Modeled Effects of Sagebrush-Steppe Restoration on Greater Sage-Grouse in the Interior Columbia Basin, U.S.A.

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Abstract: *Habitats of Greater Sage-Grouse (*Centrocercus urophasianus*) have declined across western North America, and most remaining habitats occur on lands administered by the U.S. Forest Service (FS) and U.S. Bureau of Land Management (BLM). Consequently, managers of FS-BLM lands need effective strategies to recover sagebrush (*Artemisia *spp.) habitats on which this species depends. In response to this need, we evaluated the potential benefits of two restoration scenarios on Greater Sage-Grouse in the interior Columbia Basin and adjacent portions of the Great Basin of the western United States. Scenario 1 assumed a 50% reduction in detrimental grazing effects (through changes in stocking rates and grazing systems) and a sixfold increase in areas treated with active restoration (e.g., prescribed burning, native seedings, wildfire suppression) compared with future management proposed by the FS-BLM. Scenario 2 assumed a 100% reduction in detrimental grazing effects and the same increase in active restoration as scenario 1. To evaluate benefits, we estimated the risk of population extirpation for sage grouse 100 years in the future under the two scenarios and compared this risk with that estimated for proposed (100-year) FS-BLM management. We used estimates of extirpation risk for historical (circa 1850–1890) and current time periods as a context for our comparison. Under historical conditions, risk of extirpation was very low on FS-BLM lands, but increased to a moderate probability under current conditions. Under proposed FS-BLM management, risk of extirpation on FS-BLM lands increased to a high probability 100 years in the future. Benefits of the two restoration scenarios, however, constrained the future risk of extirpation to a moderate probability. Our results suggest that expansive and sustained habitat restoration can maintain desired conditions and reduce future extirpation risk for sage grouse on FS-BLM lands in western North America. The continued spread of exotic plants, however, presents a formidable challenge to successful restoration and warrants substantial research and management attention.*

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Efectos Modelados de la Restauración de la Estepa Artemisa sobre Urogallos en el Interior de la Cuenca del Columbia, E.U.A.

Resumen: *Los hábitats del urogallo (*Centrocercus urophasianus*) han disminuido a lo largo de la región occidental de Norteamérica, y la mayoría de los hábitats restantes ocurren en terrenos administrados por el Servicio Forestal de E.U.A. (SF) y el Buró de Administración de Tierras (BAT). Por lo tanto, los encargados de las tierras SF-BAT necesitan estrategias eficaces para recuperar los hábitats de artemisa (*Artemisia *spp.) de los cuales depende esta especie. En respuesta a esta necesidad, evaluamos los beneficios potenciales de dos escenarios de restauración sobre el urogallo en el interior de la Cuenca del Columbia y porciones adyacentes de la Gran Cuenca del occidente de los Estados Unidos. El escenario 1 supone una reducción del 50% en los efectos perjudiciales del pastoreo (por medio de cambios en las tasas de aprovisionamiento y en los sistemas de pastoreo) y un incremento de seis veces en la superficie de las áreas tratadas con restauración activa (por ejemplo, quemas prescritas, plántulas nativas, supresión de fuego no controlado) comparada con la administración futura propuesta por el SF-BAT. El escenario 2 supone una reducción del 100% en los efectos de pastoreo perjudiciales y el mismo aumento en la restauración activa que en el escenario 1. Para evaluar los beneficios, estimamos el riesgo de extirpación de la población de urogallos en 100 años bajo los dos escenarios y comparamos este riesgo con el riesgo estimado por la propuesta de manejo de SF-BAT (100-años). Utilizamos estimaciones del riesgo de extirpación en períodos históricos (entre 1850 y 1890) y actuales como contexto para nuestra comparación. Bajo condiciones históricas, el riesgo de extirpación fue muy bajo en los terrenos SF-BAT pero aumentó a una probabilidad moderada bajo condiciones actuales. Bajo la administración propuesta por SF-BAT, el riesgo de extirpación en los terrenos SF-BAT aumentó a una alta probabilidad 100 años en el futuro. Sin embargo, los beneficios de los dos escenarios de restauración constriñen el riesgo de extirpación a una probabilidad moderada. Nuestros resultados sugieren que la restauración expansiva y sostenida del hábitat puede mantener condiciones deseadas y reduce el riesgo de extirpación de urogallos en terrenos SF-BAT en la región occidental de Norteamérica. Sin embargo, la continua extensión de plantas exóticas representa un reto formidable para la restauración exitosa y justifica considerable investigación y atención de manejo.*

