Sagebrush Shrublands

Photo courtesy of WGFD

Table of Contents

Habitat Description

Sagebrush is an icon of Wyoming's landscape and open spaces. Sagebrush habitats are found in cold, semi-desert climates across the Intermountain West, and Wyoming has more sagebrush than any other state. Estimates vary on the amount of sagebrush dominated communities, but range from 23.5 million acres (Knight 1994) to approximately 37 million acres (Beetle and Johnson 1982). NatureServe (2009) lists seven ecological systems associated with this habitat in Wyoming (Table 17). Scores of different associations have been identified within these ecological systems. In sagebrush dominated areas, winters can be long, summers are hot and dry, and winds are persistent. A defining attribute of sagebrush ecosystems is a high proportion of annual precipitation occurring in the winter as snow or as early spring rain (Knight 1994). Summer storms can be brief and intense, and most precipitation runs off or evaporates (Paige and Ritter 1999).

The distribution of sagebrush on the landscape depends upon the response of individual species and subspecies to soil moisture, salinity, depth, and texture, as well as to climatic factors. Species/subspecies location patterns are accentuated over short distances by wind, topography, and abrupt changes in soil conditions (Knight 1994). Sagebrush communities may range from less than 4,000 to over 9,500 feet in elevation, with annual precipitation varying from a minimum of approximately 6 inches to over 20 inches. Sagebrush occurs on a variety of aspects from basins and valley bottoms, to undulating terraces and foothills, to steep slopes and mountainous areas. Likewise, it is found in a variety of mostly xeric soil types and a variety of soil textures and depths.

Natural disturbances also play an important role in determining the pattern, age structure, and species composition of sagebrush stands. Fire has played a role in shaping the sagebrush communities in Wyoming since the last ice age (Bohne et al. 2007). The historic ecological role and frequency for fire in sagebrush communities is debated. Research indicates that fire frequency in big sagebrush community types may range from 10 to over 110 years (Wyoming Sage-Grouse Working Group 2003); while others contend that in many Wyoming big sagebrush communities the time frame maybe closer to 100 to 240 years (Baker 2006, Cooper et al. 2007), and in more xeric types, such as low sagebrush, 325 to 450 years (Baker 2006). Rates of sagebrush canopy recovery following fire also greatly vary across the landscape and between different sagebrush community types ranging from 100 to 120 years (Baker 2006) to as few as 10 years (Sturgis 1994). Patchy fires appear to have been common in many sagebrush communities while larger fires at lower frequencies occurred in other areas, depending on climate, topography, plant composition, and aridity. In addition to fire, herbivory from wild ungulates, insects, rodents, and rabbits; precipitation, particularly drought; plant disease; and the effects of burrowing animals are important natural disturbances in sagebrush habitats.

Sagebrush stands can vary from large patches dominated largely by a single species or subspecies of sagebrush to a mosaic of multiple species where sagebrush is intermixed with other shrubs, such as rabbitbrush, antelope bitterbrush, greasewood, shadscale, winter-fat, and spiny hop-sage (Paige and Ritter 1999). Stands of sagebrush can be dense, patchy, or sparse. In tall sagebrush types, sagebrush cover commonly ranges from 5–30% or greater on some sites (Dealy et al 1981). Sagebrush communities often contain three or four vegetative layers: 1) a shrub layer, 12–40 inches tall; 2) forbs and caespitose grasses, 8–24 inches;3) low-growing grasses and forbs of less than 4–8 inches tall; and 4) a biological soil crust (Miller and Eddleman 2000). The biological soil crust is composed of blue-green algae, bacteria, fungi, mosses, and lichens. Research indicates the crust may play an important role in some dry regions through stabilizing soils from wind and water erosion, contributing to soil productivity, influencing nutrient levels, retaining moisture, altering soil temperature, and

aiding seedling establishment (Paige and Ritter 1999).

Other plant communities such as aspen, mountain shrubs, salt desert shrubs, and open conifer occur in association with sagebrush communities (Wyoming Interagency Vegetation Committee 2002). Major sagebrush species that dominate or co-dominate sagebrush systems in Wyoming include big sagebrush, including Wyoming, subalpine, mountain and basin subspecies/varieties; two varieties of silver sagebrush; low sagebrush; black sagebrush; two varieties of three-tip sagebrush; early sagebrush; birdsfoot sagebrush; spiked sagebrush; bud sagebrush; sand sagebrush; and fringed sagewort. Unlike other plants, most varieties of big sagebrush lack the ability to sprout from roots or root crowns and thus are killed when the crown is removed by fire or mechanical treatments such as mowing. This attribute increases the importance of longevity and seed production for the species. Big sagebrush seedlings only become established during favorable precipitation years or following a disturbance that reduces competition from neighboring plants (Knight 1994). While the subspecies/varieties of big sagebrush have some common characteristics, they also present characteristics unique to each taxon (Winward 2004). Wyoming big sagebrush grows on the most xeric sites of all the big sagebrush taxa. Basin big sagebrush, the tallest of the western sagebrushes, is found on deep, well-drained soils, often alluvial soils. Mountain big sagebrush grows on mid-to-upper elevation (6,800–8,500 ft.) mesic sites, and subalpine big sagebrush grows at high elevations (8,500–10,000 ft.) (Winward 2004). Understanding the differences between these taxa is important to management; an issue further complicated by varying degrees of hybridization.

Silver sagebrush is a common species in the lowlands (Knight 1994). Silver sagebrush often occurs in ravines or on floodplains in areas where Wyoming big sagebrush dominates the uplands. Silver sagebrush and three-tip sagebrush resprout from the root stock when the crown is removed, and they are fire tolerant (Adams et al 2004, Winward 2004). Black sagebrush often occurs on ridge tops on drier, coarser-textured, and shallower soils than either silver or big sagebrush (Knight 1994). Low sagebrush is usually less than 10 inches tall and is only found in the western part of the state such as the lowlands of Jackson Hole and Grand Teton National Park.

In addition to wildlife, sagebrush habitats are important landscapes for people. Agriculture, energy development, outdoor recreation, and residential housing are important land uses in sagebrush habitats. About 45% of the potential sagebrush habitat in the West is no longer sagebrush due to habitat conversion to cropland or pasture, development, conifer encroachment, and conversion to annual grasslands as a result of wildfire and exotic weed infestations (Connelly et al. 2003). A large percentage of sagebrush habitats are administered by public land management agencies, particularly by the Bureau of Land Management (BLM). Throughout the West, less than 30% of all sagebrush lands are privately owned (Raphael et al. 2001). Consequently, public land use policies and decisions will have a significant influence on the future of sagebrush habitats and associated species.

