Effective management strategies for sage-grouse and sagebrush: a question of triage?


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Sagebrush: An Ecosystem Gone Wrong

The sagebrush (*Artemisia* spp.) ecosystem once occupied over 150 million acres of western North America (Barbour and Billings 1988). The ecosystem still occupies over 100 million acres (Connelly et al. 2004, Wisdom et al. 2005), but the abundance and condition of sagebrush communities are declining rapidly in response to a variety of detrimental land uses and undesirable ecological processes (Knick et al. 2003). The ecosystem has been reduced in area by 40-50 percent since pre-European settlement (Connelly et al. 2004), and less than 10 percent remains in a condition unaltered by human disturbances (West 1999).

The ills of the sagebrush ecosystem are well documented. Millions of acres have been converted to agriculture, cities, roads, transmission lines, energy developments, exotic plants, and woodlands (Connelly et al. 2004). Moreover, the loss appears to be accelerating, and management intervention thus far has been ineffective in abating the rate of loss, let alone reversing it (Hemstrom et al. 2002). Millions of acres of remaining sagebrush are threatened by the continued and widespread invasion of cheatgrass (*Bromus tectorum*) and other exotic plants, as well as by expansive encroachment of pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) woodlands (Billings 1994, Tausch et al. 1995, Wisdom et al. 2005). Finally, up to 80 percent of remaining sagebrush communities could be lost to the direct and indirect effects of global warming (Neilson et al. 2005). Direct effects are a result of substantially elevated levels of carbon dioxide from human activities (Vitousek et al. 1997). Indirect effects include the increased competitive ability of exotic annual grasses and arid vegetation of the southwestern United States, both of which are projected to invade and replace vast areas of existing sagebrush (Smith et al. 2000, Neilson et al. 2005).

Despite overwhelming evidence regarding the demise of the sagebrush ecosystem and the many causes for decline, the specific effects on many sagebrush-associated species are not well

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documented. Populations of many sagebrush-associated species, however, are declining (e.g., Wisdom et al. 2000, Dobkin and Sauder 2004), and approximately 20 percent of the ecosystem's native flora and fauna are considered imperiled (Center for Science, Economics and Environment 2002). Moreover, Raphael et al. (2001) found that the estimated risks of regional extirpation for sagebrush-associated vertebrates, under current management of public lands, were similar to risks for species in other ecosystems that were already listed as federally threatened or endangered under the U.S. Endangered Species Act. These high extirpation risks are exemplified by status and trends of greater sage-grouse (*Centrocercus urophasianus*); its populations have declined steadily over the latter half of the 20th century, the same time period in which human activities have substantially reduced the quantity and quality of sagebrush (Connelly and Braun 1997, Connelly et al. 2004, Rowland 2004). Similar population trends in response to detrimental land-use effects have been documented for the smaller populations of Gunnison sage-grouse (*Centrocercus minimus*) (Oyler-McCance et al. 2001, Schroeder et al. 2004).

Although status and trends of many sagebrush-associated species may be uncertain, it is clear that the ecosystem, as a whole, is in serious trouble. The sagebrush ecosystem is considered one of the most imperiled of all ecosystems in the United States (Noss et al. 1995, Stein et al. 2000), and recent assessments of sagebrush habitats at regional scales substantiate this view (e.g., Nachlinger et al. 2001, Connelly et al. 2004, Rowland et al. 2005, Wisdom et al. 2005). The ecosystem's native vertebrates not only face high risks of extirpation at regional scales, but major ecological processes, such as fire and hydrologic regimes, have been substantially altered (Billings 1994; Tausch et al. 1995; Bunting et al. 2002; Pierson et al. 2002, 2003). Adding to the view of ecosystem imperilment is the lack of effective management to reverse undesirable trends in vegetation dynamics and fire regimes (Hemstrom et al. 2002). Consequently, we may not understand the specific mechanisms by which many sagebrush-associated species respond to habitat loss and fragmentation, but the evidence thus far suggests that that the entire ecosystem faces an array of threats that appear to be accelerating in effect and extent.

The plethora of detrimental effects on the sagebrush ecosystem is illustrated by the long list of anthropogenic threats that have reduced the ecosystem's abundance, quality, and contiguity. Wisdom et al. (2005) identified 26 threats to sagebrush habitats and species that operate at regional scales, and thus affect, or have potential to affect, areas the size of a county, multiple counties, or even a state (Table 1). The varied range of threats--from climate change to exotic plant invasions, from roads to transmission lines, and from urban development to overgrazing by feral horses--illustrates the point that no single factor or process is responsible for the ecosystem's problems. This is perhaps the most challenging aspect of future management: no particular solution is apparent, easy, quick, or straight-forward.

What to Do?

To further belabor the many ills of the sagebrush ecosystem is to ignore the real question of importance. And that is, what can be done to improve the situation? In addressing this question, two primary objectives are likely to drive future management of public lands in the sagebrush ecosystem: (1) the desire to maintain current sagebrush habitats and associated flora and fauna; and (2) the desire to restore at least a portion of sagebrush habitats that have been lost.

To meet these objectives, managers are confronted with three related problems: (1) a high probability of threshold effects that are difficult or impossible to avoid or overcome; (2) a lack of resistance in most sagebrush communities to changes caused by human-associated disturbances; and (3) a lack of resiliency in most sagebrush communities to return to former native states once a community change occurs.

We define a threshold effect as any transition from one vegetative state to another that results in a new steady state that is extremely difficult or impossible to change, regardless of the transition agents that may be implemented in an attempt to move to a more desired state. We define resistance as the degree to which a given vegetative state can maintain itself in the face of disturbance. We define resiliency as the degree to which a given vegetative state returns to its former state when changed by a disturbance.

