming big sagebrush seedlings. Soil Science Society of America Journal. 62: 1309-1313. [92732]

683. Stahl, Peter D.; Williams, S. E.; Christensen, Martha. 1988. Efficacy of native vesicular-arbuscular mycorrhizal fungi after severe soil disturbance. New Phytologist. 110(3): 347-354. [15463]

684. Stebleton, Andrea; Bunting, Stephen. 2009. Guide for quantifying fuels in the sagebrush steppe and juniper woodlands of the Great Basin. Tech. Note 430. Denver, CO: U.S. Department of the interior, Bureau of Land Management. 81 p. [88764]

685. Stefanic, Todd. 2017. Personal communication [Email to Robin Innes]. 23 February. Regarding use of Rx fire in big sagebrush communities within the Craters of the Moon National Monument and Preserve. Arco, ID: U.S. Department of the Interior, National Park Service, Craters of the Moon National Monument and Preserve. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [91635]

686. Stevens, Richard. 1994. Interseeding and transplanting to enhance species composition. In: Monsen, Stephen B.; Kitchen, Stanley G., comp. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 300-306. [24301]

687. Stevens, Richard. 2004. Incorporating wildlife habitat needs into restoration and rehabilitation projects. In: Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol. 1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 155-174. [52826]

688. Stevens, Richard. 2004. Management of restored and revegetated sites. In: Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps. Restoring western ranges and wildlands. Gen. Tech. Rep.

RMRS-GTR-136-vol. 1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 193-198. [52828]

689. Stevens, Richard; McArthur, E. Durant. 1974. A simple field technique for identification of some sagebrush taxa. Journal of Range Management. 27(4): 325-326. [2245]

690. Stevens, Richard; Monsen, Stephen B. 2004. Guidelines for restoration and rehabilitation of principal plant communities. In: Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol. 1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 199-294. [52829]

691. Stickney, Peter F. 1989. Seral origin of species comprising secondary plant succession in northern Rocky Mountain forests. FEIS workshop: Postfire regeneration. Unpublished draft on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. 10 p. [20090]

692. Still, Shannon M.; Richardson, Bryce A. 2015. Projections of contemporary and future climate niche for Wyoming big sagebrush (Artemisia tridentata subsp. wyomingensis): A guide for restoration. Natural Areas Journal. 35(1): 30-43. [89167]

693. Strand, Eva K.; Bunting, Stephen C.; Keefe, Robert F. 2013. Influence of wildland fire along a successional gradient in sagebrush steppe and western juniper woodlands. Rangeland Ecology and Management. 66(6): 667-679. [87802]

694. Striby, Karl D.; Wambolt, Carl L.; Kelsey, Rick G.; Havstad, Kris M. 1987. Crude terpenoid influence on in vitro digestibility of sagebrush. Journal of Range Management. 40(3): 244-248. [2265]

695. Strohmeyer, Deborah C.; Peek, James M.; Bowlin, Tracy R. 1999. Wapiti bed sites in Idaho sagebrush steppe. Wildlife Society Bulletin. 27(3): 547-551. [75523]

696. Stucker, Donald E.; Peek, James M. 1984. Response of bighorn sheep to the Ship Island Burn. Report submitted to the Northern Forest Fire Laboratory: Supplement No. INT-80-108CA. 33 p. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [17070]

697. Sturges, David L. 1977. Soil water withdrawal and root characteristics of big sagebrush. The American Midland Naturalist. 98(2): 257-274. [30167]

698. Sturges, David L. 1989. Response of mountain big sagebrush to induced snow accumulation. Journal of Applied Ecology. 26: 1035-1041. [11841]

699. Sturges, David L.; Nelson, David L. 1986. Snow depth and incidence of a snowmold disease on mountain big sagebrush. In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 215-221. [2277]

700. Suminski, Rita R. 1993. Management implications for mule deer winter range in northern pinon-juniper. In: Aldon, Earl F.; Shaw, Douglas W., tech. coord. Managing pinon-juniper ecosystems for sustainability and social needs: Proceedings; 1993 April 26-30; Santa Fe, NM. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 133-139. [22864]

701. Suring, Lowell H.; Rowland, Mary M.; Wisdom, Michael J.; Schueck, Linda; Meinke, Cara W. 2005. Vegetation communities. In: Wisdom, Michael J.; Rowland, Mary M.; Suring, Lowell H., eds. Habitat threats in the sagebrush ecosystem: Methods of regional assessment and applications in the Great Basin. Lawrence, KS: Alliance Communications Group: 94-113. [67402]

702. Suring, Lowell H.; Wisdom, Michael J.; Tausch, Robin J.; Miller, Richard F.; Rowland, Mary M.; Schueck, Linda; Meinke, Cara W. 2005. Modeling threats to sagebrush and other shrubland communities.

In: Wisdom, Michael J.; Rowland, Mary M.; Suring, Lowell H., eds. Habitat threats in the sagebrush ecosystem: Methods of regional assessment and applications in the Great Basin. Lawrence, KS: Alliance Communications Group: 114-149. [67403]

703. Swanson, Donald Oscar. 1970. Roosevelt elk-forest relationships in the Douglas-fir region of the southern Oregon Coast Range. Ann Arbor, MI: University of Michigan. 173 p. Dissertation. [83259]

704. Swanson, John C.; Murphy, Peter J.; Swanson, Sherman R.; Schultz, Brad W.; McAdoo, J. Kent. 2018. Plant community factors correlated with Wyoming big sagebrush site responses to fire. Rangeland Ecology & Management. 71(1): 67-76. [92679]

705. Swanson, Sherman R.; Buckhouse, John C. 1984. Soil and nitrogen loss from Oregon lands occupied by three subspecies of big sagebrush. Journal of Range Management. 37(4): 298-302. [2299]

706. Swanson, Sherman R.; Simonson, Gerald H.; Buckhouse, John C. 1986. Physical and chemical soil properties of three big sagebrush subspecies. Soil Science Society of America Journal. 50: 783-787. [3037]

