CHAPTER TWENTY-THREE

Restoring and Rehabilitating Sagebrush Habitats

David A. Pyke

Abstract. Less than half of the original habitat of the Greater Sage-Grouse (*Centrocercus urophasianus*) currently exists. Some has been permanently lost to farms and urban areas, but the remaining varies in condition from high quality to no longer adequate. Restoration of sagebrush (*Artemisia* spp.) grassland ecosystems may be possible for resilient lands. However, Greater Sage-Grouse require a wide variety of habitats over large areas to complete their life cycle. Effective restoration will require a regional approach for prioritizing and identifying appropriate options across the landscape. A landscape triage method is recommended for prioritizing lands for restoration. Spatial models can indicate where to protect and connect intact quality habitat with other similar habitat via restoration. The ecological site concept of land classification is recommended for characterizing potential habitat across the region along with their accompanying state and transition models of plant community dynamics. These models assist in identifying if passive, management-based or active, vegetation manipulation–based restoration might accomplish the goals of improved Greater Sage-Grouse habitat. A series of guidelines help formulate questions that managers might consider when developing restoration plans: (1) site prioritization through a landscape triage; (2) soil verification and the implications of soil features on plant establishment success; (3) a comparison of the existing plant community to the potential for the site using ecological site descriptions; (4) a determination of the current successional status of the site using state and transition models to aid in predicting if passive or active restoration is necessary; and (5) implementation of post-treatment monitoring to evaluate restoration effectiveness and post-treatment management implications to restoration success.

Key Words: Artemisia, *Centrocercus urophasianus*, Greater Sage-Grouse, habitat restoration, landscape triage, restoration guidelines, sagebrush grassland.

Restaurando y Rehabilitando Hábitats de Artemisa

Resumen. Menos de la mitad del hábitat original del Greater Sage-Grouse (*Centrocercus urophasianus*) existe actualmente. Parte del hábitat se ha perdido permanentemente debido a las granjas y a las zonas urbanas, pero el remanente varía en su condición, con áreas de hábitat de alta calidad a

Pyke, D. A. 2011. Restoring and rehabilitating sagebrush habitats. Pp. 531–548 *in* S. T. Knick and J. W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA.

hábitat no adecuado. La restauración de los ecosistemas de pastizales de sagebrush (*Artemisia* spp.) puede ser posible en áreas de tierras resistentes. Sin embargo, el Greater Sage-Grouse requiere una gran variedad de hábitats sobre extensas áreas para completar su ciclo de vida. La restauración eficaz requerirá un enfoque regional para dar prioridad e identificar opciones apropiadas a lo largo de su territorio. Se recomienda utilizar un método de clasificación del paisaje para dar prioridad a las tierras para la restauración. Los modelos espaciales pueden indicar dónde proteger y conectar hábitats intactos de calidad con otros hábitats similares por medio de la restauración. Se recomienda el concepto del sitio ecológico de clasificación de tierras para caracterizar hábitats potenciales a través de la región, acompañados por sus respectivos modelos del estado y de la transición de las dinámicas de comunidades vegetales. Estos modelos asisten en identificar qué tipo de restauración (pasiva, activa o basada en el manejo, o manipulación de la vegetación) puede lograr la meta de un hábitat mejorado para el Greater Sage-Grouse. Una serie de pautas ayuda a formular preguntas que los directores pueden considerar al momento de desarrollar planes de restauración: (1) localización de sitios de prioridad a través de una clasificación del paisaje, (2) verificación del suelo y las implicaciones de las características del suelo en el éxito del establecimiento de la vegetación, (3) una comparación de la comunidad vegetal existente con el potencial del sitio mediante el uso de descripciones ecológicas del sitio, (4) una determinación del estado actual de sucesión del sitio usando modelos de estado y de transición para ayudar a predecir si es necesaria una restauración pasiva o activa, y (5) puesta en práctica de un monitoreo post-tratamiento para evaluar la eficacia de la restauración y las implicaciones del manejo post-tratamiento sobre el éxito de la restauración.

Palabras Clave: Artemisia, *Centrocercus urophasianus*, clasificación del paisaje, Greater Sage-Grouse, pastizales de artemisa, pautas de restauración, restauración del hábitat.

The sagebrush (*Artemisia* spp.) ecosystem is in jeopardy from increasing dominance of exotic annual grasses and native trees, altered fire regimes, inappropriate livestock-grazing practices and off-road vehicle activity, increasing development of energy sources, and climate change (Miller et al., this volume, chapter 10; Knick et al., this volume, chapter 12). These disturbances will likely result in temporary changes in relative dominance of plants if ecosystems are sufficiently resilient, yet all life-forms and species that make up native plant communities will be maintained. Ecosystems lacking resilience may cross ecological thresholds leading them to alternative stable communities; alternative communities differ considerably in structure and function from the original. Returning to original communities will not likely occur without human intervention, including control of undesirable species or reintroduction of previously dominant species (Briske et al. 2006). Severe alterations to original ecosystems, ranging from soil erosion to dominance of competitive invasive plants, may require introduction of new plants that provide similar structure and function, resulting in an alternative yet desirable ecosystem (Aronson et al. 1993). Changes in plant communities can result in simultaneous changes in animal communities as a result of habitat changes.

Greater Sage-Grouse (*Centrocercus urophasianus*) depend on characteristics of sagebrush ecosystems for their survival. Locations with co-dominance of a subspecies of big sagebrush (*A. tridentata*) and mid to tall perennial bunchgrasses during spring nesting and brood-rearing generally provide the most important habitat. Summer and autumn habitats vary from farmland to wet meadows to sagebrush rangelands. Greater Sage-Grouse require big sagebrush for cover and food in winter, but can use little sagebrush (*A. arbuscula*), black sagebrush (*A. nova*), scabland sagebrush (*A. rigida*), or silver sagebrush (*A. cana*) for food (Connelly et al. 2000c).

Dominance of each sagebrush species in a specific location is dependent on the suite of soil characteristics, climate, and natural disturbances that result in a dynamic set of plant species (associations) that may change in relative dominance depending on time since disturbances. The ecological site concept as defined by the United States Department of Agriculture (2003) is a land classification system that describes this set of soil-climate-plant associations across the United States. Ecological site descriptions attempt to depict the variation in plant community dynamics and natural disturbances for specific land areas. Ecological site descriptions use state (a relatively stable set of plant communities that are resilient to disturbances) and transition (the drivers of change among alternative states) as two successional concepts to describe the natural range in variation of plant communities (Westoby et al. 1989a,b; Bestelmeyer et al. 2003; Stringham et al. 2003). The reference state often includes multiple plant communities that differ in their dominant plant species relative to time since disturbance. Alternative states describe new sets of communities where relatively irreversible transitions (thresholds) may maintain these new plant communities in their own stable states with their unique set of dominant plants (Fig. 23.1).