All three concepts are based on state and transition models of vegetation development (Tausch et al. 1993; Figures 1, 2) as used in arid and semi-arid rangelands in many areas of the world (Westoby et al. 1989, Laycock 1991). All three concepts are interrelated and integral in the maintenance and restoration of sagebrush habitats, and thus are central paradigms for management. For example, overgrazing by ungulates in a Wyoming big sagebrush (*A. tridentata wyomingensis*) community with low resistance to invasion by cheatgrass may cause a transition from an understory of native, perennial grasses to one of co-dominance of native grasses and cheatgrass (Figure 1). At this point, a threshold has been crossed, in turn setting up an eventual threshold effect that is facilitated by subsequent fires. The subsequent fires progressively change the co-dominance of native grasses and cheatgrass in the understory to one of dominance by cheatgrass. Eventually, a series of high-intensity, frequent fire events transforms the sagebrush community to a homogenous stand of cheatgrass, which is highly resistant to change and highly resilient to further disturbance events. Eventually, if a transition from cheatgrass does occur, the most likely change is to other undesired, exotic perennial grasses that can dominate a site with still higher resistance and resiliency (Nancy Shaw, personal communication, 2004).

The vegetation dynamics described above are typical of Wyoming big sagebrush communities occurring in warmer, drier portions of the sagebrush ecosystem (West 1999). The Wyoming big sagebrush community in this example has low resistance and resiliency in the face of ungulate grazing, invasion by cheatgrass, and fire (see Bunting et al. 2002 and Hemstrom et al. 2002 for details about these dynamics).

Notably, the three disturbance agents work together, in a synergistic manner, to transform the Wyoming big sagebrush community to cheatgrass. In addition, other disturbance agents could function in the same manner as ungulate grazing, such as off-road vehicle use, in facilitating the initial invasion of cheatgrass. Consequently, no single disturbance agent contributes solely to the new steady state. Instead, a chronic disturbance (ungulate grazing or off-road vehicle use) initially "weakens" the community, allowing cheatgrass to spread, in turn providing sufficient fuels to carry progressively hotter and more expansive fires with each subsequent fire event. Thus, the cumulative effect of all disturbance agents causes the transition to the new steady state.

These concepts of threshold effects, resistance, and resiliency are further illustrated in a conceptual state and transition model in the mountain big sagebrush (*A. t. vaseyana*) community (Figure 2). In this example, the community is highly resistant to change in the face of chronic disturbances such as ungulate grazing or off-road recreation use, and fire events are less intense and typically invigorate the native flora inherent to the site (per descriptions by Miller and Eddelman 2001). Moreover, efforts to restore the community after land uses that intentionally transform the area to non-habitat, such as from energy development, have a higher potential for success. By contrast, restoration of the Wyoming big sagebrush community following a land transformation, such as energy development, is substantially more complicated and uncertain (Figure 1; see discussion by Bunting et al. 2002).

The disparity of responses among different sagebrush communities, like those described above, suggests that the most challenging aspect of current management is to correctly decipher which sagebrush communities, under which site conditions, are resistant and resilient, versus communities of low resistance and resilience, as well as those with characteristics intermediate to these extremes. Current knowledge suggests that little can be done to restore vast areas of sagebrush that have already been lost and experienced threshold effects that are impossible, or highly improbable, to reverse (Bunting et al. 2001). On the other hand, many areas of existing sagebrush may be close to transitioning to new steady states that may be difficult to reverse, but these transitions might be prevented through management intervention. Still other areas of sagebrush are highly resistant and resilient to most human disturbances, and currently demand less management intervention to retain native components and processes.

Given this array of conditions, managers need a systematic way of prioritizing sites, across the entire ecosystem, for application of best management practices that provide the greatest return on investment (i.e., provide the highest probability of maintaining current sagebrush communities or restoring extirpated communities). We assume that prioritization would be designed to meet the primary objective of maintaining current sagebrush communities and their native flora and fauna. We further assume that a secondary objective would be to restore a targeted portion of sagebrush communities when such restoration would best serve goals of enhancing current habitat conditions. Without new, strategic, and comprehensive methods of spatial prioritization for management, a continuing trend of expansive sagebrush loss and degradation is likely to continue (Hemstrom et al. 2002, Wisdom et al. 2002).

Accordingly, we suggest that sagebrush managers adopt a strategic process that addresses the sagebrush ecosystem as a whole, and that provides explicit rationale for spatial prioritization of best management practices to meet the above-stated objectives. The process could include the following ecological concepts and analytical considerations to increase its effectiveness.

1. *Develop a new paradigm of holistic management of all human-associated disturbances.* The 26 factors listed in Table 1 all pose threats to sagebrush habitats at some time and place, and many affect vast areas of the ecosystem in undesirable ways. If all human-associated disturbances were effectively managed, many existing sagebrush communities might be maintained, and some of the former communities would have a better chance of being restored. To focus mitigation on some threats, but ignore many other threats (Table 1), is a strategy likely to fail when applied across expansive areas that typically experience a wide variety of disturbances.
2. *Establish spatial priorities, across the entire ecosystem, for best uses of limited resources for maintenance of current, desirable conditions.* It is a myth to believe that small refinements in current management practices will maintain existing, desirable conditions in areas where sagebrush communities have low resistance and resiliency (Hemstrom et al. 2002). By contrast, sagebrush communities with high resistance and resiliency are likely to require less management attention. Finally, the many sagebrush communities that have intermediate levels of resistance and resiliency may require most of the limited resources available for best management practices, so as to prevent undesirable transitions that are likely to occur without improvements to current management. As

stated above, preventing undesirable transitions across thresholds requires comprehensive and effective management of all human-associated disturbances that operate at broad scales in the sagebrush ecosystem, such as the threats listed in Table 1.

3. *Evaluate the anticipated responses of sagebrush communities to human-associated disturbances, across the entire ecosystem, as the basis for spatial prioritization of management.* Establishing spatial priorities for management could use maps of the estimated resistance and resiliency of sagebrush communities as part of the priority-setting process. Communities with low or high resistance and resiliency would, in turn, have low or high potential for maintenance of current habitats. Spatial priorities for restoration of former habitats could also employ a similar process based on site conditions.