707. Synergy Resource Solutions, Inc. 2002. Data collection and fire modeling determine potential for the use of Plateau to establish fuel breaks in Bromus tectorum dominated rangelands. Sparks, NV: Synergy Resource Solutions, Inc. Unpublished report available on a CD-ROM. On file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT. [43417]

708. Takahashi, Masaru; Huntly, Nancy. 2010. Herbivorous insects reduce growth and reproduction of big sagebrush (Artemisia tridentata). Arthropod-Plant Interactions. 4(4): 257-266. [92736]

709. Taper, Mark L.; Gogan, Peter J. 2002. The northern Yellowstone elk: Density dependence and climatic conditions. The Journal of Wildlife Management. 66(1): 106-122. [82436]

710. Tausch, R. J.; Miller, R. F.; Boundy, B. A.; Chambers, J. C., eds. 2009. Pinon and juniper field guide: Asking the right questions to select appropriate management actions. Circular 1335. Reston, VA: U.S. Department of the Interior, Geological Survey. 96 p. [76595]

711. Tausch, R. J.; Tueller, P. T. 1990. Foliage biomass and cover relationships between tree- and shrub-dominated communities in pinyon-juniper woodlands. The Great Basin Naturalist. 50(2): 121-134. [15528]

712. Taylor, Kyle L. 2015. Exploring ecological risks facing regional sagebrush ecosystems in the 21st century. Laramie, WY: University of Wyoming. 141 p. Thesis. [90565]

713. Taylor, Megan M.; Hild, Ann L.; Shaw, Nancy L.; Norton, Urszula; Collier, Timothy R. 2014. Plant recruitment and soil microbial characteristics of rehabilitation seedings following wildfire in northern Utah. Restoration Ecology. 22(5): 598-607. [89141]

714. Taylor, Michael H.; Rollins, Kimberly; Kobayashi, Mimako; Tausch, Robin J. 2013. The economics of fuel management: Wildfire, invasive plants, and the dynamics of sagebrush rangelands in the western United States. Journal of Environmental Management. 126: 157-173. [88818]

715. Terwilliger, Charles, Jr.; Tiedeman, James A. 1978. Habitat types of the mule deer critical winter range and adjacent steppe region of Middle Park, Colorado. Final report: Cooperative Agreement No. 16-739-CA. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 108 p. [5611]

716. Thacker, Eric T.; Ralphs, Michael H.; Call, Cristopher A.; Benson, Brock; Green, Shane. 2008. Invasion of broom snakeweed (Guitierrezia sarothrae) following disturbance: Evaluating change in a state-and-transition model. Rangeland Ecology and Management. 61(3): 263-268. [92951]

717. The Wildlife Society, Nevada Chapter. 1998. Influence of fire on wildlife habitat in the Great Basin: A position statement - August 16, 1998. Transactions, Western Section of the Wildlife Society. 34: 42-57. [35093]

718. Thimmayya, Amanda C. 2010. Habitat ecology and genetic connectivity of the pygmy rabbit (Brachylagus idahoensis) across southern Wyoming. Laramie, WY: University of Wyoming. 62 p. Thesis. [93157]

719. Thompson, Tyler W.; Roundy, Bruce A.; McArthur, E. Durant; Jessop, Brad D.; Waldron, Blair; Davis, James N. 2006. Fire rehabilitation using native and introduced species: a landscape trial. Rangeland Ecology and Management. 59(3): 237-248. [63001]

720. Tiedeman, James A.; Francis, Richard E.; Terwilliger, Charles, Jr.; Carpenter, Len H. 1987. Shrub-steppe habitat types of Middle Park, Colorado. Res. Pap. RM-273. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 20 p. [2329]

721. Tipper, Gary K. 1988. Prescribed burning for wildlife in the southern East Kootenay. In: Feller, M. C.; Thomson, S. M., eds. Wildlife and range prescribed burning workshop proceedings; 1987 October 27-28; Richmond, BC. Vancouver, BC: The University of British Columbia, Faculty of Forestry: 61-69. [3100]

722. Tipton, Crystal Yates-White. 2015. Improving state-and-transition models for management of sagebrush steppe ecosystems. Fort Collins, CO: Colorado State University. 152 p. Thesis. [92950]

723. Tisdale, E. W.; Hironaka, M. 1981. The sagebrush-grass region: A review of the ecological literature. Bull. 33. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station. 31 p. [2344]

724. Tisdale, E. W.; Hironaka, M.; Fosberg, M. A. 1969. The sagebrush region in Idaho: A problem in range resource management. Bulletin 512. Moscow, ID: University of Idaho, College of Agriculture, Agricultural Experiment Station. 15 p. [7514]

725. Tisdale, Edwin W. 1994. SRM 403: Wyoming big sagebrush. In: Shiflet, Thomas N., ed. Rangeland cover types of the United States. Denver, CO: Society for Range Management: 42-43. [43363]

726. Toweill, Dale E.; Thomas, Jack Ward. 2002. The future of elk and elk management. In: Toweill, Dale E.; Thomas, Jack Ward, eds. North American elk: Ecology and management. Washington, DC: Smithsonian Institution Press: 793-841. [81807]

727. Tracy, Benjamin F. 2004. Fire effects, elk, and ecosystem resilience in Yellowstone's sagebrush grasslands. In: Wallace, Linda L., ed. After the fires: The ecology of change in Yellowstone National Park. New Haven, CT: Yale University Press: 102-116. [82007]

728. Tracy, Benjamin F.; McNaughton, Samuel J. 1996. Comparative ecosystem properties in summer and winter ungulate ranges following the 1988 fires in Yellowstone National Park. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 181-191. [27847]

729. Tracy, Benjamin F.; McNaughton, Samuel J. 1997. Elk grazing and vegetation responses following a late season fire in Yellowstone National Park. Plant Ecology. 130(2): 111-119. [28963]