The reference state of big sagebrush ecosystems is a suite of dynamic community phases changing from shrub-dominated to grass-dominated when fire removes fire-intolerant big sagebrush. Recovery of big sagebrush in burned locations requires

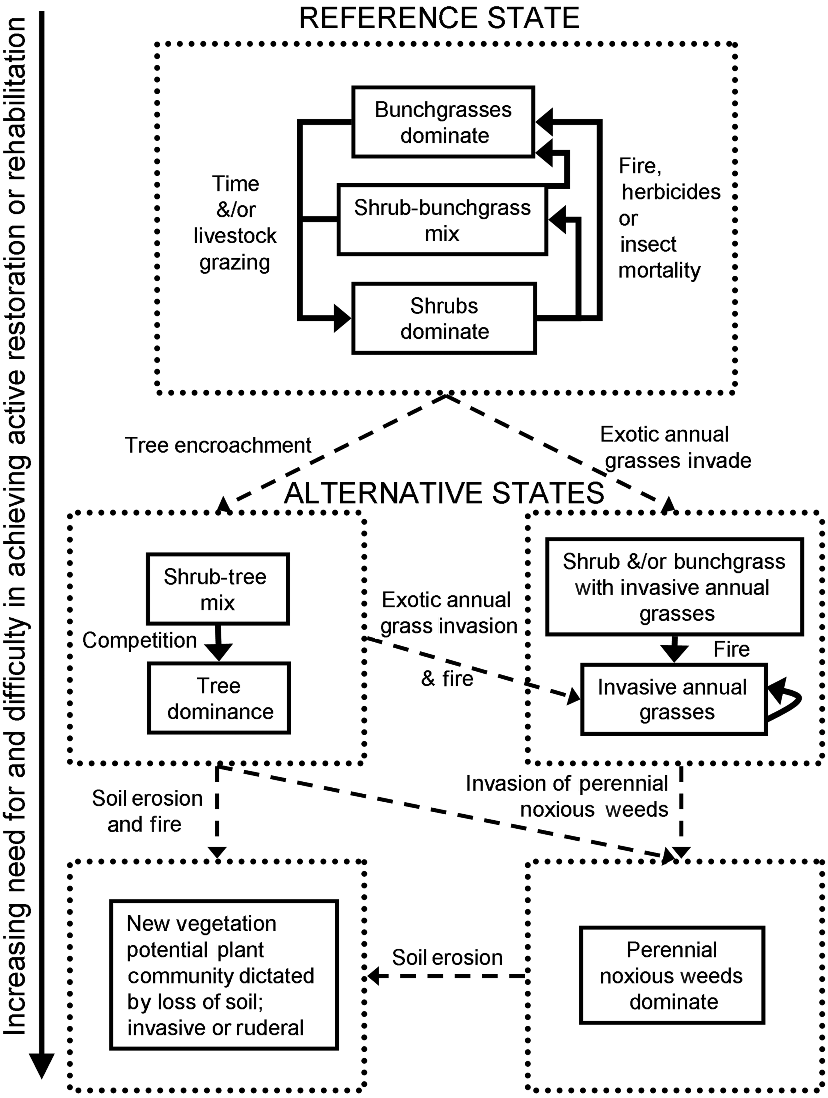

Figure 23.1. Generalized conceptual model for sagebrush ecosystems showing plant dynamics using state and transition (dotted boxes and dashed lines) models within Greater Sage-Grouse distribution. The uppermost dotted box represents the reference state for a site, while the lower dotted boxes represent various alternative states. Solid boxes and arrows within states are plant communities and pathways.

seedling establishment. This may be accomplished by seeds surviving in the soil or being dispersed from big sagebrush plants that escaped the fire. These sagebrush seedlings grow slowly, increasing in size and dominance over time and eventually leading to late successional communities represented by a combination of sagebrush and perennial grasses (20–45 years; Watts and Wambolt 1996). Mature sagebrush, once dominant, may remain dominant beyond 45 years provided livestock grazing has been removed (Robertson 1971, Sanders and Voth 1983, West et al. 1984, Allen-Diaz and Bartolomé 1998, Anderson and Inouye 2001). No evidence supports the belief that sagebrush dominance will continue at the expense of perennial grass cover or survival. Fires reset succession to perennial grass-dominated communities, and the cycle continues.

Animals that depend on habitats dominated by certain plant species may optimize their demographics within a certain plant community phase in the reference state. For example, grassland-dependent animals are favored in grass-dominated community phases developing after fires, whereas shrub-dependent species require shrub dominance. Greater Sage-Grouse tend to reach this optimum when sagebrush species co-dominate with mid-statured perennial bunchgrasses (Connelly et al. 2000c, Crawford et al. 2004). Managers who wish to optimize habitat for Greater Sage-Grouse populations might first identify the land's potential to support a specific sagebrush plant community. This potential is known as the ecological site. The current plant community that exists on the land can then be identified, as can management options for achieving the desired sage-grouse habitat.

This chapter describes a process for managing, restoring, or rehabilitating sagebrush ecosystems to achieve desired plant communities for Greater Sage-Grouse habitat. In doing this, managers might consider not only the land area where the desired plant community is the objective but also the temporal and spatial dynamics of the multitude of plant communities that currently exist and will develop across the surrounding landscape used by Greater Sage-Grouse. Some areas will require management to sustain current vegetation; some may require restoration or rehabilitation. Ecosystem restoration is the recovery of an ecosystem that has been degraded, damaged, or destroyed. The ecosystem contains a self-sustaining biotic and abiotic system through an assemblage of native species and community structures. These restored systems will maintain a suite of natural disturbances and their associated ranges of environmental conditions given the soils and climate of the location (Society for Ecological Restoration International Science and Policy Working Group 2004). Restored Greater Sage-grouse habitat will favor those plants that support self-sustaining populations of sage-grouse. Rehabilitation has the same goal of repairing ecosystem processes, productivity, and services as restoration; however, rehabilitation tends to achieve this goal using nonnative plants (Society for Ecological Restoration International Science and Policy Working Group 2004).

RESTORATION AND REHABILITATION OPTIONS

Past vegetation manipulations reflected land settlement patterns and mandated federal policies in the Greater Sage-Grouse range. Homesteading and irrigation development aided the development of farms where large expanses of sagebrush once grew (Knick, this volume, chapter 1). The Public Rangelands Improvement Act of 1978 (United States Code 43, Chapter 37 Public Rangelands Improvement Section 1901–1908) recognized the continued need to improve rangeland conditions for multiple uses of public lands. The major source of measuring land condition was based on a technique that organized plants into three categories: those that increase, decrease, or invade in response to livestock grazing (Pyke and Herrick 2003, West 2003a). Methods used to implement these improvements tended to rely on the science of the day. That science was reflected in the principal textbook of that time (Vallentine 1971), which focused on rangeland improvements as special treatments, developments, and structures used to improve range forage resources or to facilitate their use by grazing animals. The focus of many revegetation efforts was to increase forage production for livestock and to decrease the abundance of undesirable plants that interfered with livestock forage production and invasive annuals that provided unreliable forage. Undesirable plants included the major invasive plant, cheatgrass (*Bromus tectorum*; Young et al. 1972), and sagebrush. Sagebrush is still treated as a weed in some books (Whitson 1996). Restoration options may require some reductions or temporary eliminations of sagebrush if desired outcomes include increases in herbaceous life-forms in the community.

Effective restoration takes a regional perspective when considering when and where to restore lands for Greater Sage-Grouse habitat. Greater Sage-Grouse use large land areas and multiple plant communities, and have a variety of habitat needs, depending on their life stage (Crawford et al. 2004). Restoration decisions become challenging in view of economical considerations, restoration potentials, status of existing habitat, and logistical concerns such as landownership or topography. A prioritization process for selecting sites is required as the first stage in a successful restoration plan (Wisdom et al. 2005c, Meinke et al. 2009).

Landscape Triage

In ecosystem restoration terminology, triage is an initial prioritization technique where ecosystems are grouped into three categories, one that receives immediate care and two for which no immediate care is necessary. The group receiving immediate care and intervention has significant damage and benefits from aid. The other two groups are at opposite ends of the care spectrum. One needs no immediate intervention and will recover through later treatment, whereas the other has terminal damage and will not recover even with intervention (Kennedy et al. 1996, Samways 2000). Assessments ascertain ecosystem status (Groves 2003, Pyke and Herrick 2003, Wisdom et al. 2005a). Assessments of land status or ecosystem health are based on a manager's knowledge of the ecosystem's current status relative to the level of ecosystem threats—the drivers of ecosystem change—and the probability of ecosystem recovery from those threats (Hobbs and Kristjanson 2003). The ecological site land classification system, along with its accompanying ecological site description, provides a baseline in the United States for assessing land status (Briske et al. 2006). Techniques are currently being applied that use indicators of ecological processes to determine land status at multiple scales (Pyke et al. 2002, Spaeth et al. 2003, Pellant et al. 2005).

