Sagebrush-Steppe Vegetation Dynamics and Restoration Potential in the Interior Columbia Basin, U.S.A.

MILES A. HEMSTROM,* MICHAEL J. WISDOM,†‡‡ WENDEL J. HANN,‡
MARY M. ROWLAND,§ BARBARA C. WALES,† AND REBECCA A. GRAVENMIER**

*U.S. Forest Service, Pacific Northwest Research Station, P.O. Box 3623, Portland, OR 97208, U.S.A.
†U.S. Forest Service, Pacific Northwest Research Station, 1401 Gekeler Lane, La Grande, OR 97850, U.S.A.
‡U.S. Forest Service, 2015 Poplar, Leadville, CO 80461, U.S.A.
§U.S. Bureau of Land Management, 1401 Gekeler Lane, La Grande, OR 97850, U.S.A.
**U.S. Bureau of Land Management, Interior Columbia Basin Ecosystem Management Project, P.O. Box 3623, Portland, OR 97208, U.S.A.

Abstract: *We modeled the dynamics and restoration of sagebrush (*Artemisia *spp.) habitats for Greater Sage-Grouse (*Centrocercus urophasianus*) in the interior Columbia Basin and adjacent portions of the Great Basin (referred to as the basin). Greater Sage-Grouse have undergone widespread decline and are the focus of conservation on over 13 million ha of sagebrush steppe in the basin, much of which is managed by the U.S. Forest Service (FS) and U.S. Bureau of Land Management (BLM). Consequently, we evaluated changes in the amount and quality of sage-grouse habitat on 8.1 million ha of FS–BLM lands in the basin. Changes were estimated from historical to current conditions and from current conditions to those projected 100 years in the future under proposed management and under two restoration scenarios. These two scenarios were designed to improve long-term (100-year) projections of sage-grouse habitat on FS–BLM lands in relation to current conditions and proposed management. Scenario 1 assumed a 50% reduction in detrimental grazing effects by livestock (through changes in stocking rates and grazing systems) and a six-fold increase in areas treated with active restoration relative to proposed management. Scenario 2 assumed a 100% reduction in detrimental grazing effects and the same level of active restoration as scenario 1. Under the two scenarios, the amount of FS–BLM habitat for sage grouse within treated areas declined by 17–19% 100 years in the future compared with the current period, but was 10–14% higher than the 100-year projection under proposed management. Habitat quality under both scenarios was substantially improved compared with the current period and proposed management. Our results suggest that aggressive restoration could slow the rate of sagebrush loss and improve the quality of remaining habitat.*

Dinámica de la Vegetación y Restauración Potencial de una Estepa de Artemisa en la Cuenca Columbia Interior, E.U.A.

Resumen: *Modelamos las dinámicas y la restauración de hábitats de la artemisa (*Artemisia *spp.) para el urogallo (*Centrocercus urophasianus*) en la cuenca Columbia Interior y las porciones adyacentes de la Gran Cuenca (referida como cuenca). Los urogallos han experimentado una disminución generalizada y se encuentran bajo conservación en más de 13 millones de hectáreas de estepa de Artemisa en la cuenca, mucha de esta extensión es manejada por el Servicio Forestal de Estados Unidos (FS) y la Agencia de Manejo de la Tierra (BLM). Consecuentemente, evaluamos los cambios en la cantidad y calidad del hábitat del urogallo en 8.1 millones de ha de tierras FS-BLM de la cuenca. Se estimaron los cambios occuridos desde condiciones históricas hasta las actuales y desde las condiciones actuales hasta aquéllas proyectadas para 100 años en el futuro según una propuesta de manejo y en dos escenarios de restauración. Estos dos escenarios fueron dis-*

‡‡*Address correspondence to M. J. Wisdom, email mwisdom@fs.fed.us*
Paper submitted February 15, 2001; revised manuscript accepted October 31, 2001.

eñados para mejorar las proyecciones de largo plazo (100 años) del hábitat del urogallo en tierras de FS-BLM considerando las condiciones actuales y del manejo propuesto. El escenario 1 asume una reducción del 50% en los efectos perjudiciales del pastoreo por ganado (mediante cambios en las tasas de densidad y sistemas de pastoreo) y un incremento de hasta 6 veces en áreas tratadas con restauración activa relacionadas con el manejo propuesto. El escenario 2 asume un 100% de reducción en los efectos perjudiciales del pastoreo por ganado y el mismo nivel de restauración activa propuesto en el escenario 1. Bajo estos dos escenarios, la cantidad de hábitat FS-BLM para urogallos dentro de áreas tratadas disminuiría del 17 al 19% en 100 años, comparado con el periodo actual, pero esto fue 10–14% más alto que la proyección a 100 años bajo la propuesta de manejo. La calidad del hábitat bajo ambos escenarios fue sustancialmente mejorada cuando se compara con el periodo actual y el manejo propuesto. Nuestros resultados sugieren que la restauración agresiva podría detener la tasa de pérdida de Artemisa y mejorar la calidad del hábitat que aún persiste.

Introduction

The sagebrush-steppe ecosystem has experienced dramatic declines across western North America. Millions of hectares of the ecosystem have been altered or eliminated during the past century (Hann et al. 1997; West 1999). Although sagebrush steppe still occupies 44.4 million ha of land in western North America (Miller & Edelman 2000), <20% of the ecosystem remains unaltered by human activities (West 1999).

Causes for loss and degradation of sagebrush steppe are many and varied. Conversion to agriculture, urbanization and non-native livestock forage, intensive grazing by livestock, invasion of exotic vegetation, altered fire regimes, road development and use, and climate changes have contributed to the decline (Tausch et al. 1995; Schroeder et al. 1999; Miller & Edelman 2000). In particular, cheatgrass (*Bromus tectorum*) and other invasive exotic species have displaced native vegetation following intensive grazing and large, intense wildfires (Billings 1994; Hann et al. 1997). In many instances, disturbances to native understory grasses and forbs allowed or enhanced the spread of exotic understory species without replacing the sagebrush (*Artemisia* spp.) overstory (Young & Evans 1970; Bunting et al. 1987; Billings 1994; Connelly et al. 2000). This native understory is a critical habitat component for Greater Sage-Grouse (*Centrocercus urophasianus*) (Schroeder et al. 1999; Connelly et al. 2000) and other vertebrates that are sagebrush obligates (Wisdom et al. 2000).

Once established, cheatgrass is difficult to control or suppress (Monsen 1994). Hann et al. (1997) estimated that >50% of the area within sagebrush vegetation types in the interior Columbia Basin and adjacent portions of the Great Basin (hereafter referred to as the basin) was highly susceptible to cheatgrass invasion. Restoration of sagebrush steppe therefore poses a daunting challenge, owing to the many causes of change, the magnitude of change, and the spread and persistence of exotic vegetation (Knick 1999; West 1999). The resources needed for effective restoration across large landscapes, encompassing millions of hectares, appear to be substantial. Restoration of sagebrush steppe is particularly challenging for federal land managers, who have legal obligations to maintain viable populations of sagebrush-dependent species in the face of widespread habitat degradation.