730. Trainer, Charles E.; Willis, Mitchell J.; Keister, George P., Jr.; Sheehy, Dennis P. 1983. Fawn mortality and habitat use among pronghorn during spring and summer in southeastern Oregon, 1981-1982. Wildlife Research Report No. 12. Portland, OR: Oregon Department of Fish and Wildlife, Wildlife Research and Development Division. 117 p. [25692]

731. Tueller, Paul T.; Blackburn, Wilbert H. 1974. Condition and trend of the big sagebrush/needleandthread habitat type in Nevada. Journal of Range Management. 27(1): 36-40. [75992]

732. Tweit, Susan J.; Houston, Kent E. 1980. Grassland and shrubland habitat types of the Shoshone National Forest. Cody, WY: U.S. Department of Agriculture, Forest Service, Region 2, Shoshone National Forest. 143 p. [2377]

733. Updike, Douglas R.; Loft, Eric R.; Hall, Frank A. 1990. Wildfires on big sagebrush/antelope bitterbrush range in northeastern California: Implications for deer populations. In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comp. Proceedings--symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 41-46. [12734]

734. USDA, NRCS. 2019. The PLANTS Database, [Online]. U.S. Department of Agriculture, Natural Resources Conservation Service, National Plant Data Team, Greensboro, NC (Producer). Available: https://plants.usda.gov/. [34262]

735. USDA. 1989. Identification characteristics of major sagebrush taxa and species adapted to areas inhabited by each. The Habitat Express. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. No. 89-1. 2 p. [5911]

736. USDA. 2001. Guide to noxious weed prevention practices, [Online]. Washington, DC: U.S. Department of Agriculture, Forest Service (Producer). 25 p. Available online: https://www.fs.fed.us/invasivespecies/documents/FS_WeedBMP_2001.pdf [2017, January 10] [2009, November 19]. [37889]

737. USDA. 2016. Digital photo series, [Online]. Seattle, WA: Pacific Northwest Research Station, Pacific Wildlife Fire Sciences Laboratory, Fire and Environmental Research Applications Team. Available at: https://depts.washington.edu/nwfire/dps/. [2017, January 10]. [91298]

738. USDA. 2016. Pinyon-juniper natural range of variation, [Online]. In: Pacific Region, Ecology program documents, reports and publications, Natural range of variation of Sierra Nevada habitats. Vallejo, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region (Producer). Available: https://www.fs.usda.gov/detail/r5/plants-animals/?cid=stelprdb5434436 [2016, November 4]. 31 p. [+ tables & figures]. [91157]

739. USDA. 2016. Sagebrush natural range of variation, [Online]. In: Pacific Region, Ecology program documents, reports and publications, Natural range of variation of Sierra Nevada habitats. Vallejo, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region (Producer). Available: https://www.fs.usda.gov/detail/r5/plants-animals/?cid=stelprdb5434436 [2017, January 10]. 36 p. [90944]

740. USDI. 1993. Fire effects in sagebrush/grass and pinyon-juniper plant communities. In: Fire effects in plant communities on the public lands. EA #MT-930-93-01. Billings, MT: U.S. Department of the Interior, Bureau of Land Management, Montana State Office: I-1 to I-42. [55086]

741. USDI. 1996. Effects of military training and fire in the Snake River Birds of Prey National Conservation Area. BLM/IDARNG research project final report. Boise, ID: U.S. Department of Interior, U.S. Geological Survey, Biological Resources Division, Forest and Rangeland Ecosystem Science Center, Snake River Field Station. 130 p. [86714]

742. USDI. 2013. Greater sage-grouse (Centrocercus urophasianus) conservation objectives: Final report. Denver, CO: U.S. Department of the Interior, Fish and Wildlife Service. 91 p. [90064]

743. Vale, Thomas R. 1974. Sagebrush conversion projects: An element of contemporary environmental change in the western United States. Biological Conservation. 6(4): 274-284. [91588]

744. Vale, Thomas R. 2002. The pre-European landscape of the United States: Pristine or humanized? In: Vale, Thomas R., ed. Fire, native peoples, and the natural landscape. Washington: Island Press: 1-40. [88507]

745. Van de Water, Kip M.; Safford, Hugh D. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology. 7(3): 26-58. [85190]

746. Van Dyke, Fred; Darragh, Jeffrey A. 2006. Short- and longer-term effects of fire and herbivory on sagebrush communities in south-central Montana. Environmental Management. 38(3): 365-376. [63225]

747. Van Dyke, Fred; Deboer, Michael J.; Van Beek, Grant M. 1996. Winter range plant production and elk use following prescribed burning. In: Greenlee, Jason, ed. The ecological implications of fire in Greater Yellowstone: Proceedings, 2nd biennial conference on the Greater Yellowstone Ecosystem; 1993 September 19-21; Yellowstone National Park, WY. Fairfield, WA: International Association of Wildland Fire: 193-200. [27855]

748. Van Dyke, Walter A.; Sands, Alan; Yoakum, Jim; Polenz, Allan; Blaisdell, James. 1983. Wildlife habitats in managed rangelands--the Great Basin of southeastern Oregon: bighorn sheep. Gen. Tech. Rep. PNW-159. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest and Range Experiment Station. 37 p. [2417]

749. Veblen, Kari E.; Newingham, Beth A.; Bates, Jon; LaMalfa, Eric; Gicklhorn, Jeff. 2015. Post-fire grazing management in the Great Basin. Great Basin Factsheet series: 7(858), [Online]. Corvallis, OR: Oregon State University (Producer). Available: http://oregonstate.edu/dept/EOARC/sites/default/files/858_gbfs7_post-fire_grazing_2015.pdf [2016, November 9]. 4 p. [91198]

750. Vicklund, Laurel E.; Schuman, Gerald E.; Hild, Ann L. 2004. Influence of sagebrush and grass seedling rates on sagebrush density and plant size. In: Hild, Ann L.; Shaw, Nancy L.; Meyer, Susan E.; Booth, D. Terrance; McArthur, E. Durant, comps. Seed and soil dynamics in shrubland ecosystems: Proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 40-43. [49086]