Land assessments can aid in developing ecosystem intervention grids (Hobbs and Kristjanson 2003). These grids provide decision levels for prioritizing management actions and restoration options. A potential grid for sagebrush grassland ecosystems could involve extent of departure from the reference state (Fig. 23.1), and potential for land to recover—referred to as resilience—after management changes or restoration activities (Table 23.1). Land assessments provide an approximation of departure from the reference state. Ecological site descriptions provide information necessary for predicting level of resilience of ecological sites. Areas with higher annual precipitation and greater soil depth provide approximations of increasing resiliency for most sagebrush grassland ecosystems. Intervention grids may contain additional axes such as cost-benefit ratios for proposed actions (Hobbs et al. 2003) that may assist managers in deciding if investment in restoration within an area is worth the risk. These grids simplify relationships into decision groups, but many of these decisions could be represented in continuous probability scales and entered into models to formulate decision tools.

When considering type and level of restoration intervention to use for improving Greater Sage-Grouse habitat, managers might consider the status of habitats adjacent to and surrounding potential restoration projects, since these areas, in combination with restoration areas, will encompass Greater Sage-Grouse habitat. Reasons for considering larger areas than the restoration site alone are based on criteria relating to Greater Sage-Grouse biology as well as the probability of restoration success. Greater Sage-Grouse have a large home range (Connelly et al. 2000c) that generally exceeds the size of most restoration projects. Thus, it is useful to provide land status evaluations spatially over a larger landscape, ideally for the entire region where birds exist. Assessments done in a spatially balanced and consistent manner can be placed into a Geographic Information System (GIS), where supporting data layers for the same spatial location are useful in accessing probability of restoration success. These data layers may include current vegetation and its appropriateness as Greater Sage-Grouse habitat, climate, soils, topography, and Greater Sage-Grouse habitat use information. Meinke et al. (2009) demonstrated a prioritization model for sagebrush restoration that used data layers derived from environmental conditions for growth of two subspecies of big sagebrush, potential for connecting existing stands of sagebrush, locations of viable Greater Sage-Grouse populations, and potential for invasive cheatgrass to impede success. This approach would ensure that local restoration projects were considering regional

TABLE 23.1

Potential sagebrush grassland intervention grid for identifying appropriate restoration interventions (modified from Hobbs and Kristjanson 2003).

Departure from the reference state is assigned using a land status assessment similar to Interpreting Indicators of Rangeland Health (Pyke et al. 2002, Pellant et al. 2005). Information from state and transition models is employed to identify probability of recovery (Fig. 23.1).

	Departure from the reference state		
	None to slight	Moderate	State change occurred
Probability of recovery or restoration	All plant functional and structural plant groups are present, but may not be in desired composition.	Some functional or structural plant groups are missing or under represented; invasive species common, but not dominant.	Invasive plants dominate; sagebrush or tall grasses are rare; soil stability and hydrologic functioning may be impaired.
High	**No Action.** Maintain status; monitor to prevent changes. Adjust management as necessary.	**Attempt Passive Restoration** if feasible: If unsuccessful use active restoration.	**Active Restoration.** Potential for successful restoration is high because of deep soils and higher precipitation. Potential for invasive plant control is high.
Medium	**No Action.** Monitor frequently to ensure that management is adjusted before habitat quality is impaired.	**Attempt Passive Restoration** if feasible. If unsuccessful use active restoration.	**Active Restoration**, but lower priorty because of lower probability of success.
Low	**No Action.** Monitor frequently to ensure that management is adjusted before habitat quality is impaired.	**No Action.**	**Conduct Inventory** and adjust management to fit new site and conditions.

factors for success of achieving both restoration and improved habitat for Greater Sage-Grouse.

Restoration of sagebrush habitats can take two forms—passive and active (McIver and Starr 2001, Hemstrom et al. 2002). Passive forms of restoration generally do not require human-aided revegetation, nor do they require applications of herbicide to modify the habitat, because desired species exist at the site as plants or seeds. Passive restoration of desired plant communities, including factors such as community structure (plant height and cover) and ecosystem processes (e.g., nutrient cycling), may be achieved by changing current management practices. Recovery of desired species or vegetation structure in the community occurs through normal successional processes and through drivers of change via new management. Active restoration (e.g., revegetation and severe modifications of plant communities using a variety of techniques) may be necessary if desired species are eliminated from sites or are too far from locations for successful dispersal and recovery to occur.

Passive Restoration

Passive restoration may achieve desired habitat changes provided that degradation of habitat quality has not been too severe and the community has remained within the reference state (Fig. 23.1; Stringham et al. 2003). Loss of dominant species such as tall bunchgrasses or sagebrush from a community, even if they are not replaced by invasive species, may require active restoration because the community no longer has an adequate density of those species or an adequate seed bank to draw upon to reestablish them in the community. The plant composition, or relative proportions of each plant species in the community, that defines these thresholds among states is largely unknown and is an active area of research. Major shifts in relative dominance (proportion of the total cover or production) among plant structural groups from a balanced mix of grasses and shrubs may require active restoration (e.g., thinning of shrubs and seeding of additional grasses) to achieve a balanced mix. For example, <5% tall perennial grass relative canopy cover with >80% shrub relative canopy cover may keep the community within the reference state, but the community is at risk of crossing a threshold because of the lack of adequate tall perennial grasses to provide recovery. A fire in a similar at-risk community may leave a void to be filled by invasive species (Sheley et al. 1996).

Common forms of passive restoration are removals or reductions of land uses. Changes in season of use may at times be adequate to achieve desired responses. If the goal is achieving increases in tall perennial grass composition, and these plants currently exist on a site but in small numbers, ensuring reproduction of existing grasses is paramount for providing propagules of these grasses. Several bottlenecks to restoration may exist that can severely hinder recovery of species. Increases in desirable plants will rely on a combination of seed production, longevity, and dispersal in conjunction with adequate safe sites for establishment and growth of desirable species if their dominance and density are inadequate (Archer and Pyke 1991, Pyke and Archer 1991, Bakker and van Diggelen 2006, van Andel 2006a,b).

Livestock Grazing Modifications

The greatest land-use adjustment within the Greater Sage-Grouse region that might bring about passive restoration is to change livestock management, largely because of the prevalence of livestock grazing as a land use. Simple modifications, such as shifting to no livestock use, may not provide desired outcomes, such as increases in herbaceous components of the plant community (West et al. 1984). Increases in herbaceous cover occur along with increases in shrub cover (Anderson and Holte 1981). Beck and Mitchell (2000) reviewed the literature and presented evidence for both positive and negative impacts of livestock grazing on Greater Sage-Grouse habitats. Modifications to grazing management might be considered as prescriptive techniques in conjunction with other ecosystem and management options available to achieve desired habitat conditions.

Past rangeland improvements through grazing modifications (adjustments in grazing seasons, period of grazing, or numbers of animals) sought improved amounts and composition of grasses and forbs (Dyksterhuis 1949). Adjustments were achieved by constructing new fences or developing additional water sources, which spread livestock use over larger areas. The greatest change was the shift from growing-season-long grazing to seasonal-rotational-grazing practices for livestock throughout the western United States (United States General Accounting Office 1977). Season of use by livestock often differs between intermountain and Great Plains regions in sage-grouse habitat. The seasons are somewhat intermediate in Wyoming and the Colorado Plateau. Season of use often reflects differences in types of grasses growing in each region.