Introduction

Habitats and populations of Greater Sage-Grouse (*Centrocercus urophasianus*) have declined throughout western North America (Connelly & Braun 1997; Schroeder et al. 1999). Causes for declines are related to a variety of human activities, such as conversion of habitats to agricultural and urban uses, changes in fire regimes and fire management, livestock grazing, and invasion of exotic vegetation (Beck & Mitchell 2000; Miller & Eddleman 2000; Wisdom et al. 2000). Altered climate is also a potential problem (Tausch et al. 1995; Miller & Eddleman 2000). In response to these problems, the U.S. Fish and Wildlife Service recently found as warranted a petition to list the Washington population of Greater Sage-Grouse as threatened or endangered under the U.S. Endangered Species Act, and petitions to list other populations may be forthcoming (Connelly et al. 2000).

Range-wide declines of sage grouse reflect similar trends in the interior Columbia Basin and adjacent portions of the Great Basin (referred to as the basin), where habitats have declined approximately 30% (Wisdom et al. 2000) and populations have been extirpated in >40% of subwatersheds (Wisdom et al. 2002 [this issue]). Corollary to these declines are the negative effects of proposed management projected for other vertebrate species that depend on sagebrush (*Artemisia* spp.) steppe in the basin (Raphael et al. 2001). These effects were associated with three management alternatives proposed in the Supplemental Draft Environmental Impact Statement (SDEIS; U.S. Forest Service [FS] & U.S. Bureau of Land Management [BLM] 2000) of the Interior Columbia Basin Ecosystem Management Project (ICBEMP). Most species that depend on sagebrush steppe, including sage grouse, had a high probability of local or basin-wide extirpation under proposed management (Raphael et al. 2001).

The premise of the SDEIS alternatives was to restore or maintain ecosystem health and provide sustainable fish, wildlife, and native plant communities in the basin. The preferred alternative (proposed management) emphasized restoration activities to maintain or recover a variety of diverse resources to the extent that restoration funding would allow. A second alternative also emphasized restoration activities, at a higher level than the preferred alternative, but with fewer requirements for strategic planning of the activities. A third alternative called for continuation of current land uses and provided a context for evaluating the potential benefits and effects of the other two alternatives in relation to current management.

Proposed restoration activities in the SDEIS alternatives focused on forest environments, where pathways of vegetative succession remain largely intact, and the probability of restoration success was high (U.S. FS & U.S. BLM 2000). Less emphasis was placed on restoration of arid rangelands, particularly in lower-elevation, drier sites dominated by sagebrush, where restoration potential was limited by budget constraints, trade-offs with other objectives, and uncertainties about effectiveness (U.S. FS & U.S. BLM 2000). Consequently, we evaluated the potential benefits of increased habitat restora-