751. Vincent, Dwain W. 1992. The sagebrush/grasslands of the upper Rio Puerco area, New Mexico. Rangelands. 14(5): 268-271. [19698]

752. Vines, Robert A. 1960. Trees, shrubs, and woody vines of the Southwest. Austin, TX: University of Texas Press. 1104 p. [7707]

753. Vosburgh, Timothy; Kramer, Timothy. 2016. Personal communication [Email to Robin Innes]. 19 May. Regarding use of Rx fire in greater sage-grouse habitats within the Lander field office. Lander, WY: U.S. Department of the Interior, Bureau of Land Management, Wind River/Bighorn Basin District, Lander Field Office. Unpublished information on file with: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, MT; FEIS files. [90481]

754. Wagle, R. F. 1981. Fire: Its effects on plant succession and wildlife in the Southwest: Some effects of fire on plant succession and variability in the Southwest from a wildlife management viewpoint. Tucson, AZ: University of Arizona. 82 p. [4031]

755. Wagstaff, Fred J.; Welch, Bruce L. 1990. Rejuvenation of mountain big sagebrush on mule deer winter ranges using onsite plants as a seed source. In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings--symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 171-174. [12848]

756. Wakelyn, Leslie A. 1987. Changing habitat conditions on bighorn sheep ranges in Colorado. The Journal of Wildlife Management. 51(4): 904-912. [3001]

757. Walhof, Kendal Scott. 1997. A comparison of burned and unburned big sagebrush communities in southwest Montana. Bozeman, MT: Montana State University. 74 p. Thesis. [46902]

758. Wallmo, Olof C.; Regelin, Wayne L. 1981. Rocky Mountain and Intermountain habitats: Part 1. Food habits and nutrition. In: Wallmo, Olof C., ed. 1981. Mule and black-tailed deer of North America. Lincoln, NE: University of Nebraska Press: 387-398. [14387]

759. Wambolt, C. L.; Creamer, W. H.; Rossi, R. J. 1994. Predicting big sagebrush winter forage by subspecies and browse form class. Journal of Range Management. 47(3): 231-234. [23240]

760. Wambolt, C. L.; Walhof, K. S.; Frisina, M. R. 2001. Recovery of big sagebrush communities after burning in south-western Montana. Journal of Environmental Management. 61(3): 243-252. [40788]

761. Wambolt, Carl L. 1996. Mule deer and elk foraging preference for 4 sagebrush taxa. Journal of Range Management. 49(6): 499-503. [27222]

762. Wambolt, Carl L. 1998. Sagebrush and ungulate relationships on Yellowstone's Northern Range. Wildlife Society Bulletin. 26(3): 429-437. [75521]

763. Wambolt, Carl L. 2001. Mule deer foraging preference among five sagebrush (Artemisia L.) taxa. Western North American Naturalist. 61(4): 490-494. [91345]

764. Wambolt, Carl L. 2004. Browsing and plant age relationships to winter protein and fiber of big sagebrush subspecies. Journal of Range Management. 57(6): 620-623. [37475]

765. Wambolt, Carl L.; Frisina, Michael R. 2002. Montana sagebrush: A taxonomic key and habitat descriptions. Intermountain Journal of Sciences. 8(2): 46-59. [47358]

766. Wambolt, Carl L.; Harp, Aaron J.; Welch, Bruce L.; Shaw, Nancy; Connelly, John W.; Reese, Kerry P.; Braun, Clait E.; Klebenow, Donald A.; McArthur, E. Durant; Thompson, James G.; Torell, L. Allen; Tanaka, John A. 2002. Conservation of greater sage-grouse on public lands in the western U.S.: Implications of recovery and management policies. PACWPL Policy Paper SG-02-02. Caldwell, ID: Policy Analysis Center for Western Public Lands. 41 p. [47283]

767. Wambolt, Carl L.; Hoffman, Trista L.; Mehus, Chris A. 1999. Response of shrubs in big sagebrush habitats to fire on the northern Yellowstone winter range. In: McArthur, E. Durant; Ostler, W. Kent; Wambolt, Carl L., comps. Proceedings: Shrubland ecotones; 1998 August 12-14; Ephraim, UT. Proceedings RMRS-P-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 238-242. [36093]

768. Wambolt, Carl L.; Hoffman, Trista. 2004. Browsing effects on Wyoming big sagebrush plants and communities. In: Hild, Ann L.; Shaw, Nancy L.; Meyer, Susan E.; Booth, D. Terrance; McArthur, E. Durant, comps. Seed and soil dynamics in shrubland ecosystems: Proceedings; 2002 August 12-16; Laramie, WY. Proceedings RMRS-P-31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 194-197. [49138]

769. Wambolt, Carl L.; Kelsey, Rick G.; Personius, Timothy L. 1987. Preference and digestibility of three big sagebrush subspecies and black sagebrush as related to crude terpenoid chemistry. In: Provenza, Frederick D.; Flinders, Jerran T.; McArthur, E. Durant, comps. Proceedings--symposium on plant-herbivore interactions; 1985 August 7-9; Snowbird, UT. Gen. Tech. Rep. INT-222. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 71-73. [2448]

770. Wambolt, Carl L.; Payne, Gene F. 1986. An 18-year comparison of control methods for Wyoming big sagebrush in southwestern Montana. Journal of Range Management. 39(4): 314-319. [2449]

771. Wambolt, Carl L.; Rens, Reyer J. 2011. Elk and fire impacts on mountain big sagebrush range in Yellowstone. In: Wambolt, Carl L.; Kitchen, Stanley G.; Frisina, Michael R.; Sowell, Bok; Keigley, Richard B.; Palacios, Patsy; Robinson, Jill, comps. Proceedings--shrublands: Wildlands and wildlife habitats; 15th wildland shrub symposium; 2008 June 17-19; Bozeman, MT. Natural Resources and Environmental Issues, Volume XVI. Logan, UT: Utah State University, College of Natural Resources, S. J. and Jessie E. Quinney Natural Resources Research Library: 73-78. [83471]