As an example of such a process, we estimated and mapped the potential to maintain current sagebrush communities, and to restore former communities across the historical ranges of greater and Gunnison sage-grouse (see Schroeder et al. [2004] for derivation of their ranges). We used precipitation and elevation as proxies, or indicators, of community resistance and resiliency, and by extension, the potential to maintain or restore sagebrush. In general, resistance and resiliency decline with decreasing precipitation and elevation, which index a gradient of increasingly dry (low precipitation) and warm (low elevation) conditions (West 1999). As sagebrush sites become increasingly dry and warm, the probability of maintenance of sagebrush overstories and native grass understories declines in the presence of human-associated disturbances (Hemstrom et al. 2002). For example, road construction through a sagebrush site with high precipitation (e.g., over 14 inches mean annual precipitation) at colder, higher elevation (e.g., over 6,500 feet) would have a lower likelihood of facilitating the establishment and spread of non-native, invasive plants. By contrast, the same road construction through a sagebrush site with low precipitation (e.g., less than 10 inches mean annual precipitation) at warmer, lower elevation (e.g., less than 3,000 feet) would have a higher likelihood of successfully establishing and spreading invasive plants.

Based on these relations, we developed spatial rules for estimating and mapping the potential to maintain existing sagebrush or restore former sagebrush sites under varying combinations of precipitation and elevation classes (Table 2). We then applied the rules to existing cover types of sagebrush (Comer et al. 2002) to estimate the potential to maintain existing sagebrush (Figure 3). We also applied the rules to sites currently not occupied by sagebrush but identified by Küchler (1970) as potential sagebrush sites; these latter areas were mapped as a means of estimating restoration potential of sites that were likely to support sagebrush in the past.

The results of such a mapping process (Figures 3, 4) appear to provide helpful insights about spatial patterns regarding the potential to maintain and restore sagebrush communities. In general, most areas with high potential to maintain or restore sagebrush communities are concentrated in Wyoming, eastern Idaho, and northern Nevada. Areas with very low, low, or moderate potential to maintain or restore sagebrush are concentrated in Washington, Oregon, western Idaho, and much of Nevada. These patterns (Figures 3, 4) appear to closely match the geographic variation in habitat losses due to exotic plant invasions and agricultural development across the sagebrush ecosystem (Connelly et al. 2004). We also believe these patterns match the general sensitivity of sagebrush areas to human-associated disturbances. That is, sagebrush communities with high maintenance potential would be more resistant to change in the face of disturbances such as grazing, road construction, and recreation. Similarly, while land uses that transform sagebrush habitats to non-habitats have the same immediate effect, the sagebrush sites with higher potential for restoration have higher resiliency, and thus have a higher probability to "bounce back" from the transformation, once restoration is initiated (e.g., compare Figure 1 with Figure 2).

Our maps and results are not definitive, but instead demonstrate a conceptual process of characterizing the potential for sagebrush maintenance and restoration across the ecosystem. The mapping process shown here could be substantially refined and enhanced with the inclusion of additional variables, such as temperature, slope, aspect, species and subspecies of sagebrush, drought indices, soil characteristics, and human activities, each of which are likely to improve the characterization of the potential to maintain or restore sagebrush communities.

4. *Estimate the resources and budgets required over time and space to fully address all spatial priorities.* Maps like those shown in Figures 3 and 4 can be used to develop broad-scale management prescriptions for maintenance and restoration. Funds needed to fully implement all prescriptions on high-priority sites then could be estimated, independent of the considerations of current budgets or political influences. Without identification of the full level of funding needed to meet objectives for maintenance and restoration, there is no opportunity for policies to change in recognition of funding shortfalls.
5. *Adopt the concept of triage throughout the process*. Unless budgets substantially increase for public land managers of sagebrush, there simply are not enough resources to maintain all current sagebrush communities, let alone recover a portion of communities lost. In the Interior Columbia Basin, Hemstrom et al. (2002) and Wisdom et al. (2002) found that a six-fold increase in the budgets of the U.S. Department of Interior Bureau of Land Management and U.S. Department of Agriculture Forest Service for sagebrush maintenance and restoration reduced the rate of decline in habitat loss and quality, but did not reverse the decline. Notably, Hemstrom et al. (2002) and Wisdom et al. (2002) focused their management scenarios on restoration of former sagebrush sites, with less emphasis on maintenance of existing communities; increased emphasis on maintenance would likely have resulted in more effective outcomes. Regardless, the findings of these authors demonstrate that a dramatic funding increase is required to realistically expect a reversal in the accelerating loss and quality of sagebrush habitats. Consequently, the concept of "triage," defined in the medical profession as "the allocation of treatment to patients, especially battle and disaster victims, according to a system of priorities designed to maximize the number of survivors" (Merriam-Webster's Dictionary, 11th Edition), is appropriate in "sorting through the sagebrush communities to allocate resources to maximize the number, size, type, and distribution of communities that survive."

While the actual priority-setting process is beyond the scope of our paper, and is driven by legal, policy, and socio-economic criteria in combination with the ecological considerations we discuss here, the investment of resources at sites and landscapes deemed to provide the greatest return is critical. An example is the question of how best to manage and restore habitats for sage-grouse. To illustrate the choices, we summarized the area of existing and former sagebrush communities, by levels of potential to maintain or restore sagebrush (Figures 3, 4), within areas currently occupied by greater and Gunnison sage-grouse versus areas where extirpation has occurred (Figure 5). From the viewpoint of triage, assuming budgets remain inadequate to maintain and restore all habitats for the species, the following areas and sagebrush communities are likely to receive high management attention:

(1) **All remaining sagebrush habitats that exist in occupied greater sage-grouse range in Washington State, as well as all sites of former sagebrush in occupied range or adjacent to occupied range in Washington State**. These areas and habitats are essential to persistence of the small populations of greater sage-grouse in Washington, which have been designated as warranted but precluded for listing under the under the federal Endangered Species Act. Unfortunately, these areas and habitats appear to have lower potential for maintenance or restoration in contrast to other areas of occupied range (Figures 3, 4), and thus will demand substantial resources for successful management.