These management challenges are exemplified by the degraded conditions that were projected for sagebrush-associated vertebrates in the basin (Raphael et al. 2001). These conditions were projected as part of an evaluation of three alternatives for management of lands of the U.S. Forest Service (FS) and U.S. Bureau of Land Management (BLM), as outlined in a supplemental draft environmental impact statement (SDEIS) for the basin (U.S. Forest Service & U.S. Bureau of Land Management 2000). The SDEIS was developed as part of the Interior Columbia Ecosystem Management Project (ICBEMP), a joint effort by the FS and BLM to develop broad-scale, ecosystem-based strategies for managing >35 million ha of federal land in the basin (U.S. Forest Service 1996).

The preferred alternative—proposed management—in the SDEIS proposes restoration of landscape functions and processes by providing goal-oriented, broad-scale direction, describing a set of subbasins for restoration priority, and requiring the FS and BLM to use a multiscale analysis of biological and physical features before initiating most field activities. Proposed restoration was focused more on forest environments, where pathways of vegetative succession remain largely intact, with less restoration targeted for rangelands in lower-elevation, drier sites dominated by sagebrush. Restoration potential in such rangeland sites was limited by budget constraints and trade-offs with other restoration objectives (U.S. FS & U.S. BLM 2000).

The current and projected widespread degradation of sagebrush steppe begs the question of how reversible these changes are. Specifically, is it possible to restore sagebrush steppe across large landscapes, and, if so, what kinds of restoration efforts would be effective?

In response to these questions, we modeled the vegetation dynamics of sagebrush steppe and explored the potential for its restoration in the basin. We focused on the dynamics and restoration of sagebrush habitat for Greater Sage-Grouse because (1) some populations are the subject of a potential listing under the U.S. Endangered Species Act and therefore of special interest to federal agencies; (2) the species is managed as a game bird by state agencies; and (3) the species' historical range and habitats encompass most sagebrush plant communities, suggesting that sage grouse may serve as a surrogate for other sagebrush-dependent vertebrates.

Within this framework, our objectives were to (1) describe the methods and assumptions for modeling broad-scale changes in the quantity and quality of sagebrush steppe in relation to sage-grouse requirements; (2) characterize vegetation dynamics and processes as they potentially affect the quantity and quality of sagebrush steppe across the basin; (3) explore options for restoring sagebrush steppe across expansive landscapes through an intensive combination of passive and active treatments; and (4) interpret the results of two restoration scenarios, specifically addressing challenges posed in restoring sagebrush-steppe vegetation.

Study Area

The study area covers approximately 58 million ha in Washington, Oregon, Idaho, and Montana (Fig. 1). Public lands managed by the FS–BLM account for 53% of this area (Quigley & Arbelbide 1997). Elevations in the basin range from <150 to >3000 m above sea level. Average annual precipitation ranges from >250 cm in the Cascade Range to <20 cm in the central low-elevation basins and plains (Hann et al. 1997). The wide range in climate, geology, topography, hydrology, and soils supports a correspondingly broad diversity of plant and animal communities. The basin's rich biota includes an estimated 19,000 plant species, 24,000 invertebrate species, and 600 vertebrate species (Marcot et al. 1997).

Vegetation disturbances in the basin vary widely as a function of climate, topography, vegetation types, and human uses. Hann et al. (1997) and Hemstrom et al. (2001) have described various disturbances, including fire, ungulate grazing, timber management, road building, recreational activities, invasion of exotic plants, seeding of native or desirable exotic plants, herbicide use to control exotic plants, and conversion of native habitats to agriculture or urban uses. Fire and human activities are major disturbance agents in the basin, particularly on rangelands (Hann et al. 1997).

Methods

We developed two restoration scenarios based on habitat for sage grouse as our case example for exploring potential improvements in sagebrush steppe. We targeted three habitat variables for improvement: habitat amount and two indicators of habitat quality. These three vari-

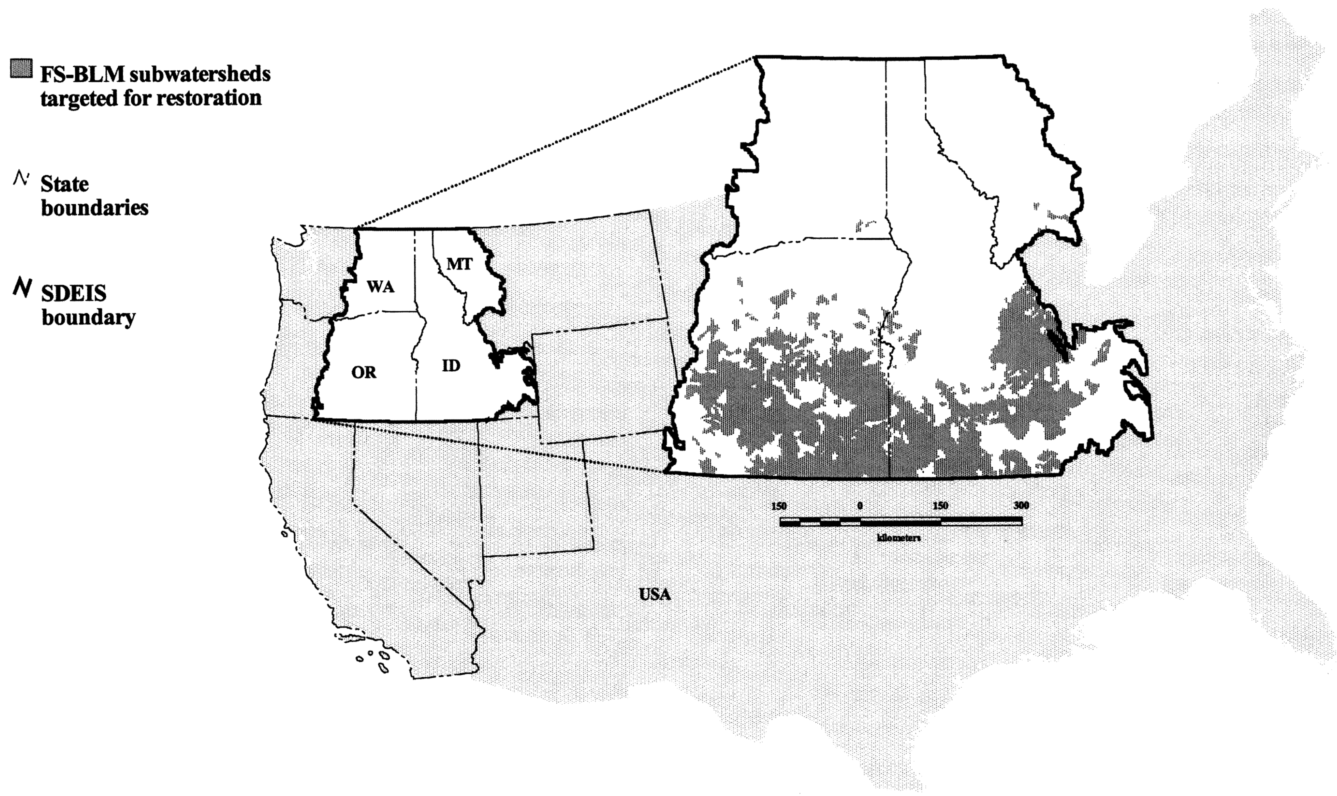

Figure 1. The supplemental draft environmental impact statement (SDEIS) area, encompassing eastern Washington (WA), eastern Oregon (OR), most of Idaho (ID), and northwestern Montana (MT) and the subwatersheds dominated by lands administered by the U.S. Forest Service (FS) and Bureau of Land Management (BLM) that contain Greater Sage-Grouse habitat within the range of the species in the interior Columbia Basin.

ables were key inputs in an environmental index model used to evaluate broad-scale conditions for sage grouse in the basin (Raphael et al. 2001; Wisdom et al. 2002 [this issue]). Our intention was to evaluate broad-scale changes in these variables on FS–BLM lands from historical to current conditions and from current conditions to those projected 100 years in the future under proposed management and under the two restoration scenarios.