772. Wambolt, Carl L.; Sherwood, Harrie W. 1999. Sagebrush response to ungulate browsing in Yellowstone. Journal of Range Management. 52(4): 363-369. [91455]

773. Wang, Han; McArthur, E. Durant; Sanderson, Stewart C.; Graham, John H.; Freeman, D. Carl. 1997. Narrow hybrid zone between two subspecies of big sagebrush (Artemisia tridentata: Asteraceae). IV. Reciprocal transplant experiments. Evolution. 51(1): 95-102. [29409]

774. Warren, Steven D.; St. Clair, Larry L.; Johansen, Jeffrey R.; Kugrens, Paul; Baggett, L. Scott; Bird, Benjamin J. 2015. Biological soil crust response to late season prescribed fire in a Great Basin juniper woodland. Rangeland Ecology and Management. 68(3): 241-247. [89252]

775. Watts, Myles J.; Wambolt, Carl L. 1996. Long-term recovery of Wyoming big sagebrush after four treatments. Journal of Environmental Management. 46(1): 95-102. [27100]

776. Weber, William A. 1987. Colorado flora: Western slope. Boulder, CO: Colorado Associated University Press. 530 p. [7706]

777. Weisberg, Peter J.; Dilts, Thomas E.; Baughman, Owen W.; Meyer, Susan E.; Leger, Elizabeth A.; Van Gunst, K. Jane; Cleeves, Lauren. 2017. Development of remote sensing indicators for mapping episodic die-off of an invasive annual grass (Bromus tectorum) from the Landsat archive. Ecological Indicators. 79: 173-181. [92769]

778. Weiss, Nondor T.; Verts, B. J. 1984. Habitat and distribution of pygmy rabbits (Sylvilagus idahoensis) in Oregon. The Great Basin Naturalist. 44(4): 563-571. [23635]

779. Welch, Bruce L. 1989. Nutritive value of shrubs. In: McKell, Cyrus M., ed. The biology and utilization of shrubs. San Diego, CA: Academic Press, Inc.: 405-424. [8041]

780. Welch, Bruce L. 1997. Seeded versus containerized big sagebrush plants for seed-increase gardens. Journal of Range Management. 50(6): 611-614. [90608]

781. Welch, Bruce L. 2002. Bird counts of burned versus unburned big sagebrush sites. Res. Note RMRS-RN-16. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 6 p. [35562]

782. Welch, Bruce L. 2005. Big sagebrush chemistry and water relations. In: Welch, Bruce L., ed. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 107-148. [55362]

783. Welch, Bruce L. 2005. Big sagebrush genetics. In: Welch, Bruce L., ed. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 149-170. [55358]

784. Welch, Bruce L. 2005. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 210 p. [55356]

785. Welch, Bruce L. 2005. Birds, mammals, and reptiles associated with big sagebrush. In: Welch, Bruce L., ed. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 47-80. [55399]

786. Welch, Bruce L. 2005. Consequences of controlling big sagebrush. In: Welch, Bruce L., ed. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 187-204. [55360]

787. Welch, Bruce L. 2005. Getting acquainted with big sagebrush. In: Welch, Bruce L., ed. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 1-46. [55357]

788. Welch, Bruce L. 2005. Other foragers and winter damage on big sagebrush. In: Welch, Bruce L., ed. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 81-106. [55361]

789. Welch, Bruce L. 2005. Putting big sagebrush back into its ecosystem. In: Welch, Bruce L., ed. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. Gen. Tech. Rep. RMRS-GTR-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 171-186. [55359]

790. Welch, Bruce L.; Briggs, Steven F.; Johansen, James H. 1996. Big sagebrush seed storage. Res. Note INT-RN-430. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 3 p. [30478]

791. Welch, Bruce L.; Criddle, Craig. 2003. Countering misinformation concerning big sagebrush. Res. Pap. RMRS-RP-40. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 28 p. [47361]

792. Welch, Bruce L.; Jacobson, Tracy L. C. 1988. Root growth of Artemisia tridentata. Journal of Range Management. 41(4): 332-334. [4559]

793. Welch, Bruce L.; McArthur, E. Durant. 1981. Variation of monoterpenoid content among subspecies and accessions of Artemisia tridentata grown in a uniform garden. Journal of Range Management. 34(5): 380-384. [91418]

794. Welch, Bruce L.; McArthur, E. Durant. 1985. Big sagebrush--its taxonomy, origin, distribution and utility. In: Fisser, Herbert G., ed. Wyoming shrublands: Proceedings, 14th Wyoming shrub ecology workshop; 1985 May 29-30; Rock Springs, WY. Laramie, WY: University of Wyoming, Department of Range Management, Wyoming Shrub Ecology Workshop: 3-19. [13903]

795. Welch, Bruce L.; McArthur, E. Durant. 1986. Growth rate of big sagebrush as influenced by accessions, sites, subspecies, and years. In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 342-346. [2483]

796. Welch, Bruce L.; McArthur, E. Durant. 1986. Wintering mule deer preference for 21 accessions of big sagebrush. The Great Basin Naturalist. 46(2): 281-286. [2484]

797. Welch, Bruce L.; McArthur, E. Durant; Davis, James N. 1981. Differential preference of wintering mule deer for accessions of big sagebrush and for black sagebrush. Journal of Range Management. 34(5): 409-411. [7801]

798. Welch, Bruce L.; Nelson, E. Dwain; Young, Stanford A.; Sands, Alan R.; Wagstaff, Fred J.; Nelson, David L. 1992. `Gordon Creek'--a superior, tested germplasm of Wyoming big sagebrush. Res. Pap. INT-461. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 p. [20832]

799. Welch, Bruce L.; Pederson, Jordan C. 1981. In vitro digestibility among accessions of big sagebrush by wild mule deer and its relationship to monoterpenoid content. Journal of Range Management. 34(6): 497-500. [91350]