(2) **Existing habitats, in occupied sage-grouse range, that have moderate or high potential to be maintained**. These areas occur within the innermost portions of occupied range (Figure 3), where populations of greater sage-grouse appear to be largest and declining least (Connelly et al. 2004). Moreover, these areas also are common throughout much of the remaining sagebrush in occupied range of Gunnison sage-grouse. Finally, these areas are most likely to be maintained under current budget and resource constraints.

(3) **Former habitats, in occupied sage-grouse range, that have moderate or high potential to be restored, and that are adjacent to or close to areas identified under number 2.** These sites have a higher probability of successful restoration, and would "block up" sage-grouse habitats, resulting in lower fragmentation, larger patch sizes, and increased abundance of sagebrush in the innermost portions of occupied ranges. The result would likely increase the probability of persistence for the largest populations of greater sage-grouse.

(4) **Existing habitats, in occupied sage-grouse range, that have low potential to be maintained**. These habitats largely are found along the boundaries of currently occupied range of sage-grouse, and their maintenance would reduce further contraction in occupied range. However, these habitats would likely demand exponentially higher funds and resources for maintenance than habitats in occupied range that have moderate or high potential to be maintained. Consequently, a careful analysis of trade-offs appears warranted to understand the consequences of giving management attention to this set of habitats over other habitats with higher probabilities of maintenance.

Cause for Hope or More of the Same?

Most or all of these concepts and analytical considerations are not new and currently are being used, to varying degrees, at local administrative units of federal land management agencies, such as from general guidance provided by U.S. Department of Interior Bureau of Land Management (2002; 2004a, b). However, these approaches have not been explicitly recognized and adopted as national policy within or among any federal agencies that have management responsibilities in the sagebrush ecosystem. Nor has any explicit management direction been developed nationally based on these concepts.

Despite the challenging outlook, a framework for planning strategically across the ecosystem, using spatially explicit, prioritized management to address maintenance needs of existing sagebrush communities, could substantially improve the odds of successfully minimizing further loss and degradation. Whether conditions improve, however, depends not only on adoption of concepts and processes like those suggested here. The sheer will of managers to collectively focus on the problems will do little to help the situation if budgets are inadequate to effectively manage the plethora of human-associated disturbances that pervade the ecosystem.

Beyond the severe budgetary constraints faced by public land managers of sagebrush, there is an ecologically-driven urgency to start now, owing to threshold effects that continue to occur, over vast areas, and that are far easier to prevent than mitigate. Although populations of species like greater sage-grouse may currently be large, it is an illusion to think that such populations can withstand additional habitat loss and degradation at the scales now occurring (Connelly et al. 2004) and projected (Wisdom et al. 2002). The concept of threshold effects applies to the situation faced by this species, as it does to the sagebrush communities on which sage-grouse and other species depend. Strategic planning and spatial prioritization of management, in a holistic manner across the entire sagebrush ecosystem, employing the concept of triage, are key ingredients for successful maintenance of remaining sagebrush communities and associated species.

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Table 1. Potential threats, associated effects, and specific examples of the effects on habitats and species in the sagebrush ecosystem (adapted from Wisdom et al. [2005]). See Wisdom et al. (2005) for supporting references included in the original table.

Potential Threat	Associated Effects	Examples
Weather, climate change, and catastrophes	*Environmental* – habitat loss or degradation	Gradually increasing temperatures have contributed to drought and more severe and frequent wildfires, escalating the spread of invasive plants such as cheatgrass in sagebrush ecosystems. Drought years in close succession can lead to losses of key forbs used by sagebrush-associated species
	Population – stochastic events	Catastrophic events such as floods and severe drought can lead to extirpation of small populations
Roads and highways	*Environmental* – habitat loss	Creation of roads and highways and their associated rights-of-way result in direct loss of habitat
	Environmental – habitat fragmentation and degradation	Creation of roads and highways and their associated rights-of-way fragments sagebrush habitats; roads may accelerate the spread of invasive plants
	Population – barrier to migration or road avoidance	Roads may serve as movement or migration barriers to less mobile species; animals may avoid traffic or other activities associated with roads
	Population – direct and indirect mortality	Death or injury from collisions with vehicles, and increased mortality from poaching due to improved access
Intensive livestock grazing	*Environmental* – habitat degradation	Ecologically inappropriate grazing by domestic stock, especially cattle and sheep, leading to loss of native perennial grasses and forbs in the understory (changes in composition and structure), with resulting declines in forage and other habitat components for species of concern and their prey (e.g., invertebrates) or facilitation of spread and establishment of exotic plants; trampling may destroy burrows used by some species such as burrowing owls (*Speotyto cunicularia*) or pygmy rabbits (*Brachylagus idahoensi*s)
	Population – direct mortality	Mortality from trampling of nests
Oil and natural gas field development	*Environmental* – habitat loss and fragmentation	Pipelines, roads, well pads, and associated collection facilities fragment habitats; outright loss of habitat also occurs from roads and well pads and other facilities constructed for field development
	Population – disturbance	Disturbance and potential abandonment of habitat due to vehicular traffic, other noise (e.g., compressor stations), and related human activity at well sites
	Environmental – habitat degradation	Disturbed sites (e.g., roadsides and well pads) may become infested with invasive species