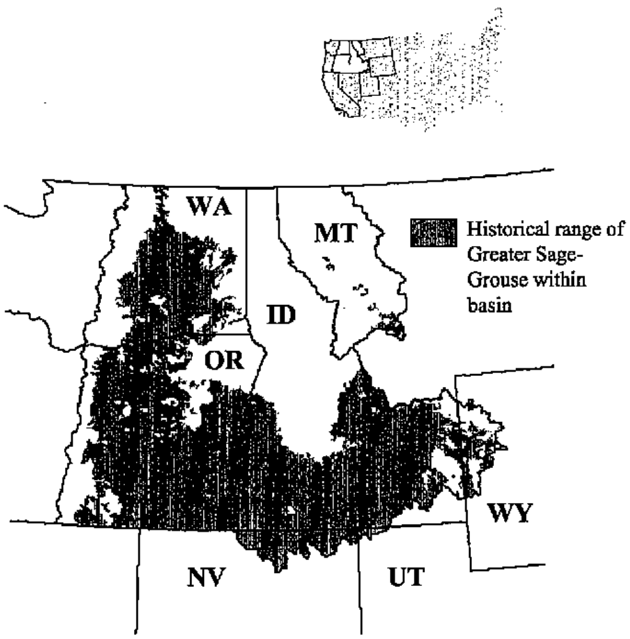

Figure 1. Interior Columbia Basin assessment area in the western United States, encompassing eastern Washington (WA), eastern Oregon (OR), most of Idaho (ID), northwest Montana (MT); adjacent areas of northwest Wyoming (WY), northwest Utah (UT), and northern Nevada (NV); and the historical range of Greater Sage-Grouse in the basin.

tion for sage grouse in the basin to understand the degree to which the negative effects associated with the SDEIS alternatives on sagebrush-steppe species might be lessened or mitigated.

The 58 million–ha basin encompasses a major portion of the current and historical range of Greater Sage-Grouse (Fig. 1; Wisdom et al. 2002 [this issue]). Proposed management of the basin's sagebrush steppe will therefore have extensive effects on sage grouse and other sagebrush obligates. Thus, our goals were to (1) summarize the historical, current, and future conditions projected for Greater Sage-Grouse from a previous study within the basin (Raphael et al. 2001); (2) compare these conditions with those projected under two sagebrush-steppe restoration scenarios; and (3) place the results in the appropriate biological context for management of sage grouse, particularly in terms of future risk of extirpation.

Methods

Restoration Modeling

We used two Bayesian belief network models (Lee 2000; Marcot et al. 2001) to evaluate the potential benefits of sagebrush-steppe restoration on Greater Sage-Grouse. These models use conditional probabilities to predict the combined effects of multiple input nodes (multiple predictor variables) on the probability of a response, or output node (Raphael et al. 2001). The models combine hypothesized and empirical relations, reflect sources of variation and uncertainty expressed through the probabilities, and can be validated with a variety of methods, including Bayesian statistics (Lee 2000; Marcot et al. 2001).

Our first model, called the environmental index model, was used to estimate the capability of the environment to support a population of sage grouse in a given subwatershed (Raphael et al. 2001). Subwatersheds in the basin have a mean size of approximately 7800 ha, with >3000 subwatersheds underlying the historical range of sage grouse in the basin. The second model, called the population outcome model, used the composite results from the environmental index model and measures of range extent and connectivity to assess the abundance and distribution of habitats and populations in terms of risk of extirpation. Raphael et al. (2001) developed the two models to project landscape conditions for sage grouse during historical (circa 1850–1890) and current periods and 100 years in the future under proposed FS–BLM management (U.S. FS & U.S. BLM 2000).

The environmental index model for sage grouse (Wisdom et al. 2002 [this issue]) consisted of five input nodes: (1) habitat density, (2) historical range of variability (HRV) departure, (3) uncharacteristic grazing, (4) road density, and (5) human population density (for more detail about input nodes, see Table 1 of Wisdom et al. 2002 [this issue]). The input of habitat density was an estimate of habitat quantity, whereas the other four inputs indexed the quality of these habitats (Wisdom et al. 2002 [this issue]). Habitats defined and used in this model consisted primarily of low to medium-height shrublands in big sagebrush (*Artemisia tridentata* ssp . *tridentata* and *wyomingensis*), mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), and low sagebrush (*A. arbuscula*) communities (Wisdom et al. 2000).