800. Welch, Bruce L.; Wagstaff, Fred J.; Roberson, Jay A. 1991. Preference of wintering sage grouse for big sagebrush. Journal of Range Management. 44(5): 462-465. [16608]

801. Weldon, L. W.; Bohmont, D. W.; Alley, H. P. 1959. The interrelation of three environmental factors affecting germination of sagebrush seed. Journal of Range Management. 12: 236-238. [2489]

802. Welsh, Stanley L.; Atwood, N. Duane; Goodrich, Sherel; Higgins, Larry C., eds. 1987. A Utah flora. The Great Basin Naturalist Memoir No. 9. Provo, UT: Brigham Young University. 894 p. [2944]

803. Weltz, Mark A.; Spaeth, Ken; Taylor, Michael H.; Rollins, Kimberly; Pierson, Fred; Jolley, Leonard; Nearing, Mark; Goodrich, Dave; Hernandez, Mariano; Nouwakpo, Sayjro K.; Rossi, Colleen. 2014.

Cheatgrass invasion and woody species encroachment in the Great Basin: Benefits of conservation. Journal of Soil and Water Conservation. 69(2): 39-44. [88918]

804. West, Neil E. 1983. Great Basin-Colorado Plateau sagebrush semi-desert. In: Goodall, David W., ed. Temperate deserts and semi-deserts. Ecosystems of the world: Vol. 5. Amsterdam; Oxford; New York: Elsevier Scientific Publishing Company: 331-349. [2505]

805. West, Neil E. 1988. Intermountain deserts, shrub steppes, and woodlands. In: Barbour, Michael G.; Billings, William Dwight, eds. North American terrestrial vegetation. New York: Cambridge University Press: 209-230. [19546]

806. West, Neil E. 2000. Synecology and disturbance regimes of sagebrush steppe ecosystems. In: Entwistle, P. G.; DeBolt, A. M.; Kaltenecker, J. H.; Steenhof, K., comps. Sagebrush steppe ecosystems symposium: Proceedings; 1999 June 21-23; Boise, ID. Publ. No. BLM/ID/PT-001001+1150. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Boise State Office: 15-26. [42712]

807. West, Neil E.; Hassan, M. A. 1985. Recovery of sagebrush-grass vegetation following wildfire. Journal of Range Management. 38(2): 131-134. [2513]

808. West, Neil E.; Provenza, Frederick D.; Johnson, Patricia S.; Owens, M. Keith. 1984. Vegetation change after 13 years of livestock grazing exclusion on sagebrush semidesert in west central Utah. Journal of Range Management. 37(3): 262-264. [7515]

809. West, Neil E.; Tausch, Robin J.; Rea, Kenneth H.; Tueller, Paul T. 1978. Taxonomic determination, distribution, and ecological indicator values of sagebrush within the pinyon-juniper woodlands of the Great Basin. Journal of Range Management. 31(2): 87-92. [2521]

810. West, Neil E.; Tausch, Robin J.; Tueller, Paul T. 1998. A management-oriented classification of pinyon-juniper woodlands of the Great Basin. Gen. Tech. Rep. RMRS-GTR-12. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 42 p. [29131]

811. West, Neil E.; Yorks, Terence P. 2002. Vegetation responses following wildfire on grazed and ungrazed sagebrush semi-desert. Journal of Range Management. 55(2): 171-181. [40796]

812. Western Association of Fish and Wildlife Agencies. 2009. Prescribed fire as a management tool in xeric sagebrush ecosystems: Is it worth the risk to sage-grouse? Boise, ID: Western Association of Fish and Wildlife Agencies. 22 pages. [91674]

813. Whisenant, Steven G. 1990. Changing fire frequencies on Idaho's Snake River Plains: Ecological and management implications. In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings--symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 4-10. [12729]

814. Whisenant, Steven G. 2004. Vegetative manipulation with prescribed burning. In: Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol-1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 101-120. [52824]

815. Whitacre, Marina K.; Call, Christopher A. 2006. Recovery and germinability of native seed fed to cattle. Western North American Naturalist. 66(1): 121-128. [93081]

816. White, Susan M.; Flinders, Jerran T.; Welch, Bruce L. 1982. Preference of pygmy rabbits (Brachylagus idahoensis) for various populations of big sagebrush (Artemisia tridentata). Journal of Range Management. 35(6): 724-726. [23636]

817. Whitlock, Cathy; Knox, Margaret A. 2002. Prehistoric burning in the Pacific Northwest: Human versus climatic influences. In: Vale, Thomas R., ed. Fire, native peoples, and the natural landscape. Washington: Island Press: 195-269. [88512]

818. Wicklow-Howard, Marcia. 1989. The occurrence of vesicular-arbuscular mycorrhizae in burned areas of the Snake River Birds of Prey Area, Idaho. Mycotaxon. 34(1): 253-257. [12312]

819. Wijayratne, Upekala C.; Pyke, David A. 2012. Burial increases seed longevity of two Artemisia tridentata (Asteraceae) subspecies. American Journal of Botany. 99(3): 438-447. [86456]

820. Williams, Gerald W. 2004. American Indian fire use in the arid west. Fire Management Today. 64(3): 10-14. [50486]

821. Williams, Mary I.; Paige, Ginger B.; Thurow, Thomas L.; Hild, Ann L.; Gerow, Kenneth G. 2011. Songbird relationships to shrub-steppe ecological site characteristics. Rangeland Ecology and Management. 64(2): 109-118. [93161]

822. Williams, Mary I.; Schuman, Gerald E.; Hild, Ann L.; Vicklund, Laurel E. 2002. Wyoming big sagebrush density: Effects of seeding rates and grass competition. Restoration Ecology. 10(2): 385-391. [43261]