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Potential Threat	Associated Effects	Examples
Fences	*Environmental* – habitat fragmentation	Construction of fences in sagebrush ecosystems can fragment habitats and interfere with animal movement such as pronghorn (*Antilocapra americana)*
	Population – direct mortality	Animals can collide with fences or become entangled, leading to injury or death
Expansion of juniper and other woodland species in sagebrush communities	*Environmental* – habitat loss and degradation	Changes in climate and fire suppression have led to expansion of pinyon pine and juniper woodlands into sites previously occupied by sagebrush, especially in mountain big sagebrush and Wyoming big sagebrush
Invasions of exotic plants	*Environmental* – habitat loss and degradation	Altered fire regimes and habitat degradation (e.g., from intensive livestock grazing) have led to increases in exotic plants (e.g., cheatgrass) in sagebrush ecosystems; noxious weeds can also be accidentally introduced during reclamation of oil and gas well sites
Reservoirs, dams, and other water developments	*Environmental* – habitat loss	Outright loss of habitat from establishment of reservoirs in sagebrush habitat
	Environmental – habitat degradation	Altered stream flows and hydrological regimes may degrade or change habitat for aquatic and riparian species
Herbicides	*Environmental* – habitat loss and fragmentation	Herbicides used extensively prior to the 1980s for conversion and removal of sagebrush, especially if native understory vegetation was in relatively good condition
Transmission lines	*Environmental* – habitat degradation	Disturbance of vegetation and soils in corridors can lead to increased invasion of exotic species in these areas
	Population – increased rates of predation	Poles and towers for transmission lines may serve as additional perches or nest sites for corvids and raptors, increasing the potential for predation on sagebrush-associated species
	Population – direct mortality	Birds may collide with transmission lines, resulting in injury or death; electrocution of perching raptors and other birds also occurs
Altered fire regimes	*Environmental* – habitat loss	Increases in catastrophic wildfires, often related to invasions of cheatgrass, have resulted in complete removal of sagebrush cover (i.e., type conversion), especially in Wyoming big sagebrush communities
	Environmental – habitat degradation	Fire suppression has led to altered fire cycles in sagebrush ecosystems, resulting in changes in vegetation composition and structure, e.g., encroachment of woodlands into sagebrush

Table 1. Potential threats, associated effects, and specific examples of the effects on habitats and species in the sagebrush ecosystem (adapted from Wisdom et al. [2005]). See Wisdom et al. (2005) for supporting references included in the original table.

Potential Threat	Associated Effects	Examples
Urban development	*Environmental* – habitat loss	Development of urban areas and "ranchettes" surrounding urban sites results in direct loss of sagebrush habitats
	Population – human disturbance	Increases in human activities in urban and exurban areas may negatively affect populations of sagebrush-associated species by displacement or abandonment. Predation rates on wildlife in sagebrush habitats also may increase from domestic dogs and cats in urban and rural settings, as well as from increased populations of predators such as corvids, due to increased availability of food resources associated with human waste (e.g., garbage dumps, trash in campgrounds).
Herbivory effects from wild ungulates	*Environmental* – habitat degradation	Localized, excessive herbivory by native ungulates can lead to degraded understories in sagebrush ecosystems (e.g., changes in species composition and structure) and reductions in sagebrush densities and canopy cover
Disease transmission	*Population* – direct mortality	Disturbance from oil and gas development may lead to concentrations of native ungulates on winter ranges, exacerbating disease transmission during the stressful winter season. In addition, man-made water sources, particularly those whose status has changed from ephemeral to permanent from human activities, may lead to increased transmission of mosquito-borne diseases such as West Nile virus.
Brood parasitism by brown-headed cowbirds (*Molothrus ater*)	*Population* – direct mortality	Populations of some avian species (e.g., many passerines) in the sagebrush ecosystem may be affected by parasitism from brown-headed cowbirds, a species that may increase in human-altered environments, such as livestock feedlots and overgrazed pastureland
Recreation	*Environmental* – habitat degradation	Off-road vehicle use can degrade habitats in the sagebrush ecosystem, e.g., by increasing presence of exotic annual grasses like cheatgrass
	Population – human disturbance	Recreational activities, such as off-road vehicle use in sagebrush habitats, may affect species of concern, e.g., displacement or nest abandonment. Recreational shooting of small mammals also can directly affect populations.
Conversion of sagebrush to cropland or tame pasture for livestock	*Environmental* – habitat loss	Removal of sagebrush cover (e.g., via brush-beating, chaining, disking, or burning) and planting with crops, such as alfalfa, or with non-native perennial grasses, such as crested wheatgrass (*Agropyron cristatum*), for livestock forage; example affected species: greater sage-grouse, swift fox (*Vulpes velox*), and ferruginous hawk (*Buteo regalis*)
	Environmental – habitat fragmentation	Removal of sagebrush may lead to fragmentation of remaining sagebrush habitats, resulting in interference with animal movements, dispersal, or population fragmentation

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Potential Threat	Associated Effects	Examples
	Population – direct mortality	Nest and egg destruction, or direct mortality of animals, from mechanical or other methods used to remove sagebrush or to cultivate lands adjacent to sagebrush
Mine development	*Environmental* – habitat loss and fragmentation	Fragmentation and outright loss of habitat to surface mines and associated mine tailings and roads, especially coal mines
	Population – disturbance	Disturbance and potential abandonment of habitat due to traffic, noise, and related human activity at mine site; example affected species: bats, greater sage-grouse
Pesticides	*Environmental* – habitat degradation	Decrease in forage base by killing of insects used as prey by sagebrush-associated species
	Population – mortality	Direct mortality of birds and other vertebrates exposed to pesticides, and indirect mortality through consumption of contaminated insects
Saline-sodic water	*Environmental* – habitat degradation	The disposal of millions of barrels of water produced during CBM extraction can lead to salinization of surrounding soils and aquatic systems into which these waters may be dumped. In addition, sodic water discharged from wells can lead to high mortality rates (up to 100%) in vegetation exposed to such discharge.
Wind energy development	*Environmental* – habitat degradation	Increase of noxious weeds in areas around turbines or along roads needed to access turbines; loss of habitat from road construction and turbine installation. In addition, some species may avoid the area near turbines due to the association of such structures with nests or perches of avian predators such as corvids
	Population – mortality	Deaths and injuries of birds and bats from collisions with wind turbines
Collection of specimens for personal, commercial, or scientific uses	*Population* – loss of individuals from the wild	Collection of rare plants and animals, especially herptiles, may pose unknown risks to populations of these species; example species: midget faded rattlesnake (*Crotalus viridis concolor*)
Groundwater depletion	*Environmental* – habitat degradation	The pumping of water for CBM may lead to excessive groundwater withdrawal in the well sites
Grazing by feral horses	*Environmental* – habitat degradation	Loss of native perennial grasses and forbs in the understory

Table 1. Potential threats, associated effects, and specific examples of the effects on habitats and species in the sagebrush ecosystem (adapted from Wisdom et al. [2005]). See Wisdom et al. (2005) for supporting references included in the original table.