Environmental index values generated from the model ranged from 0 to 2 and were classified as follows: >1, high; >0.1 but ≤1, low; and ≤0.1, zero (Raphael et al. 2001). Values at or near 0 were associated with areas of extirpation, whereas values closer to or above 1.0 were associated with areas currently occupied by sage grouse (Wisdom et al. 2002 [this issue]).

We combined results from the environmental index model with measures of range extent and connectivity in a population outcome model to assess the basin-wide distribution and abundance of sage grouse habitats and populations and to infer the risk of regional population extirpation (Wisdom et al. 2002 [this issue]). The population outcome model had three input nodes: (1) habitat capacity, (2) range extent, and (3) connectivity (Table 1 of Wisdom et al. 2002 [this issue]).

The population outcome model generated two outputs, the environmental outcome and the population outcome. The environmental outcome was an estimate of the distribution and abundance of suitable environments for sage grouse on FS-BLM lands. Environmental outcome was defined with five classes (A through E) that represented a gradient from continuous, well-distributed environments (outcome A) to sparse, highly isolated environments unlikely to support a viable population (outcome E) (Wisdom et al. 2002 [this issue]).

The second output, population outcome, was projected as a similar set of five outcome classes (A through E) that indexed the population viability of sage grouse on all lands. Definitions of population outcome classes were similar to those for environmental outcome, with the same five classes of A through E. Population outcomes were expressed in terms of the potential abundance and distribution of populations, however, in contrast to the characterization of abundance and dis- tribution of suitable environments that were defined under the environmental outcomes (Wisdom et al. 2002 [this issue]). The population outcome model also generated an expected value, which was the sum of the products of the probability of each outcome class and its numerical value. Numerical values of 1 through 5 were assigned to outcomes A through E, respectively, for classes of both the environmental outcome and the population outcome.

For sage grouse, the only difference between projections of environmental outcome and those of population outcome was the land base on which the projections were made. We projected the environmental outcome for FS-BLM lands to focus on changes in environmental conditions in response to the FS-BLM restoration scenarios. In contrast, population outcome was calculated on all lands and reflected the contribution of environmental outcome on FS-BLM lands as well as on other lands. Differences in the environmental outcome on FS-BLM lands versus the population outcome on all lands therefore reflected the degree to which FS-BLM management influences the overall population of sage grouse. For example, an environmental outcome of class B on FS-BLM lands versus a population outcome of class C on all lands indicates substantially better conditions and a lower probability of extirpation on FS-BLM lands versus the other lands that contribute to population outcome.

Based on the evaluation of the sage-grouse model's performance by Wisdom et al. (2002 [this issue]), we inferred varying degrees of risk of regional extirpation in association with the classes of environmental and population outcomes. Regional extirpation was defined as the loss of sage-grouse populations in areas encompassing substantial portions of the species' historical range in the basin, such as a subbasin or an ecological province. Such areas typically exceed 400,000 ha (see descriptions of subbasins and ecological reporting units by Hann et al. 1997). Outcome A was considered to represent a very low risk of regional extirpation, followed by low (outcome B), moderate (outcome C), high (outcome D), and very high (outcome E) degrees of risk.

These levels of risk corresponded to empirical findings of Wisdom et al. (2002 [this issue]) showing that areas of the basin historically occupied by sage grouse were associated with outcome A, whereas areas of current extirpation were associated with outcome E. Moreover, areas of the basin currently occupied by sage grouse have undergone an intermediate level of habitat loss and degradation between that estimated for historically occupied areas versus currently extirpated areas, and these currently occupied areas were associated with an intermediate outcome of class C (Wisdom et al. 2002 [this issue]).