Our methods involved several assumptions associated with the broad-scale nature of our analysis, the relative paucity of comprehensive and standardized vegetation data, and the complexity of the disturbances and pathways that occur in the various vegetation types and environments. These assumptions were as follows: (1) broad-scale (i.e., 1-km^2 pixel) representations of vegetation are sufficient to illustrate dominant conditions and changes over large areas of the basin, such as across the 8.1 million ha of potential sage-grouse habitat we evaluated; (2) our transition models accurately depict historical, current, and future (100-year) conditions over these large areas; (3) historical vegetation and disturbance conditions can be described as a baseline against which to estimate trends without accounting for changes in climate since historical times; and (4) combinations of cover and structure found historically and currently represent the likely range of conditions that could occur in the next 100 years. We recognize that each pixel is actually a mosaic of conditions at finer resolutions. However, the coarse spatial resolution of our pixel size was not intended to estimate within-pixel conditions or small areas of sagebrush steppe. We assumed that local assessments, using finer spatial resolution, would complement our work for planning local restoration activities. We made these assumptions to reduce the enormous complexity of landscape dynamics and thus allow broad-scale examination of potentially important resource and conservation issues.

Modeling Habitat Amount

Habitat amount is the area of habitat within the historical range of sage grouse in the basin, as defined by Wisdom et al. (2000). Habitat for sage grouse was identified by Wisdom et al. (2000) from vegetation classified as combinations of cover type and structural stage in the basin (Hann et al. 1997). Sage-grouse habitats in the study area primarily include low to medium-height shrublands in communities of basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*), Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*), mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), and low sagebrush (*A. arbuscula*), and in herbaceous wetlands. Our examination focused on sagebrush steppe, which is the major source of sage-grouse habitat in the interior Columbia Basin. Other vegetation types provide important habitat elsewhere within the species' range.

The foundation for our modeling of habitat amount was the vegetation information developed by Hann et al. (1997) that described 17 rangeland potential vegetation types (PVTs) in the basin and >50 combinations of cover type and structural stage nested within these PVTs. Potential vegetation types reflect biophysical conditions, disturbance regimes, and the suite of plant communities that can occupy sites over time (Hann et al. 1997). The big-sagebrush group includes basin big sagebrush steppe and Wyoming big sagebrush cool and warm types. Big sagebrush types, especially in warmer, drier environments, are highly susceptible to invasion by exotic annual grasses. The warm, dry big sagebrush type is widespread at lower elevations in the Columbia Basin. The mountain big sagebrush PVT includes variations reflecting differences between the eastern and western portion of the basin and those types that more readily become dominated by trees following fire suppression. Mountain big sagebrush types are generally in cooler and moister sites and are more productive and more resistant to invasion by exotic annual grasses than are other big sagebrush types we considered. Mountain big sagebrush and low sagebrush types become increasingly important as sage-grouse habitat in the southern portions of the basin.

Existing vegetation cover and structure are transient and reflect the vegetation present at any given time. Cover types reflect the dominant species in upper-canopy layers, whereas structural stages depict the horizontal and vertical arrangement of vegetative structures (e.g., canopy cover and height class) and are related to temporal patterns of vegetation development (Hann et al. 1997). The base vegetation data included 41 cover types and 25 structural stages across the basin that were mapped at a resolution of 1-km^2 pixels (Hann et al. 1997; Wisdom et al. 2000).

Amount of vegetation and associated disturbance regimes for the historical period were estimated through a combination of modeling and biophysical data and reflect average conditions circa 1850–1900 (Hann et al. 1997). Current vegetation maps were developed to reflect average conditions from 1985 to 1995, relying on a combination of satellite imagery, aerial photography, sample data, and a map of land-cover characteristics (Keane et al. 1996; Hann et al. 1997; Hessburg et al. 1999). Each pixel was assigned one cover type and structural stage that reflected the likely dominant condition. Assignments were refined through a rectification process to assure that cover types and structural stages would occur only on sites that had the successional potential to produce those types and stages (Wisdom et al. 2000). This rectification process improved the broad-scale accuracy of the estimates and resulted in a high spatial correlation of assignments among adjacent pixels within a given area (Wisdom et al. 2000).

Projections of future amount of vegetation under proposed management were based on state-and-transition models (transition models) that reflect combinations of vegetation cover and structure classes, transitions among them, and annual probabilities of various disturbances that determine the rate at which transitions occur (Fig. 2). These models were developed by experts in rangeland vegetation ecology, based on published literature, hypothesized relations, and empirical data (Hann et al. 1997). Similar models have been described elsewhere for rangeland ecosystems (Westoby et al. 1989; Laycock 1991; Holechek et al. 1998). Our transition models were developed for 17 regimes (prescriptions) that reflect dominant management activities and associated disturbance regimes (Hann et al. 1997). These were combined with approximately 50 potential vegetation types to derive hundreds of individual transition models (Hann et al. 1997). Our examination of habitat amount involved a subset of those prescriptions and potential vegetation types. Although our modeling included all the relevant sagebrush-steppe types in the basin, we illustrate conditions in the basin using the Wyoming big sagebrush PVT, which constitutes a substantial portion of potential sage-grouse habitat in the basin and poses serious challenges for restoration.

The choice of transition models to depict current conditions was based on current management activities and disturbances, such as levels of timber harvest and livestock grazing. In modeling future vegetation, we assigned prescriptions to all 1-km^2 pixels in the basin, depending on management regimes proposed in the SDEIS alternatives. We assumed no changes to existing management on lands not administered by the FS or BLM. Projected vegetation varied across the landscape, depending on the baseline conditions of each pixel, including PVT and management direction.

Each state in the transition models was a condition—cover type and structural stage—that could occur in the combination of PVT and management prescription being modeled (Fig. 2). Many of the models included more than one potentially stable state (e.g., two potentially stable states exist in the Wyoming big sagebrush PVT; Fig. 2). States of the cover type and structural stages in the transition models represented groups of plant species that may vary, depending on local conditions. The transition between stable states was triggered, in this example, by the interactions of frequent, substantial graz-