823. Williams, Mary I.; Thurow, Thomas L.; Paige, Ginger B.; Hild, Ann L.; Gerow, Kenneth G. 2011. Sagebrush-obligate passerine response to ecological site characteristics. In: Wambolt, Carl L.; Kitchen, Stanley G.; Frisina, Michael R.; Sowell, Bok; Keigley, Richard B.; Palacios, Patsy; Robinson, Jill, comps. Proceedings--shrublands: Wildlands and wildlife habitats; 15th wildland shrub symposium; 2008 June 17-19; Bozeman, MT. Natural Resources and Environmental Issues, Volume XVI. Logan, UT: Utah State University, College of Natural Resources, S. J. and Jessie E. Quinney Natural Resources Research Library: 63-71. [83470]

824. Wilson, Tammy L.; Howe, Frank P.; Edwards, Thomas C., Jr. 2011. Effects of sagebrush treatments on multi-scale resource selection by pygmy rabbits. The Journal of Wildlife Management. 75(2): 393-398. [83289]

825. Wilt, F. Martin; Geddes, Jason D.; Tamma, Rama V.; Miller, Glenn C.; Everett, Richard L. 1992. Interspecific variation of phenolic concentrations in persistent leaves among six taxa from subgenus Tridentatae of Artemisia (Asteraceae). Biochemical Systematics and Ecology. 20(1): 41-52. [34701]

826. Winward, A. H.; Tisdale, E. W. 1977. Taxonomy of the Artemisia tridentata complex in Idaho. Bulletin Number 19. Moscow, ID: University of Idaho, College of Forestry, Wildlife and Range Sciences, Forest, Wildlife and Range Experiment Station. 15 p. [2590]

827. Winward, Al H. 1991. A renewed commitment to management of sagebrush grasslands. In: Miller, R. F., ed. Management in the sagebrush steppe. Special Report 880. Corvallis, OR: Oregon State University, Agricultural Experiment Station: 2-7. [35554]

828. Winward, Alma H. 1970. Taxonomic and ecological relationships of the big sagebrush complex in Idaho. Moscow, ID: University of Idaho. 79 p. Dissertation. [2583]

829. Winward, Alma H. 1980. Taxonomy and ecology of sagebrush in Oregon. Station Bulletin 642. Corvallis, OR: Oregon State University, Agricultural Experiment Station. 15 p. [2585]

830. Winward, Alma H. 1985. Fire in the sagebrush-grass ecosystem--the ecological setting. In: Saunders, Ken; Durham, Jack; [and others], eds. Rangeland fire effects: Proceedings of the symposium; 1984 November 27-29; Boise, ID. Boise, ID: U.S. Department of the Interior, Bureau of Land Management, Idaho State Office: 2-6. [2587]

831. Wisdom, Michael J.; Chambers, Jeanne C. 2009. A landscape approach for ecologically based management of Great Basin shrublands. Restoration Ecology. 17(5): 740-749. [82738]

832. Wisdom, Michael J.; Rowland, Mary M.; Suring, Lowell H. 2005. Part II: Regional assessment of habitats for species of conservation concern in the Great Basin. In: Wisdom, Michael J.; Rowland, Mary M.; Suring, Lowell H., eds. Habitat threats in the sagebrush ecosystem: Methods of regional assessment and applications in the Great Basin. Lawrence, KS: Alliance Communications Group: 75-82. [67400]

833. Wisdom, Michael J.; Rowland, Mary M.; Tausch, Robin J. 2005. Effective management strategies for sage-grouse and sagebrush: A question of triage? In: Rahm, Jennifer, ed. Transactions of the 70th North American wildlife and natural resources conference: Proceedings; 2005 March 16-19; Arlington, VA. Washington, DC: Wildlife Management Institute: 206-227. [67236]

834. Wood, Christopher Karl. 2004. The effects of prescribed burning on deer and elk habitat parameters in Montana's Missouri River Breaks. Bozeman, MT: Montana State University. 68 p. Thesis. [63765]

835. Woodard, Paul M.; Van Nest, Terry. 1990. Winter burning bighorn sheep range--a proposed strategy. Forestry Chronicle. October: 473-477. [14619]

836. Wright, Clinton S. 2013. Models for predicting fuel consumption in sagebrush-dominated ecosystems. Rangeland Ecology and Management. 66(3): 254-266. [87795]

837. Wright, Clinton S.; Prichard, Susan J. 2006. Biomass consumption during prescribed fires in big sagebrush ecosystems. In: Andrews, Patricia L.; Butler, Bret W., comps. Fuels management--how to measure success: Conference proceedings; 2006 March 28-30; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 489-500. [65176]

838. Wright, Clinton S.; Vihnanek, Robert E.; Restaino, Joseph C.; Dvorak, Jon E. 2012. Photo series for quantifying natural fuels. Volume XI: Eastern Oregon sagebrush-steppe and spotted owl nesting habitat in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-878. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 85 p. [87939]

839. Wright, Henry A.; Bailey, Arthur W. 1982. Fire ecology: United States and southern Canada. New York: John Wiley & Sons. 501 p. [2620]

840. Wright, Henry A.; Neuenschwander, Leon F.; Britton, Carlton M. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities: A state-of-the-art review. Gen. Tech. Rep. INT-58. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 48 p. [2625]

841. Wright. Clinton Stewart. 2010. Effects of disturbance and fuelbed succession on spatial patterns of fuel, fire hazard, and carbon; and fuel consumption in shrub-dominated ecosystems. Seattle, WA: University of Washington. 152 p. Dissertation. [91204]

842. Wrobleski, David W. 1999. Effects of prescribed fire on Wyoming big sagebrush communities: Implications for ecological restoration of sage grouse habitat. Corvallis, OR: Oregon State University. 76 p. Thesis. [30180]

843. Wrobleski, David W.; Kauffman, J. Boone. 2003. Initial effects of prescribed fire on morphology, abundance, and phenology of forbs in big sagebrush communities in southeastern Oregon. Restoration Ecology. 11(1): 82-90. [47380]