Herbaceous vegetation in the Intermountain West is exclusively cool-season plants, whereas the Great Plains has both cool- and warm-season grasses (Sage et al. 1999). These two mechanisms for capturing solar energy and converting it into plant growth mainly differ in their optimal leaf temperatures for growth. Warm-season grasses tend to grow at optimal temperatures between 30°C and 45°C, while cool-season plants grow optimally between 20°C and 35°C. Optimal growth requires adequate moisture during the time when temperatures reach these levels.

Most of sagebrush grassland is a winter-dominated precipitation region, and cool-season plants typically dominate herbaceous layers (Miller and Eddleman 2001). Cool-season plants generally grow fastest in late spring and early summer (April–June). They reproduce and mature seeds at the end of this growth period and enter a summer dormancy period as soil moisture becomes limited and rainfall becomes less predictable during summer, or as temperatures exceed their optimum growth level. Exceptions occur in the Colorado Plateau of southern Utah, the remainder of eastern Utah, northeastern Colorado, eastern Wyoming, and eastern Montana, where tropical moisture from North American monsoons moves across the area, creating a second peak of predictable moisture in July and August. Warm-season plants may co-dominate with cool-season plants in herbaceous layers in regions with monsoonal rains, but season of active growth differs between these two plant functional types. Warm-season plants will begin to actively grow as cool-season plants reproduce and become dormant due to higher temperatures. Warm-season plants generally reproduce in mid- to late summer and become dormant as temperatures cool and moisture becomes limited in fall or winter. These periods of active growth can be important in sustaining and recovering these plants from herbivory by large grazers.

Cool-season plants typically tolerate moderate grazing (40–60% utilization) from mid-summer through early spring, when they are typically dormant or just beginning growth (Mueggler 1950, Laycock 1967, Laycock and Conrad 1981, Bork et al. 1998). Grazing at this level may not provide adequate hiding cover for sage-grouse, so lower levels of utilization may be necessary to achieve sage-grouse habitat. Reproduction normally occurs during late spring and early summer, the time of favorable active growth. These plants are highly susceptible to defoliation when reproduction occurs (Mueggler 1950, Laycock 1967, Bork et al. 1998), and defoliation of reproductive stems will reduce propagules needed for new grasses and forbs. Late spring grazing was deleterious or caused smaller increases in forb composition in threetip sagebrush (*Artemisia tripartita*) and big sagebrush ecosystems of southern Idaho and Oregon (Hyder and Sawyer 1951, Bork et al. 1998).

Resting pastures from grazing during periods of fastest growth of dominant grasses and forbs in sagebrush grasslands tends to enhance herbaceous plant growth and reproduction (Hyder and Sawyer 1951, Briske and Richards 1995, Bork et al. 1998). Pasture rest during this same period generally increases culm height, tiller production over the long term, and flower and seed production within the intermountain sagebrush steppe (Miller et al. 1994). Managers may wish to consider maintaining livestock stocking at a low enough level to achieve an average stubble height (Holechek and Galt 2000) of 18 cm, similar to recommendations of Gregg et al. (1994) and Connelly et al. (2000c), if sage-grouse nesting and hiding cover is a management goal and herbaceous plant height can potentially achieve this goal. This can also be achieved by removing livestock when the apical meristem is beginning to elevate in the culm of the grass, about one month before flowering of tall perennial grasses, so maximum leaf and inflorescence development and height may be achieved before the end of the growing season (Mueller and Richards 1986, Briske and Richards 1995). This may be as early as mid-April in arid, lower-elevation sites or as late as mid-June in mesic, higher-elevation sites, depending on the phenology of these grasses. Livestock must not graze during the dormant season, or they will likely remove this material and will not allow adequate regrowth before sage-grouse need the hiding cover in the following spring.

Grazing of the herbaceous layer late in the growing season in sagebrush grasslands favors plants avoided by grazing (Anderson and Briske 1995), such as sagebrush (Mueggler 1950, Laycock 1967). Repeated grazing during late spring and early summer, when grasses grow actively immediately before reproduction, tends to favor sagebrush growth until sagebrush becomes so dense that competition from it restricts recovery of herbaceous plants (Reichenberger and Pyke 1990). Once this level of sagebrush density and cover is achieved on a site, passive restoration may no longer be an option for improving sagebrush rangelands (Rice and Westoby 1978, West et al. 1984, Wambolt and Payne 1986).

Passive restoration through adjustments in grazing seasons or reductions in livestock numbers may improve Greater Sage-Grouse habitat quality if the vegetation community consists of adequate densities of sagebrush and perennial grass (Fig. 23.1). This community retains both sagebrush and tall bunchgrass densities necessary for quality habitat (Connelly et al. 2000c, Crawford et al. 2004), but cover or height of grasses may be inadequate. Release from livestock grazing during the later portion of the growing season should allow full expression of vegetation height for hiding cover and nest protection. Improvements in cover and height may not be expressed fully in the next growing season but may take three to five years for preexisting plants to fully express their height. Livestock grazing, when it occurs during dormant or early growing season, must be at low enough stocking levels to maintain adequate standing dead tiller density and culm height to provide cover and protection. Stubble height monitoring may provide a measure to adjust livestock stocking levels to attain adequate tiller densities with adequate height for sage-grouse. This form of passive restoration may take time and adequate weather, if seedling establishment of sagebrush or perennial grasses are required to increase proportional cover of either group. Studies tracking vegetation change after removal of livestock in big sagebrush ecosystems generally retained their initial proportions (Anderson and Holte 1981, West et al. 1984, Anderson and Inouye 2001) and took a minimum of 10–15 years for seed production, seedling establishment, and growth to occur, since these events may be episodic (Call and Roundy 1991, Pyke 1995).

Active Restoration Versus Rehabilitation

A common goal shared between restoration and rehabilitation is renewal of ecosystem processes, productivity, structure, and function (Society for Ecological Restoration International Science and Policy Working Group 2004). Restoration accomplishes this goal using native species, while rehabilitation may use species introduced to the site that may have similar structure and function. Active restoration or rehabilitation is warranted when desired species or structural groups are poorly represented in communities. Desired species are often replaced by undesirable, frequently invasive, species that can eventually dominate the site. These species include, but are not limited to, cheatgrass, noxious weeds, or native species including juniper (*Juniperus* spp.) or pinyon pine (*Pinus edulis* and *P. monophylla*; Miller et al., this volume, chapter 10). When left unchecked, these species can become dominant and lead to positive feedbacks that maintain their existence on the site and negatively impact desirable species such as sagebrush, perennial bunchgrasses, and forbs (Briske et al. 2006). A sagebrush site can progress along a transition into an alternative vegetation state, but transitions between states are generally unidirectional, without resilience, and are not likely to return to the previous state (Fig. 23.1).

Some state changes retain soils and hydrologic processes and may still retain the capability of supporting original plant communities; thus, restoration is possible if biological constraints such as weedy competitors can be reduced. Other state changes, in contrast, can result in sufficient soil loss or changes in hydrologic function so the site is no longer capable of supporting former plant communities found in reference states (Davenport et al. 1998, Briske et al. 2006). The ecological site changed because of soil loss. This new form of ecological site will eventually come to a dynamic equilibrium and will likely support a different ecological site with a new type and/or amount of plants. Restoration is no longer possible, and rehabilitation, defined as an alternative to the historic native plant community that provides similar structure and function without allowing further degradation of the site, may be the only remaining alternative that might make the site usable by Greater Sage-Grouse (Bradshaw 1983, Aronson et al. 1993).

Once lands degrade to the extent that the ecological site changes, repair of the former productivity along with its structure and function may become more difficult, if not impossible. A hypothetical example would be a mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) community that once supported an understory plant association with a wide diversity of forbs and mid to tall perennial grasses. Once pinyon and juniper trees increase in this ecosystem, sagebrush dies, the herb layer declines, and seed banks of former dominant plants in the community become depleted (Koniak and Everett 1982, Miller et al. 2000). Declines in shrub and herbaceous components of communities can leave soil susceptible to erosion (studies cited in Miller et al. 2005). Severe erosion could change the soil depth from a deep to a shallow soil. This leads to a site changing from a mountain big sagebrush community into a more arid Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) community with less herbaceous cover. Subsequent rehabilitation might lead to a less-productive site with different species and less structural diversity.