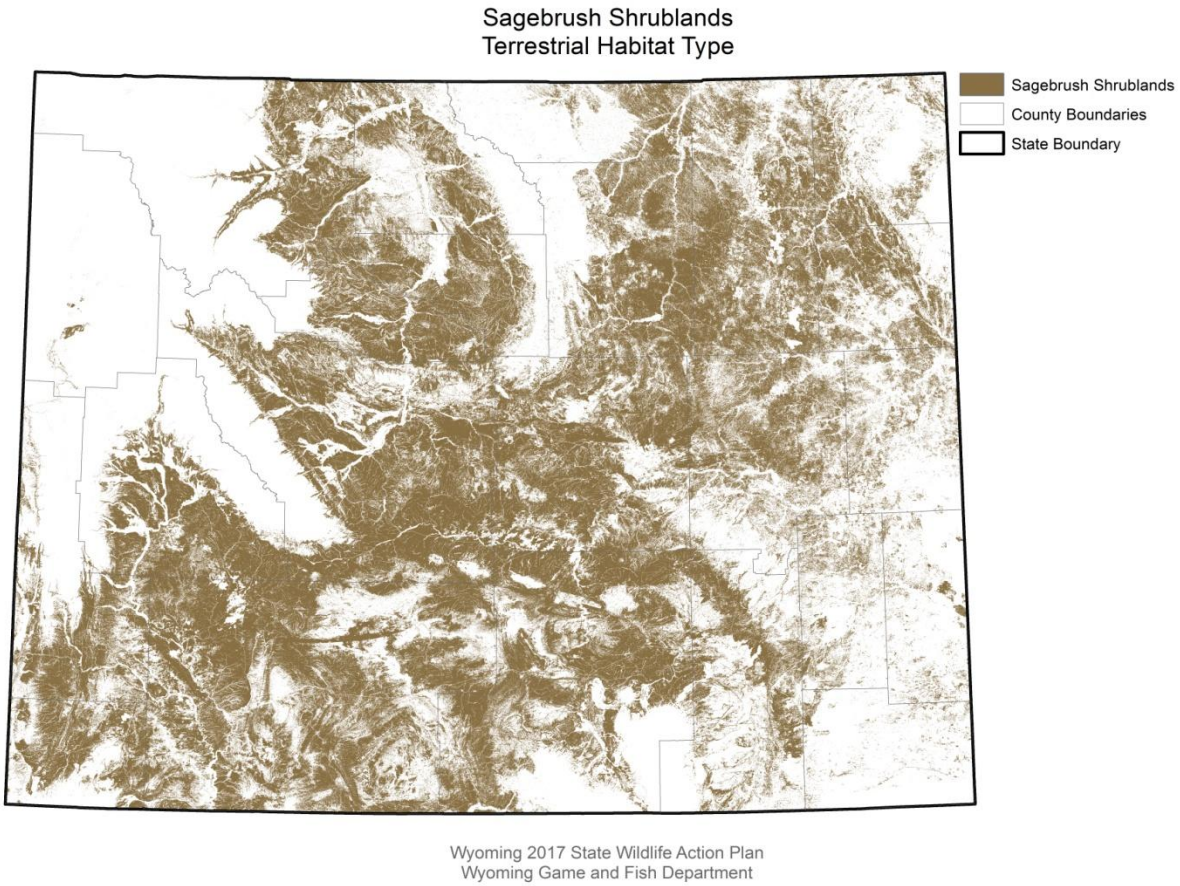


FIGURE 17. Wyoming Sagebrush Shrublands

TABLE 17. Wyoming Sagebrush Shrublands NatureServe Ecological Systems[1]

1. Great Basin Xeric Mixed Sagebrush Shrubland
2. Inter-Mountain Basins Big Sagebrush Shrubland
3. Columbia Plateau Low Sagebrush Steppe
4. Inter-Mountain Basins Big Sagebrush Steppe
5. Inter-Mountain Basins Active and Stabilized Dune
6. Wyoming Basins Dwarf Sagebrush Shrubland and Steppe

[1] Descriptions of NatureServe Ecological Systems which make up this habitat type can be found at: NatureServe Explorer: an online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, VA. http://www.natureserve.org/explorer.

TABLE 18. Wyoming Sagebrush Shrublands Species of Greatest Conservation Need

Mammals
Black-footed Ferret
Black-tailed Prairie Dog
Eastern Red Bat
Great Basin Pocket Mouse
Idaho Pocket Gopher
Olive-backed Pocket Mouse
Pallid Bat
Pygmy Rabbit
Sagebrush Vole
Sand Hills Pocket Gopher
Spotted Bat
Spotted Ground Squirrel
Swift Fox
White-tailed Prairie Dog
Yuma Myotis

Birds
Brewer's Sparrow
Columbian Sharp-tailed Grouse
Greater Sage-Grouse
Ferruginous Hawk
Loggerhead Shrike
Mountain Plover
Sagebrush Sparrow
Sage Thrasher
Swainson's Hawk

Reptiles
Great Basin Skink
Great Basin Gophersnake
Greater Short-horned Lizard
Midget Faded Rattlesnake
Northern Tree Lizard
Plains Hog-nosed Snake
Prairie Rattlesnake

Amphibians
Plains Spadefoot
Great Basin Spadefoot

Sagebrush Shrublands Wildlife

Sagebrush-associated vegetation types provide habitat for approximately 87 species of mammals; 297 species of birds; and 63 species of fish, reptiles, and amphibians (Wyoming Interagency Vegetation Committee 2002). Sagebrush ecosystems in Wyoming not only support crucial habitats for some of the largest migratory populations of ungulates in North America, but also offer the best chance to sustain healthy populations of sage-grouse and other sagebrush dependent species (Wyoming Game and Fish Department 2010a). In Wyoming, sagebrush obligates include the sage sparrow, Brewer's sparrow, sage thrasher, sage-grouse, pygmy rabbit, sagebrush vole, and sagebrush lizard (Paige and Ritter 1999).

Sagebrush itself is a keystone plant. Sagebrush ecosystems provide important food and cover, especially winter habitat, for big game species and other wildlife. Elk, mule deer, and pronghorn are the primary wild ungulates that utilize sagebrush habitat. Pronghorn attain their highest population densities in these ecosystems. Wyoming big sagebrush is also regarded as a crucial food item for sage-grouse, black-tailed jackrabbits, and pygmy rabbits, and mature sagebrush cover is important for sage-grouse broods.

The protein level and digestibility of sagebrush are typically greater during winter than other shrub and herbaceous plants (Peterson 1995). During this time, sagebrush is commonly the only green vegetation that rises above the snow. Not only does this increase its forage value for wildlife, but the comparatively tall stature of sagebrush and stiff twigs capture snow, which increases ground water content throughout the summer. The characteristic smell of sagebrush is the result of volatile oils such as terpenes, which serve as a chemical-defense mechanism to limit herbivory. Consequently, wildlife species such as pronghorn and sage-grouse that ingest large quantities of sagebrush have developed efficient digestion systems to cope with these defenses.

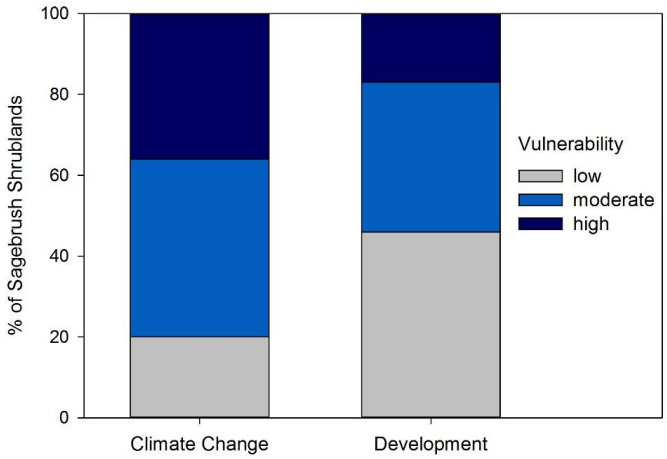
In addition to sagebrush dependent species, Wyoming sagebrush shrublands with lower shrub stature and density, such as Wyoming Basins Dwarf Sagebrush Shrubland and Steppe, are used by many grasslands wildlife species. Wyoming grasslands SGCN, including swift fox, mountain plovers, McCown's longspur, as well as other grasslands species often extend their ranges west into such sagebrush habitats. For many birds, the height, density, cover, and

patchiness of sagebrush stands have been determined to be the best indicators of species composition and abundance (Paige and Ritter 1999).