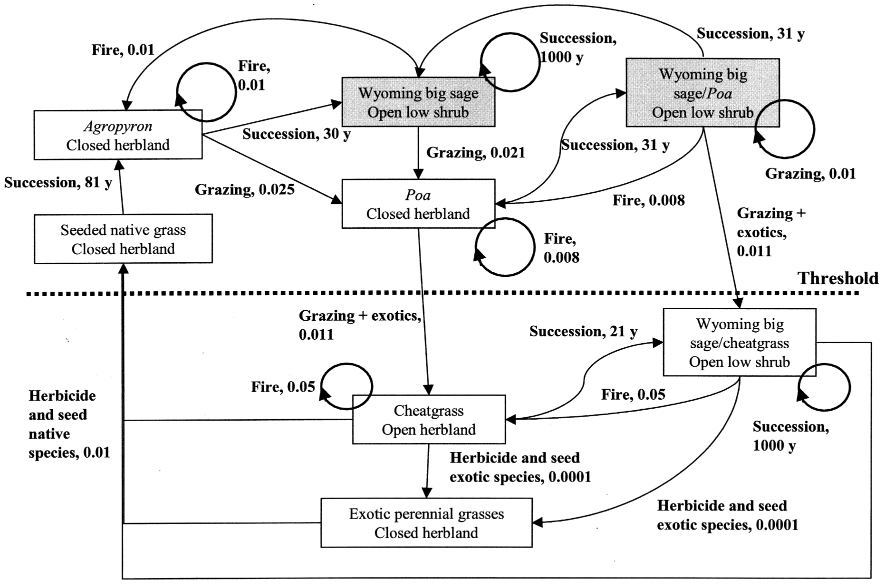

Figure 2. Example state-and-transition model (based on concepts of Westoby et al. 1989 and Laycock 1991) for the Wyoming big sagebrush potential vegetation type under an active-restoration prescription. Boxes are vegetation states and arrows are transitions from one state to another. In this example, transitions are brought about by succession and disturbance agents of fire, grazing, chemical treatments, and seedings. When disturbances are the primary cause of transition, the annual probability of moving from one state to another is shown in association with the disturbance that causes the transition (e.g., fire, 0.01). Successional transitions of 1000 years (y) indicate stable states. Restoration scenarios were designed to enhance the probability of moving to desired states (gray boxes, habitat for sage-grouse) and diminish the probability of moving to nondesired states (white boxes, nonhabitat for sage-grouse). The dotted line indicates a transition threshold below which restoration is difficult and requires a sustained, extensive combination of active and passive measures.

ing effects, wildfire, and the presence of invasive exotic plants. Relatively expensive and energy-intensive treatments, such as herbicide application and seeding native plants, were required to change undesired states to more desirable ones. The feedback loop involving wildfire and cheatgrass in this system is well documented (Pellant 1990; Billings 1994; West 1999) and poses a major challenge for restoration in the sagebrush PVTs (e.g., Fig. 2).

Modeling Habitat Quality

The dominant canopy layers of vegetation and understory composition and structure determine the quality of habitat for sage grouse (Schroeder et al. 1999; Wisdom et al. 2000). Raphael et al. (2001) used historical range of variability (HRV) departure and uncharacteristic grazing (UG) to index vegetation quality in their environmental index model for sage grouse. Historical range of variability departure is a composite measure of the departure of vegetation composition, structure, pattern, and disturbance regimes from historical conditions (Hann et al. 1997; Hemstrom et al. 2001). Causes for departure include livestock grazing, wildfire suppression, timber management, road building, and other activities that create ecological transitions and vegetation conditions unlike those that existed historically (Morgan et al. 1994).

We used HRV departure specifically to index the degree to which exotic plants have invaded and displaced components of native sagebrush steppe, particularly native grasses and forbs required by sage grouse for successful nesting and brood rearing (Connelly et al. 2000). Historical range of variability departure was reported as the probability, summarized into classes of none, low, moderate, or high, of the departure of current or future landscape mosaics from historical conditions for each subwatershed (Hemstrom et al. 2001).

We derived our estimates of historical conditions from transition models based on estimated plant communities and disturbance paths that existed prior to extensive alteration of vegetation and disturbances accompanying Euro-American settlement (Hann et al. 1997). We assumed that historical climatic conditions were similar to current climate. Our historical condition therefore depicts vegetation that might result from natural-disturbance regimes (including those related to Native American presence) under current climatic conditions. We recognize that climate in the basin has changed and that some current and future vegetation communities may not have existed historically. Our intent, however, was to examine the potential effects of future management actions in the face of altered disturbance regimes and exotic, invasive plant species.

Raphael et al. (2001) used UG to index changes in species richness, height, and cover of native understory grasses and forbs in response to livestock grazing and subsequent effects on the quality of nesting and brood-rearing habitat for sage grouse (Wisdom et al. 2002 [this issue]). Uncharacteristic grazing is a broad-scale measure of the degree to which grazing pressure by livestock exceeds that of native ungulates under historical conditions and was calculated as a probability (0–1) for each subwatershed based on current livestock grazing levels (from 10-year averaged data from FS and BLM field units) and current vegetation cover types and structural stages. A UG class (none, low, moderate, or high), based on the probabilities, was assigned to each subwatershed. Uncharacteristic grazing was assumed to have occurred where models projected current cover types and structural stages in rangeland PVTs as (1) very early seral vegetation or (2) dominated by exotic plant species. Although ungulate grazing did occur historically, the vegetation of the study area was not generally adapted to high grazing pressure, particularly pressure from bulk grazers such as cattle (Mack & Thompson 1982; Fleischner 1994; Miller et al.1994).

Classes of HRV departure and UG were assigned to each subwatershed for the current and future periods based on the level of deviation from the expected range of historical conditions. Subwatersheds within the central 50% of the historical range were assigned a departure class of none, with increasing classes (low-high) of HRV departure and UG assigned with increasing distance away from the central 50%. The choice of historical range strongly influences analyses that compare historical, current, and future conditions. We chose the central 50% because it excluded extreme fluctuations. Wide historical ranges (plus or minus 40%, for example) obscure differences between historical, current, and future conditions, whereas narrow ranges emphasize them.

Defining the Restoration Scenarios

Raphael et al. (2001) conducted their analyses of sage-grouse habitat across all lands within the historical range of the species in the basin. We limited our restoration analysis to FS–BLM lands within subwatersheds dominated by (i.e., ≥50%) FS or BLM ownership because we had no reliable information about future management practices on other lands (Fig. 1). The areas targeted for restoration (6.4 million ha) constitute 72% of FS–BLM lands and 63% of all lands that have potential to be sage-grouse habitat or that currently function as habitat within the species' historical range in the basin.

We developed two scenarios that represent a combination of active and passive restoration for the targeted areas. We define passive restoration as the process of modifying or eliminating existing management activities, such as livestock grazing, roads, or recreation, that contribute to environmental degradation of desired resources. In contrast, we define active restoration as the application of treatments that contribute to recovery of targeted resources, including appropriate use of wildfire suppression, prescribed fire, or seeding with native plants.

Scenarios 1 and 2 assumed a reduction in detrimental grazing effects of 50% and 100%, respectively, as the main form of passive restoration. We defined detrimental grazing effects in our transition models as the probability, associated with grazing, of moving from a desired vegetation state, which provides habitat for sage grouse (e.g., gray boxes, Fig. 2), to an undesired state (e.g., white boxes, or nonhabitat, Fig. 2). Accordingly, 50% and 100% reductions in detrimental grazing effects represented like reductions in the probability of transitioning from desired to undesired states for sage grouse in relation to livestock grazing. In addition, we assumed that reductions in the probability of detrimental grazing effects in our transition models equate to similar reductions in stocking rate. At finer scales, however, reduction of livestock stocking alone may not be sufficient to reduce grazing impacts, because some areas (e.g., those close to water or in gentle terrain) may continue to be heavily grazed. Our broad-scale analysis did not account for these finer-scale patterns.

Our assumed reductions in the stocking rate needed to achieve a desired reduction in detrimental grazing were based on empirical data demonstrating that herbage production on rangelands is affected mostly by variation in stocking rate and less so by changes in grazing system (Van Poolen & Lacey 1979; Holechek et al. 1998). On arid rangelands such as those dominated by sagebrush, a positive response in herbage production must include a reduction in stocking rate in combination with active restoration treatments (see empirical synthesis by Holechek et al. 1998). These assumptions seem appropriate for the dry rangelands of the intermountain West, where bulk grazers such as bison may not have played the extensive evolutionary role they did in other ecosystems (Mack & Thompson 1982; Fleischner 1994; Miller et al. 1994).