Potential Threat	Associated Effects	Examples
Selenium and other environmental contaminants	*Population* – direct threat of mortality	Poisoning of animals from uptake of selenium in contaminated aquifers, primarily from agricultural runoff
Military training	*Environmental* – habitat fragmentation	Training exercises in sagebrush habitats may result in loss of shrubs from both wildfire and destruction from tracked vehicles, and may lead to habitat fragmentation

Table 2. Spatial rules for estimating the potential to maintain existing sagebrush cover types or to restore former sagebrush cover types, using combinations of mean annual precipitation and elevation classes as proxy variables that index resistance and resiliency of sagebrush communities.

Elevation (feet)[a]	Precipitation (inches)[b]	Potential for Maintenance or Restoration
<3,281	All Values	Very Low
3,281 – 6,562	<10	Very Low
3,281 – 6,562	10 - 12	Low
3,281 – 6,562	>12 - 14	Moderate
3,281 – 6,562	>14	High
>6,562	All Values	High

[a] Based on the National Elevation Dataset (NED), derived by the U.S. Geological Survey (1999) and summarized to a 98.4-yard grid. Estimates of elevation were then overlaid on 98.4-yard grid estimates of existing sagebrush cover types derived by Comer et al. (2002) or potential sagebrush sites (Küchler 1970) summarized by U.S. Department of Agriculture Forest Service (2000).
[b] Based on mean annual precipitation, summarized for the period 1961-1990, as derived by Taylor (2000), and summarized to a 98.4-yard grid. Estimates of precipitation were then overlaid on 98.4-yard grid estimates of existing sagebrush cover types derived by Comer et al. (2002) or potential sagebrush sites (Küchler 1970).

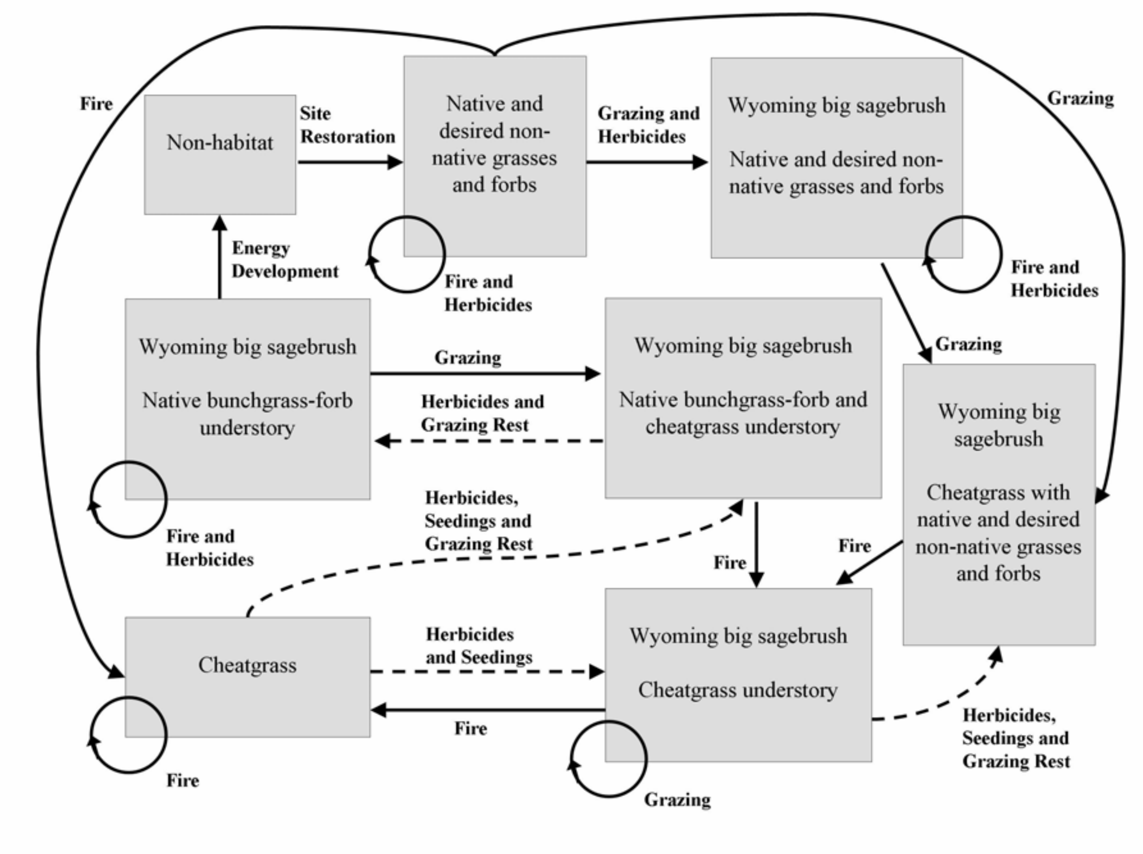

Figure 1. Example state-and-transition model for a Wyoming big sagebrush community with very low resistance and resiliency, such as might occur at sites that are extremely dry (e.g., less than 10 inches annual precipitation) and warm (e.g., less than 3,000 feet in elevation). Boxes represent vegetation states, and arrows are transitions caused by disturbance agents shown next to each arrow. Dashed arrows represent transitions that may be difficult to achieve, owing to threshold effects that have occurred (see text). Disturbance agents that sustain vegetation states are shown next to arrows with a circular path. Herbicides included as a disturbance agent are designed to control cheatgrass. Ungulate grazing is assumed to cause transitions that suppress or eliminate native grasses and forbs and confer competitive advantage to cheatgrass in the absence of herbicide treatments, and to sagebrush when grazing is combined with herbicide treatments.