Developing the Restoration Scenarios

Our goal was to evaluate the benefits of dramatically increasing the extent and intensity of restoration in sagebrush steppe to determine the potential to improve environmental and population outcomes for sage grouse and reduce the risk of extirpation compared to that under proposed management. Accordingly, Hemstrom et al. (2002 [this issue]) developed two restoration scenarios that substantially increased the combination of passive and active restoration of sagebrush steppe within the historical range of sage grouse in the basin. Hemstrom et al. (2002 [this issue]) defined passive restoration as "the process of modifying or eliminating existing management activities (e.g., livestock grazing, roads, or recreation) that contribute to environmental degradation of desired resources." In contrast, Hemstrom et al. (2002 [this issue]) defined active restoration as "the application of treatments that contribute to recovery of targeted resources (e.g., appropriate use of wildfire suppression, prescribed fire, or seeding with native plants)."

The two scenarios targeted increased levels of restoration in relation to proposed management because of managers' desire to understand the magnitude by which sagebrush habitats could be improved relative to what was originally proposed. Scenario 1 assumed a 50% reduction in detrimental grazing effects by livestock as the main form of passive restoration. To achieve this reduction, a like reduction in the stocking rate of livestock was assumed in combination with additional positive changes in livestock grazing systems (e.g., increasing rest periods in rest-rotation systems; Hemstrom et al. 2002 [this issue]). This form of passive restoration was applied to 6.4 million ha of FS-BLM lands that has the potential to be sage-grouse habitat or that currently serve as habitat (referred to as potential sage grouse habitat).

Active restoration under scenario 1 was then integrated with passive restoration on the same 6.4 million ha of potential sage grouse habitat (Hemstrom et al. 2002 [this issue]). In contrast, active restoration under proposed management targeted approximately 1.1 million ha of potential sage grouse habitat. Thus, scenario 1 represented a sixfold increase in areas treated with active restoration beyond that identified in proposed management. Key forms of active restoration included seedings and plantings of desired vegetation, particularly after fire events; wildfire suppression in vegetation types where such fires would facilitate invasion of exotic plants; prescribed fire in vegetation types where such fires would reduce woodland encroachment; and use of a variety of other chemical and mechanical treatments to control invading conifers and enhance the composition of native grasses and forbs (Hemstrom et al. 2002 [this issue]).

Restoration scenario 2 was based on a 100% reduction in detrimental grazing effects by livestock, with a like reduction in stocking rate (Hemstrom et al. 2002 [this issue]). This high level of passive restoration was integrated with the same level of active restoration assumed for scenario 1, with the same 6.4 million ha of FS-BLM lands targeted for treatment. Detailed methods, assumptions, and rationale associated with the scenarios are provided by Hemstrom et al. (2002 [this issue]).

We projected conditions under the two restoration scenarios 100 years into the future using our models, as was done for proposed management. Restoration activities for each scenario were sustained throughout the 100-year period, with the frequency, intensity, and type of each activity designed to substantially recover or maintain desired conditions (Hemstrom et al. 2002 [this issue]). Three input nodes in the environmental index model for sage grouse were targeted for improvement as part of the restoration scenarios: habitat density, HRV departure, and uncharacteristic grazing, as described in Hemstrom et al. (2002 [this issue]). Restoration activities were designed to enhance both habitat quantity, through increased habitat density, and quality, through reductions in HRV departure and uncharacteristic grazing.

Methods used to model the changes in habitat density, HRV departure, and uncharacteristic grazing under the restoration scenarios were deliberately conservative in terms of the assumed enhancements that such activities could produce (Hemstrom et al. 2002 [this issue]). We used a conservative modeling approach because of the high uncertainty of restoration outcomes in sagebrush steppe (West 1999; Hemstrom et al. 2002 [this issue]). This high uncertainty is related to incomplete knowledge of appropriate restoration methods and technologies and the logistical challenges posed by sustained and integrated application of restoration treatments across vast areas of sagebrush steppe, which to date has not been attempted (Knick 1999).

Our evaluation of the restoration scenarios was based on model inputs that were estimated at a coarse spatial resolution. For example, estimates of habitat amount from Wisdom et al. (2000) were used to populate the habitat-density node of the environmental index model, and these estimates were based on maps of 1-km^2 (100-ha) pixels whose values were summarized to the scale of the subwatershed. Data used as inputs to all other nodes were based on compositional estimates derived for each subwatershed (environmental index model) or across the species' range (population outcome model).