Restoration scenarios 1 and 2 also incorporated a sixfold increase in areas treated with active restoration relative to proposed management. Under proposed management, about 1 million ha were targeted for restoration, versus 6.4 million ha under the scenarios. Active restoration included a suite of restoration practices such as prescribed fire, wildfire suppression, seeding and planting of desired vegetation, herbicide application, and mechanical treatments. These types and levels of active restoration were combined with the specified levels of passive restoration in our transition models to project the effects of restoration on the quantity and quality of sage-grouse habitat.

Results of our initial model simulations indicated that this combined approach of passive and active restoration was required to achieve substantial improvements in habitat quantity and quality in the arid Wyoming big sagebrush PVTs that dominate large portions of sagebrush steppe in the basin. These results concur with findings summarized for sagebrush steppe and other arid rangelands in western North America (Holechek et al. 1998; McIver & Starr 2001). The need for both passive and active restoration was reflected in the transition models used in our analysis. In the example shown in Fig. 2, increases in the probability of detrimental grazing effects by livestock caused a higher probability of transition from sage grouse habitat to nonhabitat. In the absence of exotic plants, these transitions might be reversed by passive management. Once thresholds were crossed to states dominated by exotic plants, however, both active and passive restoration were required to recover the habitat. This combination of passive and active restoration, which allowed conservation of habitat and rehabilitation of nonhabitat, was the foundation for the overall restoration of sagebrush steppe under our two restoration scenarios.

Modeling the Restoration Effects

Proposed management in the SDEIS used an ecosystem-based approach focused on restoring "natural" vegetation and disturbance processes within the limitations of expected future agency funding. We assumed that proposed management could be enhanced to improve habitat amount and quality for sage grouse while retaining an ecosystem-based restoration approach in accord with SDEIS objectives. Our process involved several steps (Fig. 3). First, we examined projections of vegetation under each management prescription and selected the restoration prescription (A2 prescription, Hann et al. 1997) that provided the greatest amount and highest quality of sage-grouse habitat over 100 years in the Wyoming big sagebrush and mountain big sagebrush PVTs. These two PVTs provide the majority of habitat for sage grouse in the study area (66% and 24%, respectively). We then replaced the vegetation projected under proposed management at 100 years under three less beneficial prescriptions with vegetation projected by the A2 prescription. The result of this replacement was a new vegetation map for 100 years in the future, with revised estimates of habitat in FS–BLM–dominated subwatersheds based on the increased restoration emphasis (phase I, Fig. 3).

To further enhance our selected restoration prescription beyond the substitution of vegetation, we adjusted the disturbance and active restoration probabilities of the selected prescription to reflect those of a more aggressive rangeland restoration prescription (A3 prescription, Hann et al. 1997; phase II, Fig. 3). We also decreased the annual probability of detrimental grazing effects by 50% (scenario 1) and 100% (scenario 2) in our transition models, relative to the A2 prescription.

To complete our analyses, we ran the state-and-transition model with the adjusted restoration prescriptions

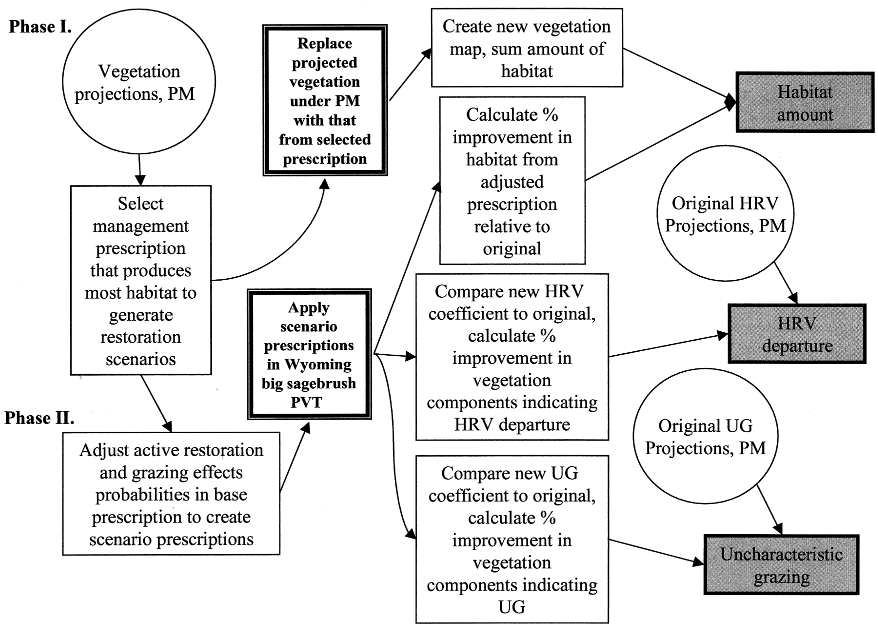

Figure 3. Process steps for modeling changes in Greater Sage-Grouse habitat under two restoration scenarios in relation to original projections under proposed management (PM). Shaded boxes indicate response variables of habitat amount and quality under the scenarios. Abbreviations: PM, proposed management under the interior Columbia Basin supplemental draft environmental impact statement; PVT, potential vegetation type; HRV, historical range of variability; UG, uncharacteristic livestock grazing effects.

(scenarios 1 and 2) in the Wyoming big sagebrush PVT and compared our results to those generated by the original restoration prescription (A2) in this PVT (phase II, Fig. 3). We then calculated factors that expressed the ratio of habitat amount produced by the restoration scenarios compared with that produced under A2. These factors, 1.05 for scenario 1 and 1.10 for scenario 2, were then multiplied by the total amount of habitat in any pixels reassigned to the adjusted restoration prescriptions, regardless of PVT, to yield revised estimates of habitat amount under the two restoration scenarios. Thus, the final estimate of habitat amount under the two scenarios reflects a two-stage process for improving conditions. First, the land base to which restoration was applied was increased; second, the restoration prescription itself was enhanced to represent more aggressive active restoration levels, coupled with either a 50% or 100% reduction in detrimental grazing effects.

The HRV departure and UG attributes, used as indices of habitat quality, were targeted for improvement under the restoration scenarios by the same method as that used for modeling improvements in habitat amount: we compared vegetation conditions projected by the transition model for the Wyoming big sagebrush PVT under the two scenarios versus original projections under the selected restoration prescription (A2). The relative proportions of selected cover types and structural stages that characterize HRV departure or UG were then used as the baseline to develop factors representing the magnitude of improvements in HRV departure and UG across FS-BLM subwatersheds. These factors were then applied to the same FS-BLM pixels that were modified for habitat quantity under the scenarios to yield the estimates of HRV departure and UG in relation to restoration improvements (Phase II, Fig. 3).

Although the restoration scenarios as designed would generally lead to increases in the amount and quality of habitat for sage grouse, in a few local areas some original prescription and PVT combinations could generate more habitat than did prescriptions under the two restoration scenarios. For example, the restoration scenarios emphasized fire suppression to prevent further invasion of cheatgrass and displacement of native sagebrush steppe. On some mountain big sagebrush sites, however, a more appropriate emphasis might have been increased use of prescribed fire to reduce juniper (*Juniperus* spp.) encroachment. Consequently, the greater overall emphasis on fire suppression to prevent cheatgrass invasion under the restoration scenarios, as applied across large areas of sagebrush steppe in the basin, likely resulted in less restoration improvement in some of these local areas.