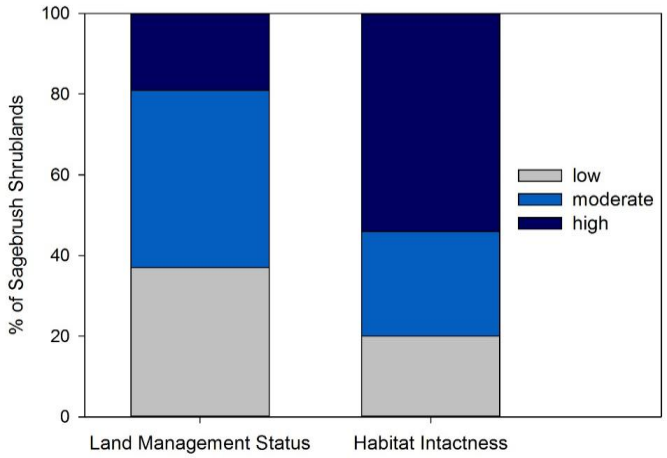
Invertebrate communities in sagebrush are not well understood, but may be critical to its effectiveness as wildlife habitat. Invertebrates represent high-protein forage, especially in spring and early summer, when plant protein is not yet available and vertebrates are generally protein-starved. Insect forage is known to be key to survival of sage-grouse chicks during the first few weeks after hatching, which in turn is key to increasing sage-grouse populations. Similar scenarios likely apply to other sagebrush-occupying wildlife. In addition to the numerous vertebrate and invertebrate animal species that depend on sagebrush for food and cover, there are several plant species primarily found only in association with sagebrush.

Sagebrush Shrublands Habitat Threats

Figure 18. Sagebrush Shrublands Vulnerability Analysis



The colored bars show the proportion of the habitat type that was identified as having low, moderate, or high vulnerability to climate change or development, based on classification of scores ranging from 0 to 1 into the following categories: low (<0.34), moderate (0.34-0.66), and high (>0.66). Rankings for climate change or development vulnerability were based on the land area of the habitat type classified as having high vulnerability: low (<10%), moderate (10-33%), or high (>33%). Vulnerability was calculated as exposure minus resilience. Development vulnerability includes existing and projected residential, oil and gas, and wind energy development. Further details are provided in the Leading Challenges section of this report and in Pocewicz et al. (2014).



The colored bars show the proportion of the habitat type that was identified as having low, moderate, or high land management status or habitat intactness. For land management status, high corresponds to the percent of the habitat occurring in GAP status 1 or 2, moderate to the percent occurring in GAP status 2b or 3, and low to the percent occurring in GAP status 4. Rankings for land management status were based on the land area of the habitat type classified as having high status or legal protection: low (<10%), moderate (10-33%), or high (>33%). For habitat intactness, scores ranging from 0 to 1 were assigned to categories as follows: low (<0.34), moderate (0.34-0.66), and high (>0.67). Rankings for intactness were based on the land area of the habitat type classified as having high intactness: low (<25%), moderate (25-75%), or high (>75%).

Invasive plants – High

It has been estimated that nonnative invasive plants are overtaking many wildland areas at the rate of about 4,600 acres a day on BLM-administered public lands alone (Bureau of Land Management 2000a). In Wyoming, there is a gradient of nonnative plant species invasion. In the higher and cooler sagebrush habitats of southern and western Wyoming, invasive plants are primarily established on disturbed sites such as roadways and well pads (Bergquist et al. 2007), whereas in the lower and warmer elevations of northern Wyoming, invasive plants are widespread throughout the understory of Wyoming big sagebrush communities.

The establishment of invasive plants can lead to loss of water and soil nutrients, increased erosion, and reduced productivity of native vegetation (see Wyoming Leading Conservation Challenges – Invasive Species). These effects reduce habitat quality for sagebrush-associated species including antelope, mule deer, elk, greater sage-grouse, pygmy rabbits, and sagebrush passerines. Ecological function deteriorates as hydrological processes are impacted, litter accumulation and organic matter breakdown decreases, and soil surfaces become denuded of native plants. Once invasive plant species become established, a seed source is developed for invasive species to expand into adjacent habitats such as riparian areas.

Cheatgrass, in particular, is a growing threat for Wyoming sagebrush habitats. Cheatgrass invasion fundamentally alters fire and vegetation patterns in sagebrush habitats by creating a bed of continuous, fine fuel that readily carries fire. Where cheatgrass has invaded the Snake River Plains of Idaho, the natural fire cycle has shortened from 30–100 years to 3–5 years (Whisenant 1990). Because sagebrush may take several years to mature before producing seed, repeated fires can eliminate sagebrush entirely. Cheatgrass dominance eventually creates uniform annual grasslands, perpetuated by large, frequent fires and void of any patches of native plant communities (Paige and Ritter 1999). Among other impacts on wildlife, increased fire frequency can decrease spring insect availability for birds.

The Wyoming Cooperative Agricultural Pest Survey (2010) data housed on the University of Wyoming website showed cheatgrass increasing in 21 of 23 counties in the state between 2003 and 2007 (updated March 2009). The survey also reported that 11 of 23 counties have more than 20,000 acres of surface dominated by cheatgrass. Notable recent increases in cheatgrass have occurred in the Bighorn Basin, the Laramie Mountains of southeastern Wyoming, as well as the foothills of the southern Wind River Mountains. Cheatgrass has also been invading more undisturbed big sagebrush communities at higher elevations, especially on south-facing slopes, as well as in ponderosa pine communities. Increased temperatures and more variable precipitation predicted for Wyoming's climate by some climate models could favor cheatgrass expansion (Bradley 2009).

Leafy spurge, spotted knapweed, Russian knapweed, hound's-tongue, halogeton, Dalmatian toadflax, Canada thistle, mustk thistle, black henbane, and white-top are other invasive species that pose a threat to sagebrush communities. Weed invasions often originate in areas of disturbed or bare soil frequently associated with construction and overgrazing.

Incompatible energy development and mining practices – High

Wyoming is one of the top energy producing states in the country (see Wyoming's Leading Wildlife Challenges – Energy Development). It is the nation's leading producer of coal (National Mining Association 2008), ranked fifth in natural gas production, and ranked eighth in crude oil production (Lawrence 2007). Wyoming ranks seventh nationally for wind-power generating potential when factoring in land status and environmental constraints (Elliott et al. 1991). Uranium, bentonite, trona, and gypsum are also mined.

Energy development can result in direct and indirect impacts to wildlife species and their habitat. Direct impacts include the removal and

fragmentation of sagebrush communities, introduction and spread of invasive species, and increased soil loss and erosion resulting from activities such as mine excavation and the building of roads, drill pads, fences, power lines, and pipelines. Soil disturbance from roads and other types of construction and increased vehicle traffic are significant contributors to the establishment and spread of invasive weed species in sagebrush communities.

Indirect impacts include increased human activity, noise, and predator intrusion into previously unbroken habitats (Bui 2009). These impacts can displace animals and decrease reproductive success if animals are forced to use less productive habitats or expend more energy avoiding people and predators. For example, the density of sagebrush-obligate birds within 328 feet of roads constructed for natural gas development in Wyoming was 50% lower than the density at greater distances (Ingelfinger 2001). The increase in the number of roads providing greater access into sagebrush habitat may also increase both the legal and illegal harvest of wildlife.

Direct mortality of wildlife from energy development can be associated with higher wildlife–vehicle collision rates from increased traffic. Sage-grouse and bats have been known to drown in water evaporation ponds and production pits (Adams 2003, Wyoming Sage-Grouse Working Group 2003). An increase in the amount of standing water associated with some energy development techniques (Zou et al. 2006) may facilitate the breeding of mosquitoes that spread West Nile virus, which is lethal to many bird species including sage-grouse (Marra et al. 2004).