Another scenario using the Wyoming big sagebrush community might include natural disturbances, such as fire. Fire normally eliminates or reduces trees, but as trees age and they dominate sagebrush sites, fires become rare (Miller and Tausch 2001; Miller et al., this volume, chapter 10). Fires that occur after tree dominance tend to be severe crown fires of high intensity. High-intensity fires on warm, dry sites often dominated by Wyoming big sagebrush are capable of causing shifts from woodlands to introduced annual plant communities (Tausch 1999a,b).

Invasions of exotic annual grasses often make communities more susceptible to frequent fires because of the increase in fuel continuity caused by the annual grasses filling the interspaces between perennials (Whisenant 1990). Fine fuels in the pre-invasion community represented by the reference state would be distributed in patches represented by perennial bunchgrasses (Fig. 23.1). Cheatgrass is known to be a successful competitor against native plants for resources necessary to establish and grow (Harris 1967, Melgoza et al. 1990, Booth et al. 2003, Chambers et al. 2007). This alternative state for the ecosystem may require rehabilitation rather than restoration to successfully renew ecosystem structure and function.

Greater Sage-Grouse Habitat Goals Through Restoration or Rehabilitation

Greater Sage-Grouse use a diverse set of plant communities within a year, and their population success requires specific habitat needs for each stage of their seasonal life cycle (Connelly et al., this volume, chapter 4). The key for overall sage-grouse population sustainability and improvement, especially for successful reproduction and winter survival, is expanses of big sagebrush or silver sagebrush >4,000 ha (Leonard et al. 2000, Walker et al. 2007a). Woodward (2006) recommended not sacrificing preexisting stands of sagebrush, even if the herbaceous community is depleted and not ideal for Greater Sage-Grouse habitat. Fires will burn these stands eventually, allowing an opportunity to restore the herbaceous component. Connelly et al. (2000c) recommended altering a maximum of 20% of large sagebrush stands only if managers deem that the alteration is necessary.

Grass cover, in addition to sagebrush, is important during nesting because it provides horizontal cover to reduce depredation of sage-grouse eggs or young (Connelly et al., this volume, chapter 4). Forbs provide important food for hens and chicks in the spring and early summer. This combination of herbaceous plants with sagebrush is a habitat goal in nesting and brood-rearing areas. Diverse mixtures of plant species in communities should provide a diverse mixture of invertebrates, another critical sage-grouse food during fledging (Connelly et al., this volume, chapter 4).

Restoration and rehabilitation of Greater Sage-Grouse habitat should focus on maintaining or improving key habitat components for survival and reproductive success. Passive restoration goals focus on maintaining sagebrush cover while increasing grass cover and height and increasing forb cover and reproduction. This could be achieved by setting appropriate stocking levels for livestock while shifting grazing seasons to periods when active growth is slow and plant reproduction has not been initiated. Active restoration goals attempt to reestablish a sagebrush overstory with an understory mixture of native short, mid, and tall grasses and forbs. Rehabilitation should seek to achieve these same goals even though they may require introduced species to achieve them. The shrub component of these rehabilitated communities should include the appropriate native sagebrush species or subspecies for the site. Sage-grouse may nest under shrubs other than sagebrush, but most records of successful nesting are associated with one of the larger sagebrush species (Connelly et al. 1991; Schroeder and Vander Haegen, this volume, chapter 22). Studies have shown sage-grouse nesting or using lands sown with some introduced grasses (Connelly et al., this volume, chapter 4; Schroeder and Vander Haegen, this volume, chapter 22). Thus, rehabilitation using introduced perennial grasses may benefit sage-grouse populations. These studies also warn that the benefit may be related to proximity of large areas with mature sagebrush; an isolated rehabilitation within a large expanse of farmed land may not benefit sage-grouse. Most of these studies have not focused on the amount of cover of introduced grasses; this is a future research need.

PAST AND CURRENT VEGETATION MANIPULATION APPROACHES

Types of active revegetation and rehabilitation used within Greater Sage-Grouse habitats vary. Some involve revegetation, while others only control for invasive or undesirable species. Combinations of vegetation control followed by revegetation are common (Monsen et al. 2004). Each of these approaches has advantages and disadvantages that should be considered before applying a particular set of techniques.

Woody Plant Removal

Removal of woody plants (trees and shrubs) to increase herbaceous forage and allow grasses and forbs to dominate has been a common habitat treatment (Vale 1974, Olson and Whitson 2002). The original goal of eliminating sagebrush because it was considered a weed that competes with forage for livestock has been replaced in many locations with a goal to achieve a balance between shrubs and herbaceous plants to provide not only forage for livestock but also habitat for wildlife (Whitson 1996, Olson and Whitson 2002). Several techniques have been used to accomplish this balance with differing impacts on spatial and temporal development of structure and function of the ecosystem.

Prescribed fires may kill, eliminate, or reduce the density of most woody species and provide a temporary flush of nutrients that may result in increases in herbaceous plants, but may also leave sites susceptible to soil erosion during the first years after the fire (Blank et al. 1994, Stubbs 2000, Wrobleski and Kaufmann 2003). This tool is currently being used on sagebrush rangelands where pinyon or juniper have increased. Tree increases, if left unchecked, may decrease species diversity, increase soil loss, and reduce the potential for ecosystem recovery of former sagebrush grasslands (Miller and Tausch 2001). A good example of when to use fire as a restoration tool was presented in Miller et al. (2007). Managers considering using fire as a tool for controlling woody plants should consider that sagebrush dominance may be, in some ecosystems, lost for 25–45 years (Watts and Wambolt 1996, Wambolt et al. 2001) depending on distance from seed sources. However, sagebrush dominance in more mesic mountain big sagebrush communities may recover in less time (Miller et al., this volume, chapter 10).

Herbicide applications of 2,4-D or tebuthiuron have been used to kill large expanses of sagebrush, leaving standing dead skeletons of shrubs (Crawford et al. 2004). Western juniper (*Juniperus occidentalis*) was controlled successfully with tebuthiuron and picloram (Britton and Sneva 1981, Evans and Young 1985). These chemicals have an advantage over fire in that they lower the risk of soil erosion, as grasses and grass-like plants in the community generally remain unharmed and will likely increase as a result of decreasing competition from woody plants.

Complete elimination of sagebrush is not a goal for sage-grouse habitat; thus, partial reduction may be preferred because the understory is anticipated to respond and increase. Tebuthiuron used at low rates is a technique for thinning dense sagebrush and opening the community for herbaceous plants, including forbs, to respond (Olson and Whitson 2002), but effectiveness is highly dependent on soil type and depth. This technique might yield improvements to habitat quality, provided herbaceous perennial plants exist in the understory. Unfortunately, if exotic annual grasses exist in the community, expansion and spread of these invasive plants may result. Herbicides such as tebuthiuron and 2,4-D, if used at strengths recommended for killing all sagebrush, may kill or injure many forbs, since active ingredients that kill sagebrush also kill forbs.