844. Wyoming Game and Fish Department. 2010. Sagebrush shrublands, [Online]. Cheyenne, WY: Wyoming Game and Fish Department (Producer). Available: https://wgfd.wyo.gov/Habitat/Habitat-Plans/Wyoming-State-Wildlife-Action-Plan/Terrestrial-Habitat-Types [2016, December 2]. [91222]

845. Wyoming Interagency Vegetation Committee. 2002. Wyoming guidelines for managing sagebrush communities with emphasis on fire management. Cheyenne, WY: U.S. Department of the Interior, Bureau of Land Management, Wyoming Game and Fish Department. 53 p. [90582]

846. Yanish, Curtis R. 2002. Western juniper succession: Changing fuels and fire behavior. Moscow, ID: University of Idaho. 85 p. Thesis. [47382]

847. Yanish, Curtis R.; Bunting, Stephen C.; Kingery, James L. 2005. Western juniper (Juniperus occidentalis) succession: Changing fuels and fire behavior. In: Sagebrush steppe and pinyon-juniper ecosystems: Effects of changing fire regimes, increased fuel loads, and invasive species. Final Report to the

Joint Fire Science Program: Project Number 00-1-1-03. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 16-24. [64234]

848. Yeo, Jeffrey J. 2005. Effects of grazing exclusion of rangeland vegetation and soils, east central Idaho. Western North American Naturalist. 65(1): 91-102. [54783]

849. Yoakum, James D. 1979. Managing rangelands for pronghorns. Rangelands. 1(4): 146-148. [25689]

850. Yoakum, Jim D. 2000. An assessment of wildfires and pioneering pronghorn in Long Valley, California/Nevada. In: Fischer, Jon K., ed. Proceedings of the 17th biennial pronghorn antelope workshop; 1996 June 4-7; Lake Tahoe, CA. Sacramento, CA: California Department of Fish and Game: 86-90. [91498]

851. Yoakum, Jim. 1980. Habitat management guides for the American pronghorn antelope. Tech. Note 347. Denver, CO: U.S. Department of the Interior, Bureau of Land Management, Denver Service Center. 77 p. [23170]

852. Yoakum, Jim. 1983. Managing vegetation for pronghorns in the Great Basin. In: Monsen, Stephen B.; Shaw, Nancy, comps. Managing Intermountain rangelands - Improvement of range and wildlife habitats: Proceedings; 1981 Sept 15-17; Twin Falls, ID; 1982 June 22- 24; Elko, NV. Gen. Tech. Rept. INT-157. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 189-193. [2637]

853. Yoakum, Jim. 1986. Use of Artemisia and Chrysothamnus by pronghorns. In: McArthur, E. Durant; Welch, Bruce L., comps. Proceedings--symposium on the biology of Artemisia and Chrysothamnus; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 176-180. [2638]

854. Young, James A.; Allen, Fay L. 1997. Cheatgrass and range science: 1930-1950. Journal of Range Management. 50(5): 530-535. [30455]

855. Young, James A.; Clements, Charlie D.; Jansen, Henricus. 2007. Sagebrush steppe. In: Barbour, Michael G.; Keeler-Wolf, Todd; Schoenherr, Allan A., eds. Terrestrial vegetation of California. Berkeley, CA: University of California Press: 587-608. [82714]

856. Young, James A.; Evans, Raymond A. 1978. Population dynamics after wildfires in sagebrush grasslands. Journal of Range Management. 31(4): 283-289. [2657]

857. Young, James A.; Evans, Raymond A. 1981. Demography and fire history of a western juniper stand. Journal of Range Management. 34(6): 501-505. [2659]

858. Young, James A.; Evans, Raymond A. 1989. Dispersal and germination of big sagebrush (Artemisia tridentata) seeds. Weed Science. 37(2): 201-206. [7235]

859. Young, James A.; Evans, Raymond A. 1989. Reciprocal common garden studies of the germination of seeds of Big Sagebrush (Artemisia tridentata). Weed Science. 37: 319-325. [8692]

860. Young, James A.; Evans, Raymond A.; Eckert, Richard E., Jr.; Kay, Burgess L. 1987. Cheatgrass. Rangelands. 9(6): 266-270. [288]

861. Young, James A.; Evans, Raymond A.; Gifford, Richard O.; Eckert, Richard E., Jr. 1970. Germination characteristics of three species of Cruciferae. Weed Science. 18: 41-48. [9499]

862. Young, Jim. 2000. Bromus tectorum L. In: Bossard, Carla C.; Randall, John M.; Hoshovsky, Marc C., eds. Invasive plants of California's wildlands. Berkeley, CA: University of California Press: 76-80. [41490]

863. Young, Kert R.; Roundy, Bruce A.; Bunting, Stephen C.; Eggett, Dennis L. 2015. Utah juniper and two-needle pinon reduction alters fuel loads. International Journal of Wildland Fire. 24(2): 236-248. [89970]

864. Younkin-Kury, Brenda Kristine. 2004. Greenstrip establishment and management in the Intermountain West. Logan, UT: Utah State University. 96 p. Thesis. [92946]

865. Ypsilantis, William G. 2003. Risk of cheatgrass after fire in selected sagebrush community types. Resource Notes. 63: 1-2. [91591]

866. Ziegenhagen, Lori L. 2003. Shrub reestablishment following fire in the mountain big sagebrush (Artemisia tridentata Nutt. spp. vaseyana (Rydb.) Beetle) alliance. Corvallis, OR: Oregon State University. 102 p. Thesis. [90185]

867. Ziegenhagen, Lori L.; Miller, Richard F. 2009. Postfire recovery of two shrubs in the interiors of large burns in the Intermountain West, USA. Western North American Naturalist. 69(2): 195-205. [81840]

868. Ziska, L. H.; Reeves, J. B., III; Blank, B. 2005. The impact of recent increases in atmospheric CO2 on biomass production and vegetative retention of cheatgrass (Bromus tectorum): Implications for fire disturbance. Global Change Biology. 11(8): 1325-1332. [71252]

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