Produced water from oil and gas wells may be considered for enhancement of fish and wildlife habitats. For example, the creation of more mesic sites using produced waters may improve brood-rearing areas for species such as sage-grouse that tend to favor sites with abundant, succulent forbs (Aldridge and Boyce 2007). Utilization of produced waters can also increase forage and water reservoirs for other wildlife including ungulates. The Wyoming Game and Fish Department (WGFD) has several programs that can provide funds for the development of water resources located by oil and gas drilling (Wyoming Game and Fish Department 2010c).

Some habitat impacts from energy development can be minimized by mitigation strategies, reclamation projects, and adequate planning efforts. Often these impacts are short-term and related to specific periods of activity which can be managed with timing stipulations to avoid conflicts with wildlife use of specific sites. Other impacts have yet to be thoroughly researched and associated rehabilitation and reclamation can be problematic and may take many years to achieve the complete recovery of a functioning sagebrush habitat (Monsen et al. 2004).

Little research has been conducted to quantify the impacts of wind-energy development on sagebrush-dependent wildlife species. Bird strikes and bat mortality are commonly known to occur at wind energy facilities, but the effects on species that inhabit open landscapes, such as pronghorn and sage-grouse, are largely unknown. Some researchers have proposed similar impacts on wildlife from wind-energy development as those documented for oil and gas development (Becker et al. 2009).

Rural subdivision – High

Rural subdivision and development can reduce, degrade, and fragment sagebrush habitats (see Wyoming Leading Wildlife Conservation Challenges – Rural Subdivision and Development). Houses, outbuildings, and lawns directly replace native wildlife habitat. Soil disturbance from construction, year-round grazing of horses and other hobby livestock, and the use of nonnative plants as ornamentals can facilitate the establishment of invasive species (Maestas et al. 2002).

Wildlife commonly abandons or alters use of habitats with greater human and pet activity. Increased energy expenditures in avoiding people or greater use of lower quality habitats can decrease animal health and reproductive capacity. Greater road densities and traffic

volume can increase wildlife–vehicle collisions. Predation on wildlife can intensify with greater numbers of domestic dogs and cats, as well as increases in generalist predatory species such as ravens and human-commensal species such as raccoons (U.S. Department of Agriculture 2007).

Off-road vehicle use – Moderate
Off-road vehicle use, primarily by all-terrain vehicles (ATVs), is increasing in sagebrush habitats. Driving vehicles off established roads can enhance the spread of invasive species, especially spotted knapweed and cheatgrass (Rooney 2005). Tires can damage biological soil crusts leading to decreased organism diversity, soil nutrients, soil stability, and organic matter, as well as increased erosion, which may negatively impact water quality. Managing off-road vehicle use can be difficult and controversial in sagebrush ecosystems where new trails are relatively easy to create and where some off-road vehicle users have little value for what appears to be an unproductive and barren landscape. Wildlife frequently avoids areas of increased noise and disturbance from outdoor recreational vehicles, and this type of activity may impact sage-grouse use of leks, nesting sites, and brood-rearing habitat.

Varying management goals and conflicting views about sagebrush ecosystem ecology and wildlife habitat management – Moderate
An existing lack of knowledge and agreement among scientist and natural resource managers regarding sagebrush ecosystem ecology and wildlife habitat management is an obstacle to advancing coordinated sagebrush conservation actions.

Due to disruption of natural disturbance regimes, particularly fire, it is felt by many that sagebrush in Wyoming is in late successional stages dominated by plants of relatively even age classes and older than 50 years of age (Winward 1991, Miller et al.1994, Wyoming Interagency Vegetation Committee 2002). These stands are commonly believed to display reduced vigor, productivity, diversity, and nutritional quality (Wyoming Interagency Vegetation Committee 2002). It is also believed that a mosaic of sagebrush age classes are required to best meet wildlife forage, and cover needs. As a consequence, sagebrush habitats have been subjected to a variety of treatments including burning, chemical control, and mechanical manipulation to improve wildlife habitat and livestock forage production. In addition to treatments, the widespread removal and conversion of sagebrush habitats to grasslands to increase livestock production was common in the past. (Vale 1974).

However, there is no widespread agreement on what constitutes decadence and poor vigor, particularly among wildlife biologists and range managers. Prescribed fire programs and other sagebrush habitat treatments are often based on the assumption that fire suppression has substantially reduced the frequency of fire in sagebrush vegetation; however, this assumption is very hard to prove (Baker 2006). While fire suppression is most often associated with the perceived decadence of sagebrush systems, drought stress over the past decade has likely played a role. As a result of these uncertainties, it is difficult for natural resource managers to quantify the size and scope of the problem, determine its cause, and apply appropriate management actions.

Furthermore, there is often little systematic monitoring following habitat treatments to document their extent and effectiveness. The Wyoming Governor's Sage-grouse Implementation Team identified the potential positive or negative effects of various habitat treatment practices (e.g., mowing/burning sagebrush, interseeding, grazing) and recommends that additional monitoring and research be conducted.

Incompatible grazing management practices – Moderate
Excessive grazing by domestic livestock during the late 1800s and early 1900s, coupled with severe drought, significantly impacted sagebrush ecosystems (Yensen 1981, Young and Sparks 2002). Since this time, livestock management

has improved with the adaptation of practices to control the intensity, interval, and season of use for grazing. However, in some areas grazing techniques could still be improved to benefit wildlife. Grazing has an influence on sagebrush density, canopy cover, and re-establishment rates as well as herbaceous composition (Wyoming Interagency Vegetation Committee 2002). Grazing may also reduce fine fuels and alter fire regimes (Beck and Mitchell 2000). Spring developments, water pipelines, and fencing have distributed livestock and wildlife use over areas that were formerly only occasionally or lightly grazed by large herbivores. Grazing practices that do not promote cool season grasses, especially bunchgrasses, and lead to a loss or alteration of forbs and shrubs, can interfere with ecological process, increase the spread of invasive weeds, and reduce habitat quality for wildlife. Managing the timing and intensity of grazing is particularly important for retaining residual grass cover, which has a strong influence on nesting success for sage-grouse and ground-nesting birds by providing cover to hide nests and hatchlings from predators.

Valuable biological soil crust in ephemeral riparian areas can be damaged by livestock hoof action during wet periods and soil compaction is common during dry periods. This can limit seedling establishment for forbs and grasses in areas with little to no growing season rain. Excess browsing by wild ungulates can damage sagebrush plants, which can lead to mortality. Winter range in some areas has been damaged by drought and big game herd numbers that exceeded management objectives.

Conifer encroachment – Moderate
In certain areas of Wyoming, Wyoming big sagebrush communities and mountain big sagebrush communities have been impacted by encroachment from juniper, ponderosa pine, and limber pine. This expansion has been documented by repeat photography, discussions with long-time residents, and fossil packrat-midden studies (Jackson et al. 2005). Suppression of wildfire is thought to be a primary reason for coniferous species invading sagebrush habitats, but changes in grazing and climate may also play a role. Conifer encroachment into sagebrush communities reduces shrub density and cover and herbaceous species diversity and production, and it lowers water yield. Cheatgrass invasion can be greatly enhanced if juniper densities reach a point where crown fires can be sustained. Suitable habitat for sage-grouse, pronghorn, mule deer, and other species that depend upon sagebrush habitats may decline. Sage-grouse, in particular, are known to avoid juniper communities (Commons et al. 1999, Doherty et al. 2008, Freese 2009). While juniper thinning projects are common in the state, it is important to balance these projects with the need to provide locations of adequate habitat for juniper obligate species (see Habitat Terrestrial Type – Xeric and Lower Montane Forests).