Mechanical techniques are designed to remove all or a portion of the aboveground plant growth (e.g., mowing, roller chopping, rotobeating, and harrowing) or to uproot some or all of the plants from soil (e.g., grubbing, plowing, bulldozing, anchor chaining, cabling, railing, raking, and plowing)(Scifres 1980, Stevens and Monsen 2004). Some techniques such as sawing or mastication focus on cutting or grinding individual plants. Indiscriminate techniques tend to remove the more upright and stiff woody plants, while shorter, younger, or more pliable woody species survive being pushed over. Uprooting techniques create the greatest soil disturbance, adding to the risk of post-treatment soil erosion. They may tend to harm the herbaceous community, at least initially, by uprooting plants, but strong evidence for this in chaining is lacking (Ott et al. 2003). Control of pinyon and juniper through removal of individual trees can have minor impacts on the shrub community because they tend to be selective (Miller et al. 2005). Removal of tree competition should also facilitate rapid recovery of the shrub and herb understory if adequate densities are present prior to treatment. Mowing, roller chopping, rotobeating, and plowing will have a greater and longer-lasting impact on the shrub layer. Critical for success of these techniques is that the community remains in the reference state and that invasive annual grasses do not exist within the community (Fig. 23.1). Some mechanical removal techniques are capable of preparing a seedbed for revegetation if communities entered an alternative state dominated by trees (Fig. 23.1; Stevens and Monsen 2004).

Livestock may also be used to reduce woody plants in a targeted grazing approach, but generally plants need to be young, the browsing animal must be appropriate, and browsing must occur at a time when the animal's preference favors woody plants. Mueggler (1950), Laycock (1967), and Bork et al. (1998) cited long-term declines in threetip sagebrush with recovery of herbaceous vegetation at high-elevation sites in Idaho. Declines of Wyoming and mountain big sagebrush densities due to browsing by deer (*Odocoileus* spp.) or elk (*Cervus elaphus*) have been noted in Utah and Montana (Smith 1949, Austin et al. 1986, McArthur et al. 1988, Patten 1993, Wambolt 1996). The potential exists for goat browsing to target and reduce juniper density, provided trees are small (Fuhlendorf et al. 1997, Pritz et al. 1997). However, direct findings within the sagebrush steppe region have proved promising only with threetip sagebrush, not with big sagebrush or with western junipers (Fajemisin et al. 1996). Further research on use of woody versus herbaceous plants needs to be evaluated before any recommendation can be given.

Revegetation

Historic revegetation on most sagebrush grasslands had the goal of improving livestock forage, including replacing invasive forbs and annual grasses such as *Halogeton glomeratus* and cheatgrass with perennial grasses while protecting soils from erosion. Early trials comparing native versus introduced grasses in several locations within the Greater Sage-Grouse distribution found that native species often did not establish or produced less forage than introduced species. Recommendations during early history of rangeland revegetation favored use of introduced grasses, such as crested wheatgrass (*Agropyron cristatum* or *A. desertorum*) to meet combined goals of livestock forage production and erosion control (Asay et al. 2001).

Wildfire rehabilitation is a major source of revegetation in the Great Basin. The mandated goals of these projects are to: (1) reduce soil loss, (2) provide species palatable to livestock, and (3) reduce spread of invasive species. Total restoration of ecosystems with a complete suite of plant life-forms is not a designated objective for expenditure of funds. Thus, comparisons with restoration projects often show use of fewer plant species and an emphasis on introduced grasses that establish quickly (Richards et al. 1998). Only modest increases in use of native plants were reported in recent evaluations, although federal policies have advocated use of native plants in revegetation efforts when natives are available (Clinton 1999). The average number of species used on a rehabilitation project has remained between four and five, while the number of native species in the mixture has increased from one before 1996 to two after 1996, and the proportional increase in weight of native bulk seeds has been from 20% to 40% (Pyke et al. 2003). Land managers cited poor competitiveness and poor establishment of natives and high seed cost compared with introduced grasses as main reasons why they elected to use introduced species (McArthur 2004).

Currently, the prevalence and continued spread of exotic annual grasses, specifically cheatgrass and medusahead (*Taeniatherum caput-medusae*), throughout most of the sagebrush biome (Miller et al., this volume, chapter 10) has created the desire for revegetation projects to stop this trend (Monsen and Kitchen 1994). In addition, federal legislation encouraged use of grasses that could quickly stabilize soils, effectively compete with weedy or poisonous plants, and provide ample forage for livestock (Young and McKenzie 1982, Young and Evans 1986). Research during the mid-1900s pointed directly to the use of introduced forage grasses to meet these goals (Young and McKenzie 1982, Young and Evans 1986, Pellant and Lysne 2005). Characteristics that made these species effective also created communities dominated by near monocultures of introduced grasses that are less diverse (e.g., lacking sagebrush or forbs) and created poor habitat quality for Greater Sage-Grouse (Crawford et al. 2004). Methods for improving these sites have been proposed and are currently being tested in expanded trials (Cox and Anderson 2004, Pellant and Lysne 2005). One proposal is for revegetation of annual grass-dominated lands using competitive introduced forage grasses. An assisted succession approach may be used to reintroduce native plants into communities once introduced forage grasses dominate the site (Cox and Anderson 2004). Pellant and Lysne (2005) provide details for this process, which includes: (1) reduction in density and thus competition of introduced forage grasses, (2) seeding or transplanting of desired native plants, and (3) adaptive management to encourage establishment and reproduction of desired plants. Caution is advised in using these techniques. Timing of reductions in introduced forage grasses is critical for success (Fansler 2007). Sage-grouse may use introduced grasses if they include sagebrush and are near large stands of sagebrush

(Connelly et al., this volume, chapter 4; Schroeder and Vander Haegen, this volume, chapter 22). Thus, this technique should focus on reestablishing sagebrush in these communities to improve these lands for Greater Sage-Grouse habitat.

Replacing Annual Grasslands with Native Perennials

Rehabilitation and restoration techniques to transform lands currently dominated by invasive annual grasses into quality Greater Sage-Grouse habitat are largely unproven and experimental. Several components of the process are being investigated with varying success. The first of the process is reduction in the competition that invasive annual grasses provide against native seedlings during the establishment phase. Methods to reduce annual grass densities are therefore necessary. Techniques often mentioned are herbicides (Ogg 1994), defoliation via livestock grazing (Hulbert 1955, Finnerty and Klingman 1961, Mosley 1996, but see limitations in Hempy-Mayer and Pyke 2008), pathogenic bacteria (Kennedy et al. 1991), and fungi (Meyer et al. 2001, Beckstead and Augspurger 2004). Prescribed fire may be an effective technique if applied in combination with an herbicide treatment and if fire is conducted in either late spring or autumn. Prescribed fire alone is not recommended (Mosley et al. 1999, DiTomaso et al. 2006).

Herbicides have been widely applied throughout the Intermountain West (Vallentine 2004). At least 21 herbicides are labeled for use in controlling cheatgrass (Ogg 1994), but not all are registered for rangelands. Paraquat and atrazine were early herbicides that showed promise in controlling annual grasses, but environmental concerns led to their elimination as rangeland chemicals (Young and Clements 2000). Two herbicide groups currently used to control invasive annual grasses are broad-spectrum contact herbicides that kill or injure most plants they contact and preemergent herbicides that kill plants as they germinate but are less damaging to those plants already established.

Glyphosate (including Roundup®) is a contact systemic herbicide that kills most plants growing actively at time of application. It has no soil residual activity, and any plants emerging after application will survive. It kills plants late in the growing season and can prepare a fuel bed for fire that can reduce residual seeds of cheatgrass in litter seed banks. Follow-up applications of glyphosate the next spring may be necessary to ensure that cheatgrass populations are decreased sufficiently to reduce competition with any seeded desirable plants. Applications of carbon in a form readily available for soil microbial uptake may increase soil microbial content and cause microbes to reduce available soil nitrogen, reducing growth and potentially reducing competition with cheatgrass (McLendon and Redente 1990, 1992; Young et al. 1997; Blumenthal et al. 2003).