Rationale and Assumptions for Restoration

We deliberately used a conservative approach under our restoration scenarios in assigning factors that increase habitat quantity and quality. This approach was deemed necessary because we did not want to overestimate our ability to restore arid habitats of sagebrush steppe, where such large-scale restoration as we modeled has not been attempted and where major obstacles to restoration are apparent (Knick 1999; West 1999). We assumed that improvements in the Wyoming big sagebrush PVT under our scenarios would be equivalent to those in other PVTs not modeled explicitly under our scenarios. Moister sagebrush sites, such as those dominated by mountain big sagebrush, may be easier to restore than Wyoming big sagebrush types (Miller & Edelman 2000). Great uncertainty about the restoration potential of all sagebrush communities, however, is as-

Table 1. Changes in Greater Sage-Grouse habitat from historical to current and future time periods under current management, proposed management (PM), and two restoration scenarios on U. S. Forest Service (FS) and U. S. Bureau of Land Management (BLM) lands in FS–BLM-dominated subwatersheds in the range of sage grouse in the interior Columbia Basin.

*Time period**	*Hectares (million)*	*Percent change*	*Reference*
Historical	8.1		
Current	7.7	−5	historical
PM	5.6	−27	current
Scenario 1	6.2	−19	current
Scenario 2	6.4	−17	current

**The proposed management and scenario projections are for 100 years in the future.*

sociated with incomplete knowledge of appropriate restoration methods and technologies and with the logistical challenges posed by sustained and integrated application of restoration treatments across vast areas of sagebrush steppe. Our conservative approach reflects this uncertainty.

Results

Habitat Amount and Transitions

Habitat for sage grouse historically covered about 8.1 million ha of FS–BLM lands in the study area and declined by approximately 5% from historical to current periods (Table 1). Most of the decline occurred in the Wyoming big sagebrush PVT, where fire and grazing converted habitat to herbaceous vegetation dominated by exotic species (Table 2). Habitat also declined a small amount (about 1%) in mountain big sagebrush types (Table 2), where large losses of habitat to woodland encroachment were balanced by gains associated with succession of herblands and grasslands to shrublands (a fire-suppression effect).

More dramatic habitat losses were projected under proposed management and the restoration scenarios of 100 years in the future. Sage-grouse habitat on FS–BLM lands was projected to decline by 27% under proposed management compared with current estimates (Table 1). Habitat declined more slowly under restoration scenarios 1 and 2 (by about 19% and 17%, respectively), but neither scenario halted the long-term downward trend. Most future habitat loss was associated with transitions to herblands and grasslands dominated by exotic plants in the Wyoming big sagebrush PVT. Smaller future habitat losses were projected in the mountain big sagebrush PVT (Table 2), due mostly to invasion of exotic plants and forest encroachment. Exotic plant invasion is most likely to occur at lower elevations and on drier sites in the mountain big sagebrush PVT, whereas woodland and forest encroachment are more likely on mesic and higher-elevation sites. Additional small habitat declines were projected for other rangeland PVTs in the study area.

Restoration scenarios 1 and 2 increased habitat amount relative to proposed management, by about 0.6 million ha and 0.8 million ha, respectively, on FS–BLM lands (Table 1). Our model projections indicated that a substantial increase in habitat from passive and active restoration would be offset by large losses (>1 million ha) associated mostly with wildfire and the subsequent invasion of exotic grasses in the Wyoming big sagebrush PVT.

Habitat Quality

Habitat quality improved substantially under the restoration scenarios compared with proposed management, as indexed by UG and HRV departure (Fig. 4). Only 22% and 12% of subwatersheds were characterized by high UG under scenarios 1 and 2, respectively, whereas high UG occurred in 68% and 53% of subwatersheds during the current period and under proposed management, respectively. The percentage of subwatersheds with high HRV departure under the restoration scenarios (2%) also was substantially lower than the percentage with high

Table 2. Transitions in sage-grouse habitat in Wyoming big sagebrush and mountain big sagebrush potential vegetation types, based on habitat gains (positive numbers) and losses (negative numbers) in relation to unsuitable herblands and forests under proposed management (PM) and two restoration scenarios[a] on U. S. Forest Service (FS) and U. S. Bureau of Land Management (BLM) lands in FS–BLM–dominated subwatersheds in the range of sage grouse in the interior Columbia Basin.[b]

	Wyoming big sagebrush			*Mountain big sagebrush*		
Time period	*herbland (%)*	*forest (%)*	*net change (%)*	*herbland (%)*	*forest (%)*	*net change (%)*
Historical to current	−6	0	−6	7	−8	−1
Current to future, PM	−32	0	−32	−2	−1	−3
Current to future, restoration scenarios	−23	3	−20	−2	−1	−3

[a]The proposed management and scenario projections are for 100 years in the future.
[b]Herblands include unsuitable grasslands and forblands, especially areas dominated by exotic plants. Forest includes unsuitable forest and woodland.