Drought and climate change – Moderate
Studies of age-class structure in sagebrush communities suggest that the establishment of new sagebrush plants is episodic and in many cases depends on above-average precipitation either during the first or second year of growth (Cawker 1980, Maier et al. 2001). Some climate models predict that Wyoming's climate will become drier (Christensen et al. 2007). More frequent and severe dry years could decrease the establishment of new sagebrush plants and slow or prevent recovery of sagebrush stands following fire, habitat enhancement treatments, or other disturbances that kill adult shrubs.

Many sagebrush communities exist in areas of low annual precipitation, and some communities may be at the limit of their range due to water availability. Drought causes a decrease in the production of herbaceous cover and forb availability which may affect the abundance of many species of wildlife. The difference between sagebrush production in drought versus non-drought years can be as much as 900% (Wyoming Interagency Vegetation Committee 2002). Loss in production can lead to increased competition between livestock and wildlife for food and cover.

Current Sagebrush Shrublands Habitat Conservation Initiatives

Increasing levels of energy development and declines in sage-grouse and mule deer numbers have greatly increased attention toward conserving sagebrush habitats. Sagebrush habitat management and conservation have been a priority for the WGFD since it embarked on the development of the statewide *Wyoming Greater Sage-grouse Conservation Plan* in 2000. Completed in 2003, this plan considers sagebrush conservation challenges and offers recommendations to address issues such as conflicting wildlife and wild horse management goals, invasive weeds, livestock grazing, energy development, recreation, residential development, vegetation management, and weather. The *Wyoming Greater Sage-grouse Conservation Plan* recommendations were also the genesis for the establishment of eight sage-grouse local working groups that direct on-the-ground habitat enhancement, population monitoring, and planning projects. Subsequently, each working group has developed a local sage-grouse conservation plan to guide these efforts.

A similar, more regional effort, the *Conservation Assessment of Greater Sage-grouse and Sagebrush Habitats* (Connelly et al. 2004), was completed by the Western Association of Fish and Wildlife Agencies (WAFWA) in 2004. As a follow-up document, WAFWA produced the *Greater Sage-grouse Comprehensive Conservation Strategy* in 2006 (Stiver et al. 2006).

In 2007, in response to the possibility of listing the greater sage-grouse under the Endangered Species Act, Governor Freudenthal formed two sage-grouse working teams: the Sage-grouse Implementation Team and the Science Technical Team. These teams were to develop recommendations for conserving greater sage-grouse across land ownership boundaries in Wyoming. First, the implementation team recommended extensive statewide mapping of sage-grouse habitat and habitat enhancement efforts. In April of 2008, Governor Freudenthal issued Executive Order 2008-2 which set forth Wyoming's Core Area Strategy. This strategy directs state agencies to focus sagebrush and sage-grouse conservation efforts within Core Population Areas developed by the Governor's Sage-grouse Implementation Team. New development within Core Population Areas would be authorized when it is demonstrated that the activity will not cause declines in greater sage-grouse populations. Incentives would be provided to encourage development outside Core Population Areas and to enhance reclamation in habitats adjacent to Core Population Areas. The sage-grouse Executive Order has been modified and reissued by Governor Freudenthal in 2010, and by Governor Mead in 2011 and 2015.

Also in response to a potential listing decision, the U.S. Fish and Wildlife Service in coordination with state and federal partners developed the Greater Sage-Grouse Candidate Conservation Agreement with Assurances for Ranch Management (CCAA). The Greater Sage-Grouse CCAA is a voluntary agreement between a private landowner and the U.S. Fish and Wildlife Service that utilizes a suite of habitat conservation measures to benefit both sage-grouse and the landowner's existing agricultural operation. The CCAA addresses the primary threat to sage-grouse identified by the U.S. Fish and Wildlife Service, which is loss of habitat. Subsequently, the BLM and U.S. Forest Service developed a Candidate Conservation Agreement (CCA) to apply to federal lands. As of June 2016, Wyoming has completed 40 CCAAs and 24 CCAs, enrolling over 1.5 million acres in these conservation agreements.

In 2008, WAFWA, U.S. Forest Service, BLM, U.S. Fish and Wildlife Service, U.S. Geological Survey, Natural Resources Conservation Services (NRCS), and the Farm Service Agency entered into a memorandum of understanding to increase cooperation in the conservation and management of greater sage-grouse, sagebrush habitats, and sagebrush-dependent wildlife. This would be accomplished through the implementation of WAFWA's *Greater Sage-grouse Comprehensive Conservation Strategy* and

conservation actions for other sagebrush-dependent species, adopting an adaptive management approach that recognized current uncertainties, and establishing partnerships with agencies, organizations, communities, and private landowners.

Sagebrush was also identified as one of eight priority habitats to enhance or maintain within the WGFD Strategic Habitat Plan (SHP). First created in 2001, revised in 2009, and most recently in 2015, the purpose of the SHP is to strategically guide WGFD habitat improvement and protection activities. Regional priority areas for conservation work are identified including crucial areas, necessary for maintaining terrestrial and aquatic wildlife populations and enhancement areas, where there is the potential to enhance or improve important wildlife habitats that have been degraded. Narratives for both crucial and enhancement areas describing the location, boundaries, values, issues, species, and solutions/actions were prepared (http://gf.state.wy.us/habitat/PriorityAreas/index.asp).

The WGFD Mule Deer Working Group (MDWG) was established in 1998 to explore solutions to the many challenges confronting mule deer conservation and management. Crucial areas for mule deer often encompass sagebrush habitat, particularly on mule deer winter range. In 2007, the MDWG drafted the *Wyoming Mule Deer Initiative* which was adopted by the Wyoming Game and Fish Commission. Among other topics, the initiative addresses habitat issues pertaining to crucial mule deer habitat improvement, the implementation of strategies to minimize negative impacts of energy development, and habitat monitoring to ensure that deer populations do not negatively impact plant species on which they browse. Beginning in 2016 the Wyoming Game and Fish Commission began allocating $500,000 per year through the Mule Deer Initiative with the intent of working collaboratively with partners to improve habitat conditions for mule deer as well as furthering knowledge on migration routes, corridors and stopover sites.

There are several efforts in Wyoming focused on reducing the negative effects of energy development on sagebrush habitats through planning and mitigation. The Wyoming Landscape Conservation Initiative (WLCI) is a multi-stakeholder initiative in southwest Wyoming focused on data collection, monitoring, research, and facilitating land management actions to protect or enhance wildlife habitat and other resource values. The Jonah Interagency Office (JIO) is a $24-million mitigation fund that has been established to support projects to maintain important biological areas in the vicinity of natural resource development near Pinedale. Similar mitigation activities are underway for other oil and gas fields, including the Continental Divide-Creston, Hiawatha, and Pinedale Anticline.

Since 1975, Coordinated Resource Management (CRM) teams have used a collaborative, stakeholder-based approach to address land management issues in Wyoming. Currently, there are approximately 40 CRM teams composed of ranchers, land and wildlife management agency personnel, conservation organizations, and sportsmen in Wyoming, many of whom are focused on improving management techniques to benefit wildlife and livestock in sagebrush habitats. In partnership with the BLM and U.S. Forest Service, some federal grazing permittees are incorporating private sagebrush monitoring and best management practices into their ranching operations.