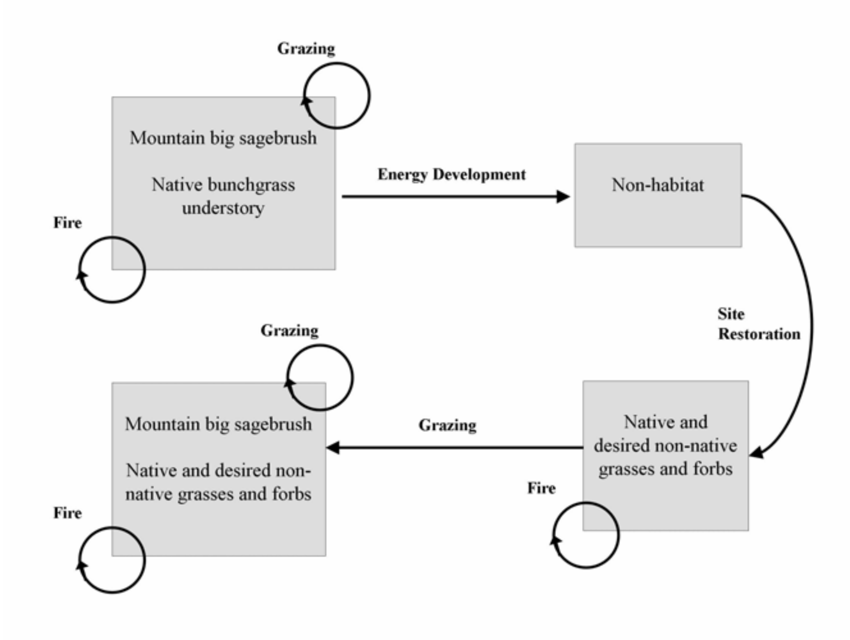

Figure 2. Example state-and-transition model for a mountain big sagebrush community with high resistance and resiliency, such as might occur at sites that are very wet (e.g., over 14 inches annual precipitation) and cold (e.g., over 6,500 feet in elevation). Boxes represent vegetation states, and arrows are transitions caused by disturbance agents shown next to each arrow. Disturbance agents that sustain vegetation states are shown next to arrows with a circular path.

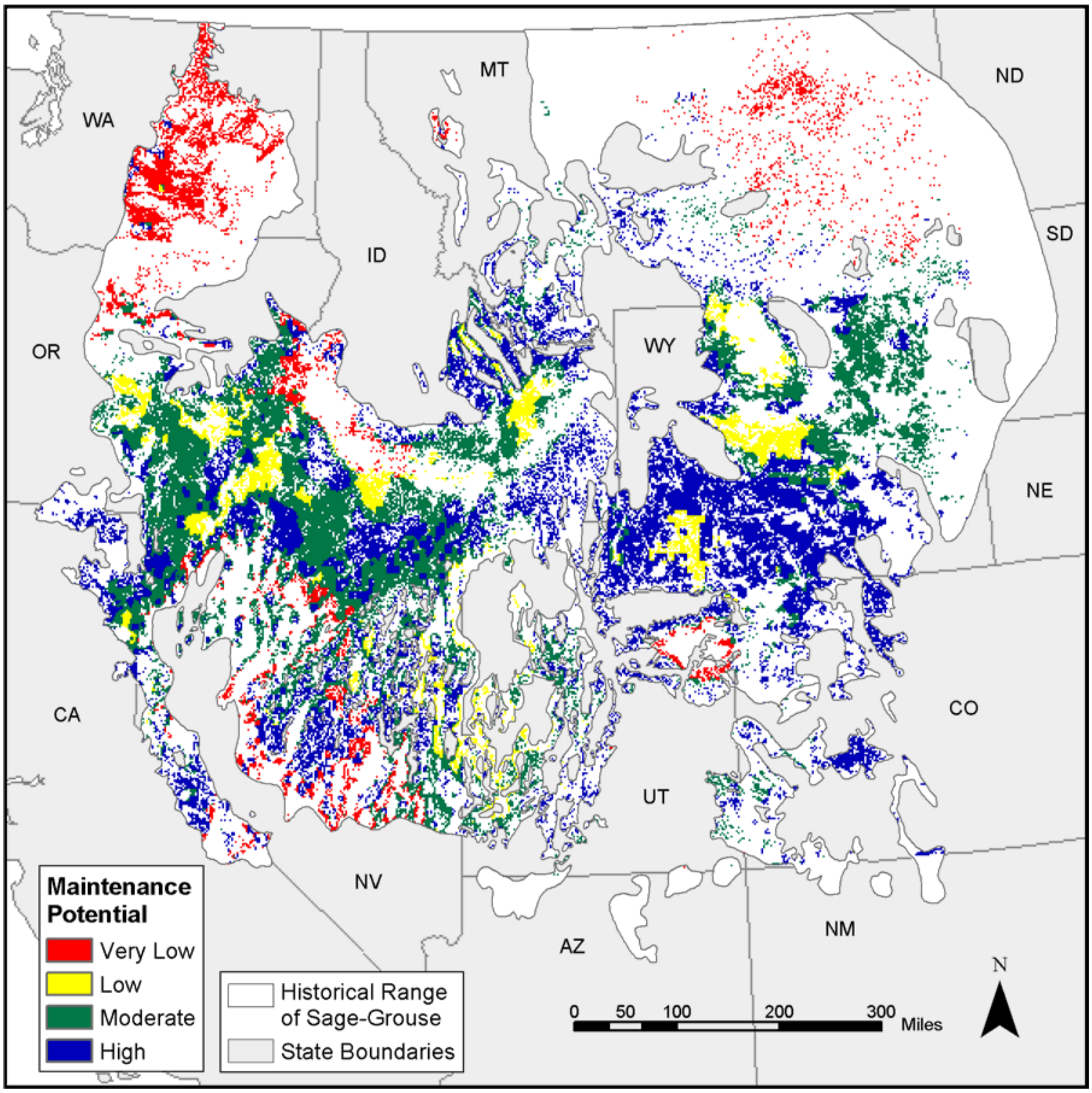

Figure 3. Estimated potential to maintain existing sagebrush communities within the historical ranges of greater and Gunnison sage-grouse, based on the estimated resistance and resiliency of the communities.