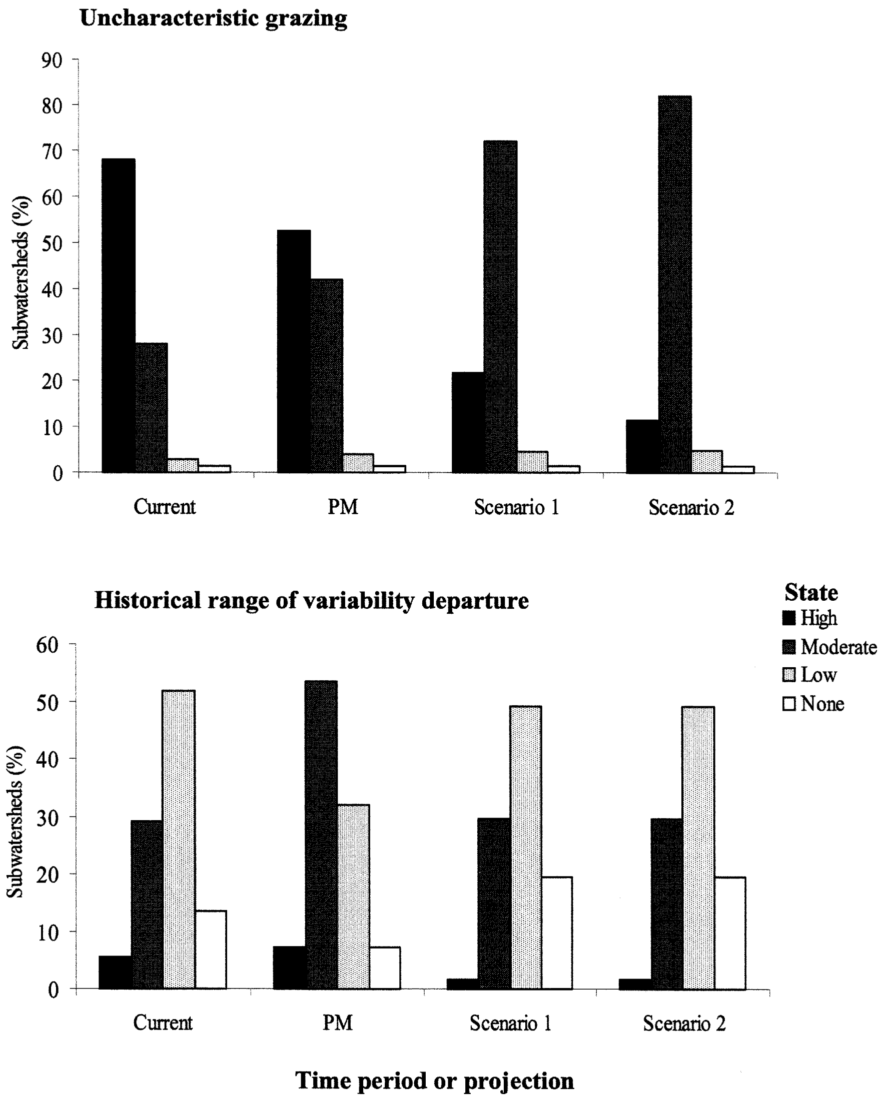

Figure 4. Current and long-term (100-year) distribution of states (none to high) for uncharacteristic grazing and historical range of variability departure in 1831 subwatersheds on lands of the U.S. Forest Service (FS) and Bureau of Land Management (BLM) in the historical range of Greater Sage-Grouse in the interior Columbia Basin. Proposed management (PM) represents the preferred alternative in the supplemental draft environmental impact statement for management of FS and BLM lands in the basin. The restoration scenarios represent increased active restoration coupled with a 50% (scenario 1) and 100% (scenario 2) reduction in livestock grazing effects.

HRV departure currently (6%) and under proposed management (7%). The restoration scenarios also had a higher percentage of subwatersheds in the low and none classes of UG and HRV departure compared to current conditions and proposed management (Fig. 4).

Discussion

Our projections may provide insight into the practical potential for restoring sagebrush steppe. The restoration scenarios did not reverse the downward trend for habitat amount from current to future conditions under proposed management. The scenarios were effective, however, in slowing the rate of habitat loss and improving the quality of habitat compared to proposed management. This finding is similar to that of Knick (1999), who predicted that >100 years were required to replace shrublands lost in just 20 years, assuming optimal conditions, favorable climate, and fire control. Our models also did not incorporate potential climate change, which may substantially alter restoration potential (Tausch et al. 1995).

Future habitat loss on FS- and BLM-administered lands is likely to be associated with a feedback loop involving exotic plants (cheatgrass and others) and fire or, alternatively, with transitions to forest environments. Transitions to cheatgrass and the ensuing changes in fire regimes reflect the continued and pervasive spread of this plant species in sagebrush steppe, particularly following disturbance by livestock grazing, wildfire events, and road development and use (Pellant 1990; Billings 1994; Monsen 1994). The continued transition of sagebrush to cheatgrass is particularly evident in the Wyoming big sagebrush PVT, which occurs on lower-elevation, drier sites that are particularly prone to cheatgrass invasion following disturbance events (Miller & Edelman 2000).

Although minimal habitat loss has occurred on FS–BLM lands to the current period, past declines have been substantially greater on nonfederal land (Wisdom et al. 2000) and all lands combined (West 1999). Differences in habitat declines between federally administered lands and other lands are due primarily to past large-scale conversion of habitat to agricultural and urban uses on private lands (Wisdom et al. 2000). The substantial acceleration in habitat loss projected for FS–BLM lands in the future, however, will add to the considerable habitat loss that has occurred in the past on nonfederal lands.

Our transition models identified states dominated by exotic plants where fire frequency and intensity and fuel levels have increased dramatically, resulting in long-term stable conditions that are resistant to change (Pellant 1990; West 1999; Miller & Edelman 2000). Transitions from states dominated by exotic plants to native vegetation require aggressive levels of active restoration and reduced grazing pressure to maintain the newly established native habitats.

Our results also illustrate the influence of transitions from sagebrush steppe to woodland and forest environments in the mountain big sagebrush PVTs. These transitions reflect long-term wildfire suppression in moister areas of sagebrush steppe where fire would normally retard the establishment and growth of trees. It is interesting that, in the absence of wildfire suppression, sites that would otherwise be overtaken by trees may nonetheless transition out of sagebrush. Instead, wildfire may lead to the replacement of sagebrush with exotic grasslands, especially at lower elevations and on drier sites. Such scenarios suggest that prescribed burning, followed by rehabilitation of lower-elevation mountain big sagebrush sites with native vegetation (through seedings and plantings), is critical to preventing transitions of sagebrush to forest environments and to cheatgrass (Miller & Eddleman 2000).

Substantial improvements in habitat quality under our restoration scenarios suggest that sagebrush habitats containing remnant components of native grasses and forbs, especially at higher elevations and on more mesic sites, are most amenable to improvement and recovery. These habitats would be important to map and characterize in terms of their fragmentation and connectivity. Such maps, combined with site-specific data on sagebrush stands that contain remnant components of understory native grasses and forbs, could be used to build broad-scale strategies for restoration. Sagebrush-steppe restoration without consideration of spatial context may produce fragmented landscapes, particularly in relation to sage-grouse distribution, seasonal movements, and dispersal capabilities.

Although our results show limited improvement in habitat amount, it is important that our restoration scenarios incorporated an ecosystem-based suite of restoration prescriptions, rather than being specifically targeted to improve sage grouse habitat. Notably, the restoration prescriptions under proposed management yielded, in some locales, habitat quality and quantity superior to those resulting from our restoration scenarios. This is not surprising given the conservative nature of the scenarios, which was based on our uncertainty about achieving restoration success, especially in the arid Wyoming big sagebrush PVT. The prescriptions in our scenarios move sagebrush steppe closer to historical conditions and may improve habitat for a variety of species, but a strategy more focused on individual species such as sage grouse would likely provide better conditions for those species. A more focused strategy, however, would not necessarily meet the restoration needs of other ecosystem components.

Conclusions

Our results suggest that the restoration of sagebrush steppe will require application at monumental spatial and temporal scales if downward trends are to be slowed or reversed. Although sagebrush steppe on FS–BLM lands has not been altered as much as that on other lands, federal lands in this ecosystem appear to be susceptible to a dramatic acceleration in loss and degradation, illustrated by our projections for sagebrush steppe under proposed management.

Future degradation of sagebrush steppe, especially in the drier Wyoming big sagebrush types, is likely to be driven by a combination of wildfire and exotic plants. To mitigate these processes, restoration of sagebrush steppe is likely to require integration of wildfire suppression, prescribed fire, chemical and mechanical treatments, rehabilitation with desired vegetation, and reduced livestock grazing. Integration of these treatments and their effective application over large areas will require broad-scale conservation and restoration strategies. Our exploration of two restoration scenarios is a starting point for the development of broad-scale strategies that would facilitate effective recovery of the sagebrush-steppe ecosystem.

Acknowledgments

We appreciate the long-standing support of T. Quigley, Science Group Leader of the Interior Columbia Ecosystem Management Project, and T. Mills, Director of the U.S. Forest Service Pacific Northwest Research Station. R. Noss, E. Main, S. Karl, R. Graham, and two anonymous reviewers provided helpful comments on previous drafts of this paper. We especially appreciate the many rangeland scientists and managers who assisted in the development of our state and transition models. A. Miller and N. Shankar performed miraculous feats of analysis under pressure. C. McCarthy generated our map products in short order. Thanks to all of you.