Imazapic (Plateau®, Panoramic 2SL®) and sulfometuron-methyl (Oust®, SFM 75®, Spyder®) are preemergent as well as contact herbicides. Sulfometuron-methyl showed promise in reducing the continuity of cheatgrass fuels in stands of crested wheatgrass (Pellant et al. 1999). Some agricultural crops are highly sensitive to this herbicide, and caution is paramount when applying near crops. Imazapic has recently been tested successfully within the sagebrush biome for the control of cheatgrass (Shinn and Thill 2002). It is an amino-acid–inhibiting herbicide that can operate as a preemergent or a contact herbicide. Annual plants are generally more susceptible than perennials to this herbicide, but some perennials such as antelope bitterbrush (*Purshia tridentata*) can vary in their susceptibility from being killed to having reproduction reduced during year of application (e.g., Wyoming big sagebrush; Eddington 2006, Vollmer and Vollmer 2008). Fall applications followed by sowing of six native species, including Wyoming big sagebrush, successfully controlled cheatgrass and medusahead while providing mixed results for native plant establishment (Bekedam 2004). Susceptibility of native perennial plants as adults or seedlings is unknown for many species and soil types; thus, care should be taken when managers use this herbicide as a selective herbicide for annual plants with the hope of retaining native perennials or revegetating immediately after herbicide applications. Imazapic applied to reduce cheatgrass fuel continuity has been successful and has not reduced some perennial grasses (Shinn and Thill 2004, Miller 2006, Davison and Smith 2007). Native annual plants, if they emerge at the same time as invasive annual grasses, may also be susceptible and harmed by imazapic applications. This herbicide has shown considerable promise, but continued monitoring and interpreting the impacts of its application are needed.

Immediate revegetation is advised after use of any of these density-reduction techniques; otherwise, invasive annual grasses that escape control treatments will likely grow unabated and quickly dominate sites by producing large numbers of seeds (Mack and Pyke 1983). No evidence for complete eradication of invasive annual grasses with control techniques and revegetation has been noted. However, successful revegetation efforts that have controlled invasive annual grass populations and have maintained perennial plants are generally rehabilitation projects sown with introduced forage grasses (Asay et al. 2001). Some evidence from wildfire rehabilitation studies shows that native plants can be sown and eventually coexist with invasive annuals, but these were generally sown in combination with introduced grasses (Pyke et al. 2003, Cox and Anderson 2004). Theoretical frameworks hypothesize that multiple native species representing a variety of growth and life-forms may successfully compete with invasive plants where any one species would be unsuccessful (Sheley et al. 1996). Invasive annual grasses can germinate in fall or early winter, and an appropriate mixture of plants would require perennials with shallow and deep roots and with early, middle, and late phenological development.

Restoration of Greater Sage-Grouse habitat will require time for sagebrush to establish and mature. It is critical when revegetating big sagebrush that appropriate subspecies are selected for the site. Big sagebrush has a number of subspecies, however three are most common—basin big sagebrush (*A. tridentata* ssp. *tridentata*), Wyoming big sagebrush, and mountain big sagebrush. These subspecies dominate in distinctly different environments (West 1983a). Mountain big sagebrush occurs most often in cooler and moister sites, while Wyoming big sagebrush dominates warmer and drier sites. Basin big sagebrush grows on deep soils, many of which are now farmed. A common problem associated with seeding big sagebrush has been that purchased seed often included more than one subspecies, even when only a single subspecies was requested (Dalzal 2004). Matching subspecies to the site is critical for establishment and growth of sagebrush and can be associated with seeding failure (Lysne 2005, Shaw et al. 2005a). Surface sowing of big sagebrush followed by soil-surface compaction may be necessary for establishment (Shaw et al. 2005a). Broadcasting seeds of Wyoming big sagebrush without covering the seed or pressing it into soil was unsuccessful in southern Idaho (Dalzal 2004) and should be used cautiously elsewhere in the region.

Locations that have been dominated by invasive annual grasses often have few forbs remaining, and forb species should be considered as part of seed mixtures. Establishment of forbs important to Greater Sage-Grouse has also shown promise (Wirth and Pyke 2003), but availability of seed tends to limit widespread use in rangeland restoration and rehabilitation projects (McArthur 2004). That limitation is being addressed, with more seed becoming available each year (Walker and Shaw 2005).

BOTTLENECKS TO SUCCESS

Availability and cost of native seed are major obstructions to use of native seeds in revegetation projects (McArthur 2004). The difficulties and vagaries of collecting, growing, and selling native seeds that have not been used historically within sagebrush ecosystems tends to raise prices and increase risks to both sellers and buyers (Bermant and Spackeen 1997, Currans et al. 1997, Roundy et al. 1997, Dunne 1999) relative to tested and released plants that are widely available (Currans et al. 1997).

Equipment for sowing native seeds is not widely available (Wiedemann 2005). Most revegetation projects in sagebrush habitats use rangeland drills that were developed for the rough terrain of wildland environments and for ease of seeding introduced forage grasses. Many native seeds, because of their differing sizes and appendages, require mixing within seed boxes on drills to ensure equal proportions of all seeds are sown on a site or will require separate seed boxes with effective depth bands to allow seeds of different sizes to be buried at different optimal depths (Boltz 1994, Stevens and Monsen 2004). These requirements will either require purchases of new seed drills or retrofitting of old drills to accommodate these needs.

GUIDELINES FOR RESTORATION PROJECTS

Success is not guaranteed when conducting Greater Sage-Grouse habitat restoration projects in semiarid environments. The only guarantee is that annual weather conditions can vary widely and that these often dictate success of restoration projects. Managers cannot influence immediate weather in a region to assist in restoration, and it is necessary to follow useful guidelines in preparing and implementing a restoration project. Goals and objectives should be explicitly stated and should represent both management and sampling objectives for projects. Wirth and Pyke (2007) provide examples of how to state these objectives and outline a potential monitoring protocol. These are important for monitoring and ultimately for adaptive management. The steps and questions in Table 23.2 are modified from those developed for management of western juniper on sagebrush grasslands (Miller et al. 2007), and are intended to aid managers in making restoration decisions. The initial step is to examine the region and prioritize lands into those that provide adequate Greater Sage-Grouse habitat and those that do not. Sites that do not provide adequate habitat but have the potential to provide it are affected by the soils and climate at the site. This process leads to identification of the ecological site for each soil unit. The decision of which areas to choose for restoration or rehabilitation of sage-grouse habitat is made during this stage using geospatial tools described in Wisdom et al. (2005c) or Meinke et al. (2009).

The second step involves ascertaining if the plant community currently existing on the site is one of the community phases within the reference state for the community dynamics model of that site (Fig. 23.1). Managers can refer to ecological site descriptions to make this assessment. Conducting a rangeland health assessment (Pyke et al. 2002, Pellant et al. 2005) may be helpful in identifying the status of the site relative to state and transition model.

The appropriate action for restoring or rehabilitating sage-grouse habitat is the third step. This involves estimating the relative cover or production that sagebrush, grasses, and forbs make to the overall dominance of the plant community. This informs managers if the site has the potential to restore itself through changes in the current management practice of passive restoration or if it may require greater intervention to achieve adequate sage-grouse habitat. Managers will decide if plant control techniques will be necessary and how restoration or rehabilitation will be conducted. Managers might consult resources for selecting appropriate plants if active restoration or rehabilitation is necessary. An initial resource is the local United States Department of Agriculture (USDA) Natural Resources Conservation Service rangeland management specialist who is trained and has access to plant materials information appropriate for local sites. Other general resources are ecological site descriptions for the soil. These can be found at the Ecological Site Information System on the USDA Natural Resources Conservation Service website (http://plants.usda.gov). This source will have lists of native species that typically occur on the site. Several publications (Vallentine 1989, Whisenant 1999, Monsen et al. 2004, Shaw et al. 2005b) provide recommendations for developing revegetation plans including plant control techniques, species recommendations, and development of seed mixtures, seeding techniques, and rates.