Prescribed burning and mechanical treatments are commonly used in sagebrush habitats to improve forage, increase age and structural diversity, and reduce encroachment by conifers. Treatments include targeting individual junipers or treating large patches with prescribed fire, mastication with heavy equipment, and hand cutting administered by seasonal fire crews. Aerial spraying to control cheatgrass has been initiated in many areas following guidance from the State Weed and Pest Plan, Wyoming Cheatgrass Task Force, and more recently by the Wyoming Cheatgrass Task Force. Public land and wildlife agencies including the BLM,

U.S. Forest Service, WGFD, and Wyoming State Land Board have worked on initiating road closures in sensitive sagebrush habitats. Conservation easements held by a variety of land conservation organizations and the Wyoming Game and Fish Commission are being negotiated with willing landowners in sagebrush habitats.

Recommended Sagebrush Shrublands Conservation Actions

Increase research and develop plans to address the establishment and spread of cheatgrass and other invasive species in sagebrush habitats.
A literature review and discussions with researchers and land managers should occur to develop a comprehensive understanding of recent changes in cheatgrass abundance and density in Wyoming, and to determine the likely causes of this increase. Climatologists should be included in these discussions to develop a better understanding of how potential changes in future temperature and precipitation patterns in Wyoming may influence the spread of cheatgrass. This information could be used to identify regions of Wyoming which will likely be susceptible to significant increases in cheatgrass abundance. Results of this analysis could then be communicated to landowners and natural resource professionals to help guide cheatgrass control efforts. Efforts to minimize the spread of other invasive species, including black henbane, should continue. County Weed and Pest District invasive species control efforts should be supported and enhanced. Education and partnership opportunities for invasive species control exist with the energy industry.

Increase research on the sagebrush habitat ecology and the effects of habitat treatments.
Research should focus on determining the influence of management practices on multiple wildlife species and ecological functions. Investigations relative to the type of management practice (e.g., seeding, thinning, removal, and no treatment), the method of treatment (e.g., mechanical, herbicide, fire, or a combination of these), and associated grazing strategies (e.g., prior, during, and post treatment) are needed. The size of treatment, species composition, and site condition should be among the parameters investigated. Until more information is available, prescribed fire should not be used where sagebrush cover is a limiting factor for sage-grouse, where the understory lacks perennial forbs and grasses, or where invasive species or high amounts of less palatable shrubs such as rabbitbrush, horsebrush, or broom snakeweed are present (Miller and Eddleman 2001).

A variety of entities have been successful in mediating conflicting perceptions about sagebrush management into integrated habitat plans. These include the University of Wyoming Cooperative Extension Service, local conservation districts, and local Coordinated Resource Management teams. Efforts should be made to increase general public awareness about sagebrush conservation issues and the value of sagebrush habitats to wildlife.

Enhance planning and mitigation efforts to minimize the negative impacts of energy development on sagebrush habitats.
The development and implementation of energy-development plans, particularly for oil, gas, and wind, is crucial to the success of accommodating growth in these industries while minimizing negative impacts to sagebrush ecosystems, wildlife habitats, and wildlife species. Mitigation plans should stress avoiding biologically sensitive areas within project sites and directing off-site mitigation funds to nearby high-value wildlife locations. Energy development planning and mitigation efforts could be specifically benefited by:

- Continued research about the effects of energy development on sagebrush wildlife species and ecosystems, the Wyoming Chapter of the Nature Conservancy, Wyoming Natural Diversity Database, and Wyoming Game and Fish Department completed research evaluating the

vulnerability of Wyoming terrestrial SGCN to oil, gas, and wind development. Vulnerability was investigated by evaluating each species' potential exposure and sensitivity to energy development. Exposure was evaluated through a GIS analysis that overlays distribution maps of SGCN with areas of known and projected energy development. Sensitivity was determined by examining habitat and behavioral attributes of SGCN as well as reviewing existing impact studies. Research results give an indication of which species and taxonomic groups are potentially vulnerable to development, as well as help direct future research to address information gaps. The project can be found at: http://www.nature.org/media/wyoming/wyoming-wildlife-vulnerability-assessment-June-2014.pdf.

- Review management actions proposed by state and federal agencies involving sagebrush ecosystems and associated wildlife habitats, and work closely with the Wyoming Governor's office, industry, private land owners, and agency staff during early stages of energy development project planning. The SWAP, SHP, and Sage-grouse Core Population Areas should be consulted during development and mitigation planning. Maintaining connectivity between core areas will be important for the long-term conservation of sage-grouse and other sagebrush associated species.
- Where appropriate, encourage the implementation of mitigation measures and/or best management practices detailed within the Wyoming Game and Fish Commission documents: *Recommendations for Development of Oil and Gas Resources within Crucial and Important Wildlife Habitats* (Wyoming Game and Fish Department 2010a) and *Recommendations for Wind Energy Development in Crucial and Important Wildlife Habitat* (Wyoming Game and Fish Department 2010b). Sage-grouse habitat protection recommendations for uranium and bentonite mining as well as other significant surface disturbing activities are addressed in the Sage-grouse Core Area Implementation Recommendations available on the WGFD website. Development of stipulations for Sage-grouse core population areas and noncore areas and the *BLM Instructional Memorandum on Sage-grouse* should be reviewed.

Develop long-term grazing and habitat management plans for sagebrush ecosystems within identified priority sage-grouse habitats and big game winter range. Long-term, interagency management plans should be developed in key wildlife areas including those identified within Wyoming's SWAP, WGFD SHP, and Sage-grouse Core Population Areas. The publication *Grazing Influence, Management and Objective Development in Wyoming's Greater Sage-grouse Habitat – With Emphasis on Nesting and Early Brood Rearing* (University of Wyoming 2009) provides an excellent overview and discussion relative to the influences of livestock grazing on sagebrush ecosystems and sage-grouse habitat. Wet meadows within sagebrush systems deserve particular attention. Livestock prefer these sites as the summer progresses and uplands become desiccated, which increases the tendency for over utilization. Many wildlife species use these sites during critical periods, such as pronghorn and mule deer fawning and sage-grouse late brood-rearing. However, meadows excluded from livestock grazing by fences may need to be periodically grazed to reduce dense grassy cover that may inhibit forb availability for wildlife.

While fences are effective for livestock management, they can also be barriers to wildlife movement and cause direct mortality. Fences should be designed to readily allow the passage of big game including pronghorn. Fencing design and instructions can be found in the WGFD Habitat Extension Service Bulletin No. 53 *Fencing Guidelines for Wildlife* (WGFD 2004). Fences also can be a source of mortality to sage-grouse from strikes by flying birds (Wyoming Game and Fish Department 2009a).

Strikes have been documented in winter sage-grouse foraging areas, near leks, and fences around riparian areas used by sage-grouse broods in the summer. Problem fences should be modified, removed, or fitted with marking devices so grouse can see the wires while in flight in low visibility situations.

Efforts should be made to maintain big game herd numbers at ecologically sustainable levels that account for the carrying capacities of the herd unit's summer and winter ranges.

Develop incentives for landowners and land operators to adopt actions identified in the SWAP.
Many ranching operations own and use sagebrush dominated systems for various activities including livestock grazing. Additional incentives need to be developed before management strategies focused on increasing wildlife habitat values in sagebrush systems can be widely adopted. Examples of successful incentives include grassbanks, management agreements encouraging prescribed livestock grazing, and conservation easements. NRCS Farm Bill programs, the NRCS 2010 Sage-grouse Initiative, the USFWS Candidate Conservation Agreement with Assurances, and Wyoming Local Sage-grouse Working Groups all provide opportunities for the establishment of cooperative habitat improvement projects. Additional funding sources include the WGFD Trust Fund Program and Sage-grouse Programs, Tom Thorne Sage-grouse Fund, and Wyoming Wildlife and Natural Resource Trust.