Literature Cited

Billings, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. Pages 22–30 in S. B. Monsen and S. G. Kitchen, editors. Proceedings: ecology and management of annual rangelands. General technical report INT-GTR-313. U.S. Forest Service Intermountain Research Station, Ogden, Utah.

Bunting, S. C., B. M. Kilgore, and C. L. Bushey. 1987. Guidelines for prescribed burning of sagebrush-grass rangelands in the northern Great Basin. General technical report INT-231. U.S. Forest Service Intermountain Research Station, Ogden, Utah.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin **28:**967–985.

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology **8:**629–644.

Hann, W. J., J. L. Jones, M. G. Karl, P. F. Hessburg, R .E. Keane, D. G. Long, J. P. Menakis, C. H. McNicoll, S. G. Leonard, R. A. Gravenmier, and B. G. Smith. 1997. Landscape dynamics of the basin. Pages 337–1055 in T. M. Quigley and S. J. Arbelbide, technical editors. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great Basins. Volume 2. General technical report PNW-GTR-405. U.S. Forest Service Pacific Northwest Research Station, Portland, Oregon.

Hemstrom, M. A., J. J. Korol, and W. J. Hann. 2001. Trends in terrestrial plant communities and landscape health indicate the effects of alternative management strategies in the interior Columbia River basin. Forest Ecology and Management **153:**105–126.

Hessburg, P. F., B. G. Smith, S. D. Kreiter, C. A. Miller, R. B. Salter, C. H. McNicoll, and W. J. Hann. 1999. Historical and current forest and rangeland landscapes in the interior Columbia River Basin and portions of the Klamath and Great Basins. 1. Linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances. General technical report PNW-GTR-458. U.S. Forest Service Pacific Northwest Research Station, Portland, Oregon.

Holechek, J. L., R. D. Pieper, and C. H. Herbel. 1998. Range management: principles and practices. 3rd edition. Prentice Hall, Upper Saddle River, New Jersey.

Keane, R. E., D. G. Long, J. P. Menakis, W. J. Hann, and C. D. Bevins. 1996. Simulating course-scale vegetation dynamics using the Columbia River Basin succession model—CRBSUM. General technical report INT-GTR-340. U.S. Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah.

Knick, S. T. 1999. Requiem for a sagebrush ecosystem? Northwest Science **73:**53–57.

Laycock, W. A. 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. Journal of Range Management **44:**427–434.

Mack, R. N., and J. N. Thompson. 1982. Evolution in steppe with few large, hooved mammals. The American Naturalist **119:**758–773.

Marcot, B. G., M. A. Castellano, J. A. Christy, L. K. Croft, J. F. Lehmkuhl, R. H. Naney, R. E. Rosentreter, R. E. Sandquist, and E. Zieroth. 1997. Terrestrial ecology assessment. Pages 1497–1713 in T. M. Quigley and S. J. Arbelbide, editors. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great basins. General technical report PNW-GTR-405. U.S. Forest Service Pacific Northwest Research Station, Portland, Oregon.

McIver, J., and L. Starr. 2001. Restoration of degraded lands in the interior Columbia River basin: passive versus active approaches. Forest Ecology and Management **153:**15–18.

Miller, R. F., and L. L. Edelman. 2000. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Technical bulletin 151. Agricultural Experiment Station, Oregon State University, Corvallis, Oregon.

Miller, R. F., T. J. Svejcar, and N. E. West. 1994. Implications of livestock grazing in the intermountain sagebrush region: plant composition. Pages 101–146 in M. Vavra, W. A. Laycock, and R. D. Pieper, editors. Ecological implications of livestock herbivory in the West. Society for Range Management, Denver, Colorado.

Monsen, S. B. 1994. The competitive influences of cheatgrass (*Bromus tectorum*) on site restoration. Pages 43–50 in S. B. Monsen and S. G. Kitchen, editors. Proceedings: ecology and management of annual rangelands. General technical report INT-GTR-313. U.S. Forest Service Intermountain Research Station, Ogden, Utah.

Morgan, P., G. H. Aplet, J. B. Haufler, H. C. Humphries, M. M. Moore, and W. D. Wilson. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry **2:** 87–111.

Pellant, M. 1990. The cheatgrass-wildfire cycle: are there any solutions? Pages 11–17 in E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller, compilers. Proceedings: symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. General technical report INT-GTR-276. U.S. Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah.

Quigley, T. M., and S. J. Arbelbide, technical editors. 1997. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great basins. Volumes 1–4. General technical report PNW-GTR-405. U.S. Forest Service Pacific Northwest Research Station, Portland, Oregon.

Raphael, M. G., M. J. Wisdom, M. M. Rowland, R. S. Holthausen, B. C. Wales, B. G. Marcot, and T. D. Rich. 2001. Status and trends of habitats of terrestrial vertebrates in relation to land management in the interior Columbia River basin. Forest Ecology and Management **153:**63–88.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Number 425 in A. Poole and F. Gill, editors. The birds of North America. The Birds of North America, Inc., Philadelphia, Pennsylvania.

Tausch, R. J., J. C. Chambers, R. R. Blank, and R. S. Nowak. 1995. Differential establishment of perennial grass and cheatgrass following fire on an ungrazed sagebrush-juniper site. Pages 252–257 in B. A. Roundy, E. D. McArthur, J. S. Haley, and D. K. Mann, compilers. Proceedings: wildland shrub and arid land restoration symposium. General technical report INT-GTR-313. U.S. Forest Service Intermountain Research Station, Ogden, Utah.

U.S. Forest Service. 1996. Status of the interior Columbia Basin: summary of scientific findings. General technical report PNW-GTR-385. U.S. Forest Service, Pacific Northwest Research Station and U.S. Bureau of Land Management, Portland, Oregon.

U.S. Forest Service (FS) and U.S. Bureau of Land Management (BLM). 2000. Interior Columbia Basin supplemental draft environmental impact statement, BLM/OR/WA/Pt-00/019+1792. U.S. BLM, Portland, Oregon.

Van Poolen, H. W., and J. R. Lacey. 1979. Herbage response to grazing systems and stocking intensities. Journal of Range Management **32:** 250–253.

West, N. E. 1999. Managing for biodiversity of rangelands. Pages 101–126 in W. W. Collins and C. O. Qualset, editors. Biodiversity in agroecosystems. CRC Press, Boca Raton, Florida.

Westoby, M., B. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management **42:**266–276.

Wisdom, M. J., R. S. Holthausen, B. C. Wales, C. D. Hargis, V. A. Saab, D. C. Lee, W. J. Hann, T. D. Rich, M. M. Rowland, W. J. Murphy, and M. R. Eames. 2000. Habitats for terrestrial vertebrates of focus in the interior Columbia Basin: broad-scale trends and management implications. General technical report PNW-GTR-485. U.S. Forest Service Pacific Northwest Research Station, Portland, Oregon.

Wisdom, M. J., M. M. Rowland, B. C. Wales, M. A. Hemstrom, W. J. Hann, M. G. Raphael, R. S. Holthausen, R. G. Gravenmier, and T. D. Rich. 2002. Modeled effects of sagebrush-steppe restoration on Greater Sage-Grouse in the interior Columbia Basin, U.S.A. Conservation Biology **16:**1223–1231.

Young, J. A., and R. A. Evans. 1970. Invasion of medusahead into the Great Basin. Weed Science **18:**89–97.