Decisions regarding protecting the site from disturbances must be made if active restoration or rehabilitation has been used. Often sites are closed to livestock grazing and recreational uses to provide seedlings the best potential for establishment and growth. Unfortunately, most recommendations are based on expert observations rather than replicated studies. Stevens and Monsen (2004) and Shaw et al. (2005a) offer recommendations of two or more years of protection. Stevens (2004) recommends a base time for protection ranging from two years (mountain big sagebrush in sites with $>$36 cm annual precipitation) to four years (Wyoming big sagebrush in sites with $<$36 cm annual precipitation). Managers may need to add one to six additional years, depending on type of restoration project and environmental conditions before and after project implementation.

A critical element is post-project effectiveness monitoring. Monitoring provides knowledge regarding where, when, and with what species successful restoration and rehabilitation projects occur. The United States General Accounting Office (2003) conducted an intensive analysis of emergency stabilization and rehabilitation projects in the United States Departments of Agriculture and the Interior and found that neither department could report on the effectiveness of their projects. These projects represent the largest set of revegetation treatments conducted on federal lands, most of which fall within the habitat range of Greater Sage-Grouse. The United States General Accounting Office (2003)

TABLE 23.2

Guidelines for conducting a restoration project for improving Greater Sage-Grouse habitat

Steps in the process	Questions to be asked	How to answer the question
I. Identify landscape priorities and ecological sites	1. Where are priority sites for restoration?	Conduct a landscape triage.
	2. What kind of soils are on the site?	Verify soils mapped to the location and provide further detail regarding the distribution of soil components at the site. This will require collecting information on soil texture and depth and some basic soil chemistry (pH, calcium carbonate presence).
	3. How will soils and physical features affect vegetation establishment and erosion?	Erosion is a major concern with any restoration project, especially if it is necessary to remove vegetation or disturb soils to conduct the project. Finer soils and steeper slopes generally have an increased risk of erosion. Soil descriptions will provide a guide regarding erosion risks on sites. Caution should be used in conducting soil disturbances on highly erosive sites. If revegetation is attempted, use fast-growing plants to protect and stabilize soils quickly. Generally, revegetation to protect soils from erosion takes many years and often does not provide adequate protection if high rainfall occurs (Robichaud et al. 2000).
	4. What is the native plant community for this site?	Match soil components on the site to their correlated ecological site description (ESD). Generally, there is only one ecological site mapped to a single soil component. The ESD will provide details on plant species and relative composition of these species in the community. This will provide an initial list of potential species for the site.
	5. Is old-growth juniper growing?	If yes, site may be a juniper site. Refer to Miller et al. (2007) for guidance. This site may not be appropriate for restoration. If no, proceed onward.
II. Determine current state of the site	6. Is site still within the reference state for the state and transition (S&T) model of this ecological site?	Compare current plant community on the site to those described in the S&T model. If plant community appears to fit in the reference state, and soil and hydrology of the site appear intact, then attempt passive restoration to improve habitat.
III. Select appropriate action	7. Does sagebrush dominate, yet herbaceous life-forms that should be co-dominant are missing from the site and annual invasive plants are rare?	This is a difficult situation. A need exists to reintroduce the herbaceous component of the habitat, but sagebrush competition may make revegetation difficult (Reichenberger and Pyke 1990). Consider restoring other higher-priority sites and wait to restore this site until fire burns sagebrush on the site.

Steps in the process	Questions to be asked	How to answer the question
	8. Is sagebrush missing, but native herbaceous life-forms are present and dominant?	Although sagebrush seed could be added to this site, it might be more cost-effective to introduce small patches of sagebrush transplants. As those plants mature, they will reproduce and spread seed naturally.
	9. Do invasive annual grasses co-dominate with native plants on the site?	Consider passive restoration first to attempt to increase competitive ability of native plants. Otherwise, wait for a fire to occur and attempt active restoration with herbicide to control annual grasses.
	10. Do invasive annual grasses dominate the site while native life-forms are missing or severely underrepresented?	Active restoration is necessary to restore habitat.
IV. Determine post-treatment management	11. How long should the site be protected before land uses begin?	Although some authors believe that only a minimum of two years of protection is necessary (Stevens 1994), most believe that two years is too short when native plants are being used in the restoration (Stevens 2004, Shaw et al. 2005a). A good rule of thumb is to continue protection until two-thirds of the restored plants become reproductive. Stevens (2004) provides some guidelines for increasing the time of protection depending on the ecosystem and precipitation after seeding. Uses should aim to minimize defoliation and trampling during the most active growing period (from just before reproduction until after seed dispersal).
	12. How will monitoring occur?	Monitoring of effectiveness of restoration treatments requires that a complete set of monitoring elements be completed such that an analysis and report are completed.
	13. Are adjustments to the restoration recommended?	Adaptive management is complete when lessons learned from the previous project can be applied in future projects. This requires completion of reports and meta-analyses of these reports to provide spatial recommendations based on consistent findings in multiple locations. This can be expedited through a common database for restoration monitoring reports.

SOURCE: Modified from Miller et al. 2007.

recommended that projects be monitored using similar techniques and that data be stored and made available for future query in a common database. Wirth and Pyke (2007) provide an example of a monitoring system with methods and a database that meets these goals. Monitoring data should reflect the quantitative objectives the manager wants to achieve with restoration or rehabilitation projects. Data analysis is directed at learning if projects were successful in achieving management objectives using simple statistical methods with graphical interpretations (Wirth and Pyke 2007). Consideration of a similar monitoring storage and retrieval database and analysis tool for sage-grouse restoration and rehabilitation projects would be useful to provide region-wide information for adaptive management of Greater Sage-Grouse habitat restoration and rehabilitation.

CONSERVATION IMPLICATIONS

Dramatic changes within sagebrush grassland ecosystems are a major contributor to population changes of Greater Sage-Grouse. However, the large spatial area that represents the distribution of Greater Sage-Grouse and variety of types of plant communities that are optimal for population growth and sustenance (Connelly et al. 2000c) require planning and prioritization to accomplish needed changes. Restoration, whether passive or active, often carries economic costs that are borne by private or government entities. Risks of not succeeding due to factors out of the manager's control, such as weather, may add to costs of these projects.

Restoration of habitat for Greater Sage-Grouse is more complex than the typical restoration project, which generally is site-specific, with goals and objectives dependent on a single site, and often smaller than the home range of a Greater Sage-Grouse. Successful restoration of Greater Sage-Grouse habitat will require not only vegetation changes in a single area but also connectivity among patches of currently intact vegetation. Many partnerships and working groups throughout the region have begun to implement efforts to assist in conservation of Greater Sage-Grouse, including some restoration projects (Western Governors' Association 2004). Coordination of these efforts might improve these projects and increase their effectiveness in providing habitat for Greater Sage-Grouse where it is most needed.

The most effective restoration for Greater Sage-Grouse habitat will require regional assessments of current status of sagebrush grasslands. It will require protection and proper management for the maintenance of intact sagebrush grasslands while identifying those lands where modifications to management may improve and restore quality habitat for this native and endemic bird. Active restoration will be needed to ultimately improve areas where current vegetation has already crossed a threshold and management alone will not achieve habitat improvement. For these projects, strategic placement will be critical for enhancing the likelihood of restoration success while keeping economic costs reasonable.

ACKNOWLEDGMENTS

This manuscript benefited from comments by anonymous reviewers from the Ecological Society of America, who reviewed previous material in the Range-wide Conservation Assessment for Greater Sage-Grouse and Sagebrush Habitats, as well as R. F. Miller, E. B. Allen, D. D. Musil, C. E. Braun, S. T. Knick, and C. D. Marti, who aided in editing and improvements. This is contribution Number 26 of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP Proj #05-S-08), funded by the United States Joint Fire Science Program. Additional financial support came from U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Coordinated Intermountain Restoration Project (9354-AKFC1). Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.