Manage off-road vehicle use in environmentally sensitive areas or during seasons where wildlife is particularly sensitive to disturbance.
More efforts should be made on public lands to identify areas that are appropriate and inappropriate for off-road vehicle use including using Carsonite markers. Locations may vary seasonally to minimize disturbance to wildlife during critical periods such as when animals are on winter range or during nesting or fawning seasons. Public education should include increasing awareness of the ecological role of maintaining unbroken biological soil crust and the value of all types of vegetation.

Conduct more research about the potential effects of climate change on sagebrush ecosystems.
Reduced establishment of new sagebrush plants resulting from changes in climate, while currently hypothetical, could have serious consequences for the future of sagebrush ecosystems and wildlife in Wyoming. Additional research and modeling are needed to better understand the influence of temperature and precipitation on the establishment of sagebrush plants and potential future changes to Wyoming's climate patterns. This information could be used to make predictions on how climate change may influence sagebrush system health and distribution and where in the state these changes are likely to occur. This information should be communicated to wildlife biologists, natural resource managers, and landowners throughout the state to assist in sagebrush ecosystem and wildlife conservation planning.

Sagebrush Shrublands Monitoring Activities

Continue monitoring population trends or changes in distribution of sagebrush SGCN and other obligates in order to infer changes in habitat quality or other threats.
Monitoring should be used to determine distribution and seasonal habitat use to refine priority habitat maps.

Monitor the size and landscape distribution of sagebrush shrublands through remote sensing.
Remote sensing is useful in tracking the size and distribution of this habitat type in Wyoming. Information gathered would be helpful in determining the cumulative impacts of activities and events such as energy development, rural subdivision, road construction, conifer encroachment, and the spread of invasive species. Monitoring should also be conducted

in relation to the possible effects of climate change.

Establish sites and protocols for long-term monitoring to evaluate the effects of habitat management activities on individual plants, vegetation communities, wildlife species, and ecological processes.
Inventory and monitor sagebrush systems and habitats in federal grazing allotments as part of annual inspections and during the 10-year allotment reviews.
Monitoring should include evaluation of livestock and wildlife browsing levels, invasive species, conifer encroachment, and plant understory composition.

Literature Cited

Adams, R. A. 2003. Bats of the Rocky Mountain West: natural history, ecology, and conservation. University Press of Colorado, Boulder.

ADAMS, B.W., L. POULIN, D. MOISEY, AND R. MCNEIL. 2004. Rangeland plant communities and range health assessment guidelines for the dry mixed grass natural sub region of Alberta. Rangeland Management Branch, Public Lands Division, Alberta Sustainable Resource Development, Pub. No. T/040. Lethbridge, Canada.

ALDRIDGE, C. L., AND M. S. BOYCE. 2007. Linking occurrence and fitness to persistence: a habitat-based approach for endangered greater sage-grouse. Ecological Applications 17:508-526.

BAKER, W. L. 2006. Fire and restoration of sagebrush ecosystems. Wildlife Society Bulletin 34(1):177–185.

BECK, J. L. AND D. L. MITCHELL. 2000. Influences of livestock grazing on sage-grouse habitat. Wildlife Society Bulletin 28:993–1002.

BECKER, J. M., C. A. DUBERSTEIN, J.D. TAGESTAD, AND J.L. DOWNS. 2009. Sage-grouse and wind energy: biology, habits, and potential effects from development. Pacific Northwest Laboratory under contract to U. S. Department of Energy. PNNL–18567.

BEETLE, A. A. AND K. L. JOHNSON. 1982. Sagebrush in Wyoming. Univ. Wyo. Agric. Exp. Sta. Bull. 779. Laramie, WY.

BERGQUIST, E., P. EVANGELISTA, T. J. STOHLGREN AND N. ALLEY. 2007. Invasive species and coal bed methane development in the Powder River Basin, Wyoming. Environmental Monitoring and Assessment 128(1-3):381–394.

BOHNE, J., T. RINKES, AND S. KILPATRICK. 2007. Sage-grouse habitat management guidelines for Wyoming. Wyoming Game and Fish Department. Cheyenne, WY.

BUI, T.D. 2009. The effects of nest and brood predation by common ravens (*Corvus corax*) on greater sage-grouse (*Centrocercus urophasianus*) in relation to land use in western Wyoming. M.Sc. thesis. University of Washington, Seattle, WA.

BUREAU OF LAND MANAGEMENT. 2000a. The war on weeds – winning it for wildlife. Washington, DC.

_____. 2000b. A biological emergency – and how you can help stop the spread of invasive plants in wildlands. Washington, DC.

_____. 2001. Map of Wyoming sagebrush communities. Prepared by Tom Rinkes, Bureau of Land Management, Wyoming State Office, Cheyenne, WY.

_____. 2001. Wyoming sagebrush/sage grouse habitats. GIS Map. WY Bureau of Land Management, Wyoming State Office, Cheyenne, WY.

_____. 2009. Instructional Memorandums on Sage grouse. Memorandum WO-2010-071

BRADLEY, B. A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. Global Change Biology 15:196–208.

CAWKER, K. B. 1980. Evidence of climatic control from population age structure of *Artemisia tridentata* Nutt. in southern British Columbia. Journal of Biogeography 7:237–248.

CHRISTENSEN, J. H., B. HEWITSON, A. BUSUIOC, ET AL. 2007. Regional climate projections. *In:* Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

CONNELLY, J. W., S. T. KNICK, M. A. SCHROEDER, AND S. J. STIVER. 2004. Conservation Assessment of Greater Sage-grouse and Sagebrush Habitats. Western Association of Fish and Wildlife

Agencies. Unpublished Report. Cheyenne, Wyoming.

CONNELLY, J.W., K, P. REESE, M. A. SCHROEDER . 2003. Monitoring of Greater Sage-grouse Habitats and Populations. 2003. University of Idaho, College of Natural Resources Experiment Station. Station Bulletin 80.

COMMONS, M. L., R. K. BAYDACK, AND C. E. BRAUN. 1999. Sage-grouse response to pinyon-juniper management. Pages 238–239 *In* Monsen, S.B. and R. Stevens, eds. Proceedings: Ecology and management of Pinyon Juniper Communities within the Interior West. U.S.D.A. U.S. Forest Service Rocky Mountain Research Station RMRS-P9, Fort Collins, CO.

COOPER, W. V., P. LESICA, AND G. M. KUDRAY. 2007. Post-fire recovery of Wyoming big sagebrush shrub-steppe in central and southeast Montana. MT. Natural Heritage Program.

DEALY, J. E., D. A. LECKENBY, AND D. M. CONCANNON. 1981. Wildlife habitats in managed rangelands – the Great Basin of southeastern Oregon: plant communities and their importance to wildlife. USDA Forest Service General Technical Report. PNW-120.

DOHERTY, K. E., D. E. NAUGLE, B. L. WALKER, AND J M. GRAHAM. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187–195.

ELLIOTT, D.L. WENDELL, L.L., AND G.L. GOWER. 1991. An analysis of windy land areas and wind potential in the contiguous United States. Pacific Northwest Laboratory, PNL-7789

FREESE, M. T. 2009. inking greater sage-grouse habitat use and suitability across spatiotemporal scales in central Oregon. M.S. thesis, Oregon State University, Corvallis, OR.

INGELFINGER, F. 2001. The effects of natural gas development on sagebrush steppe passerines in Sublette County, Wyoming. M.Sc. thesis. University of Wyoming, Laramie, WY.