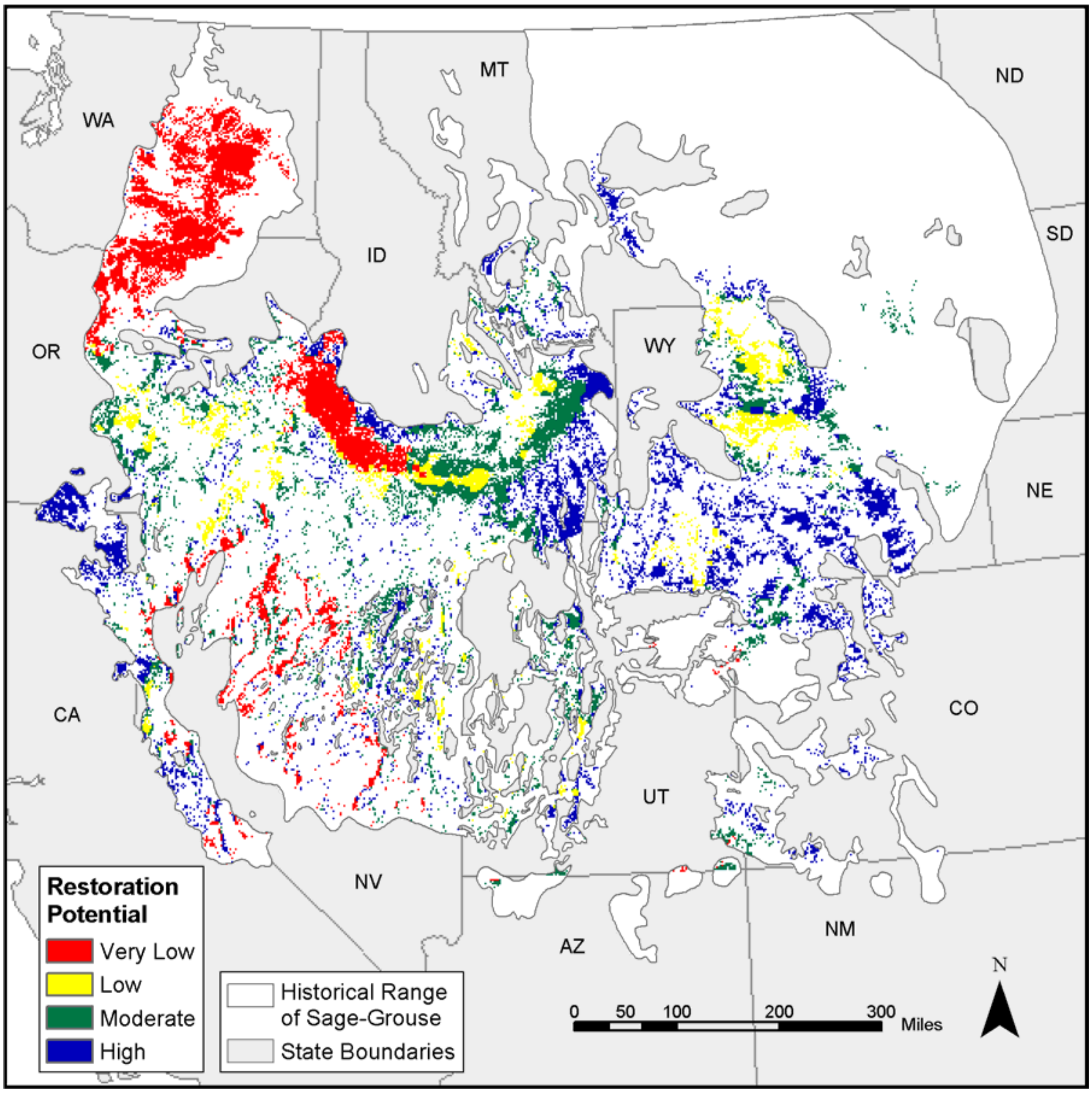

Figure 4. Estimated potential to restore former sagebrush communities within the historical ranges of greater and Gunnison Sage-grouse, based on the estimated resistance and resiliency provided by the sites.

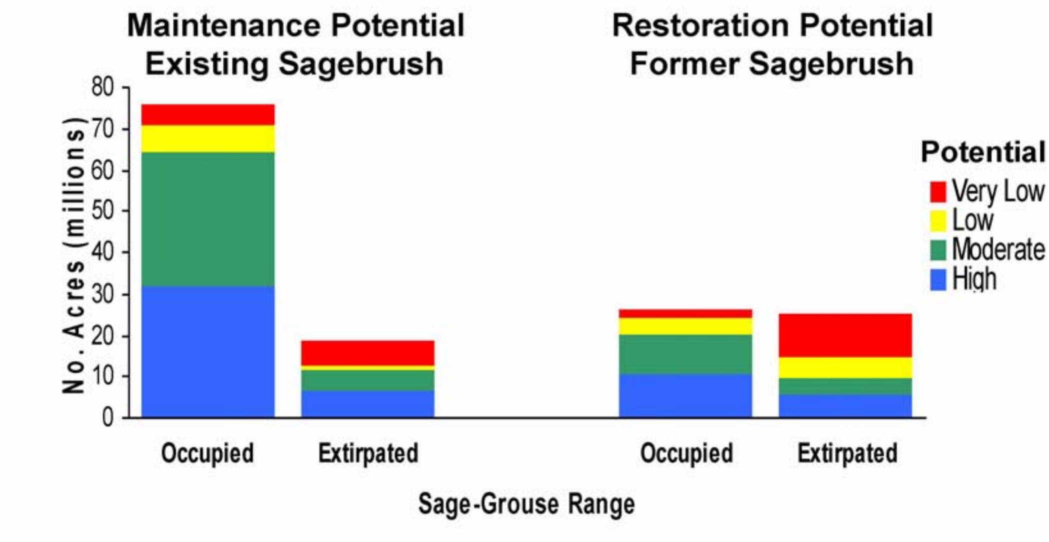

Figure 5. Area of sagebrush cover types estimated as very low, low, moderate, and high potential for maintenance and for restoration, summarized by occupied versus extirpated ranges of greater and Gunnison sage-grouse.