JACKSON, S. T., J. L. BETANCOURT, M. E. LYFORD, S. E. GRAY, C. L. FASTIE, AND S. THARNSTROM. 2005. Late Holocene expansion of Utah juniper in Wyoming: a modeling system for studying ecology of natural invasions. NSF-DEB-9815500 Final Report.

KNIGHT, D. H. 1994. Mountains and plains: the ecology of Wyoming landscapes. Yale University Press.

LAWRENCE, F.J. (ed). 2007. The oil and gas producing industry in your state. Independent Petroleum Association of America, Washington, D.C. Vol. 75, No. 17.

MAESTAS, J. D, R. L. KNIGHT, AND W. C. GILGERT. 2002. Cows, condos, or neither: what's best for rangeland ecosystems? Find out how plant communities vary across ranches, ranchettes, and nature reserves in one Colorado watershed. Rangelands 24(6):36–42.

MAIER, A. M., B. L. PERRYMAN, R. A. OLSON, AND A. L. HILD. 2001. Climatic influences on recruitment of 3 subspecies of *Artemisia tridentata*. Journal of Range Management 54:699–703.

MARRA, P. P., S. GRIFFING, C. CAFFREY, A. M. KILPATRICK, R. MCLEAN, C. BRAND, E. SAITO, A. P. DUPUIS, L. KRAMER, AND R. NOVAK. 2004. West Nile virus and wildlife. BioScience 54 (5) 393–402.

MILLER, R. F., T. J. SVEJCAR, AND N. E. WEST. 1994. Implications of livestock grazing in the Intermountain sagebrush region, p. 101–146 *in* M. Vara, W. A. Laycock, and R. D. Piper (eds).77 Ecological Implications for Livestock Herbivory in the West. Soc. For Range Manage. Denver. CO.

MILLER, R. F. AND L. L. EDDLEMAN. 2000. Spatial and temporal changes of sage-grouse in the sagebrush biome. Oregon State Agric. Exp. Sta. Tech. Bull. 151.

_____. 2001. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Agricultural Experiment Station Technical Bulletin 151. Oregon State University, Corvallis, OR.

MONSEN, S. B., R. STEVENS, AND N. L. SHAW, compilers. 2004. Restoring western ranges and wildlands. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-136-vol-1-3. Fort Collins, CO.

NATIONAL MINING ASSOCIATION. 2008. Mining Statistics. Washington, D.C.

NATURESERVE. 2009. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, VA.

PAIGE, C. AND S. A. RITTER. 1999. Birds in a sagebrush sea - managing sagebrush habitats for bird communities. Partners in Flight – Western Working Group. Boise, ID.

PETERSON, J. G. 1995. Sagebrush: ecology implications of sagebrush manipulation. Montana Department of Fish, Wildlife and Parks, Helena, MT.

POCEWICZ, A., H. E. COPELAND, M. B. GRENIER, D. A. KEINATH, AND L. M. WASHKOVIAK. 2014. Assessing the future vulnerability of Wyoming's terrestrial wildlife species and habitats. The Nature Conservancy, Wyoming Game and Fish Department, Wyoming Natural Diversity Database, Lander, Wyoming.

RAPHAEL, M. G., M. J. WISDOM, M. M. ROWLAND, R. S. HOLTHAUSEN, B. C. WALES, B. G. MARCOT, AND T. D. RICH. 2001. Status and trends of habitats of terrestrial vertebrates in relation to land management in the interior Columbia River Basin. Forest Ecology and Management 153:63–68.

ROONEY, T. P. 2005. Distribution of ecologically invasive plants along off-road vehicle trails in the Chequamegon National Forest, Wisconsin. The Michigan Botanist 44:178–182.

STIVER, S.J., A.D. APA, J.R. BOHNE, S.D. BUNNELL, P.A. DEIBERT, S.C. GARDNER, M.A. HILLIARD, C.W. MCCARTHY, AND M.A. SCHROEDER. 2006. Greater Sage-grouse Comprehensive Conservation Strategy. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming.

STURGIS, D. L. 1994. High-elevation watershed response to sagebrush control in southcentral Wyoming. Res. Pap. RM-318. Fort Collins, CO. USDA For. Serv. Rocky Mountain Forest and Range Experiment Station.

UNIVERSITY OF WYOMING. 2009. Grazing Influence, Objective Development and Management in Wyoming's Greater Sage-Grouse Habitat With Emphasis on Nesting and Early Brood Rearing. (CEC publication.)

U.S. DEPARTMENT OF AGRICULTURE, NATURAL RESOURCES CONSERVATION SERVICE. 2007. Effects of Exurban Development on Wildlife and Plant Communities, by J. D. Maestas. Technical Note No. X, Washington, DC.

VALE, T. R. 1974. Sagebrush conversion projects: an element of contemporary environmental change in the Western United States. Biological Conservation 6(4) 274–284.

WHISENANT, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains. Ecological and management implications. Pp. 4–10 *In* E. D. McArthur, E. M. Romney, S. D. Smith and P. T. Tueller, compilers. Symposium of cheatgrass invasion, shrub die-off and other aspects of shrub biology and management. USDA. For. Ser. Gen. Tech. Rep. INR-276.

WINWARD, A. H. 1991. A renewed commitment to management of sagebrush grasslands in Research in Rangeland Management. Oregon State Univ. Agr. Exp. Spec. Rep. 880. Corvallis, OR.

_____. 2004. Sagebrush of Colorado: taxonomy, distribution, ecology and management. CO Division of Wildlife. Denver, CO.

WYOMING COOPERATIVE AGRICULTURAL PEST SURVEY. 2010. Cheatgrass (*Bromus tectorum*). Online at: http://www.uwyo.edu/capsweb/

WYOMING INTERAGENCY VEGETATION COMMITTEE. 2002. Wyoming guidelines for managing sagebrush communities with emphasis on fire management. Wyoming Game and Fish Department and Wyoming Bureau of Land Management, Cheyenne, WY.

WYOMING GAME AND FISH DEPARTMENT. 2004. Fencing guidelines for wildlife. Habitat extension bulletin No. 53. Cheyenne, WY.

_____. 2009a. Fence Marking to Reduce Greater Sage-grouse (*Centrocercus urophasianus*) Collisions and Mortality near Farson, Wyoming – Summary of Interim Results http://gf.state.wy.us/downloads/pdf/FenceMarkingInterimReport10-26-09corrected.pdf

_____. 2009b. Strategic Habitat Plan. Cheyenne, WY.

_____. 2010a. Recommendations for Development of Oil and Gas Resources Within Important Wildlife Habitats. Version 6. Cheyenne, WY.

_____. 2010b. Recommendations for wind energy development in crucial and important wildlife habitat. Cheyenne, WY.

_____. 2010c. Aquatic Standard Commenting Recommendations. Cheyenne, WY.

WYOMING SAGE-GROUSE WORKING GROUP. 2003. Wyoming Greater Sage-Grouse Conservation Plan. Wyoming Game and Fish Department, Cheyenne, WY.

YENSEN, D. L. 1981. The 1900 invasion of alien plans into southern Idaho. Great Basin Naturalist 41:176–183.

YOUNG, J. A., AND B. A. SPARKS. 2002. Cattle in the cold desert. University of Nevada Press, Reno, NV.

ZOU, L., S. N. MILLER, AND E. T. SCHMIDTMANN. 2006. Mosquito larval habitat mapping using remote sensing and GIS: implications of coalbed methane development and West Nile virus. Journal of Medical Entomology 43:1034–1041.