Similar levels of spatial resolution were used by Hann et al. (1997), Wisdom et al. (2000), Hemstrom et al. (2001), and Raphael et al. (2001) to evaluate regional conditions of sagebrush steppe for FS-BLM managers, and our evaluation was intended to build on this work with comparable methods. Our coarse spatial resolution was not intended to evaluate local areas, however, such as within-pixel conditions or small areas of sagebrush steppe within individual subwatersheds (see accuracy and limits of inference described by Hann et al. [1997] and Wisdom et al. [2000]). Consequently, we assumed that local assessments, using a finer spatial resolution, would be an effective complement to our work for local planning of restoration activities.

Restoration Effects by Land Ownership

The 6.4 million ha of potential sage-grouse habitat that was targeted under the restoration scenarios occurred within subwatersheds that contained at least 50% FS-BLM ownership and that were within the species' historical range (for details see Hemstrom et al. 2002 [this issue]). This targeted area encompassed 72% and 63% of potential sage grouse habitat on FS-BLM lands and all lands, respectively, within the species' historical range in the basin.

Results from the environmental index model were summarized in two ways to reflect the difference between the areas of restoration focus versus the entire land base that composed sage grouse habitat. One summary was for subwatersheds containing FS-BLM habitat for sage grouse which received the restoration treatments. The other summary was for habitat in all subwatersheds within the historical range of sage grouse in the basin.

Results from the population outcome model also were summarized in two ways. One summary was for subwatersheds dominated by FS-BLM lands, where the environmental outcome was reported. This summary reflected the effects of restoration on the risk of sage grouse extirpation on FS-BLM lands. The second summary was for all lands, where the population outcome was reported. The population outcome reflected the combined contribution of environmental outcome on FS-BLM lands, and that on all other lands, to the overall risk of sage grouse extirpation.

Results

Environmental Index Values

Environmental index values were higher under the two restoration scenarios than under proposed management (Figs. 2 & 3). In particular, the number of subwatersheds

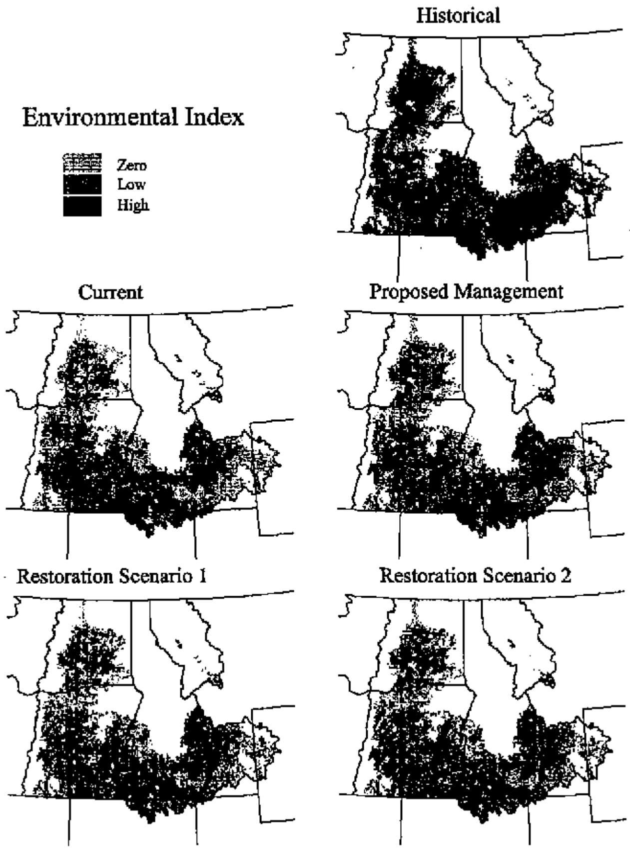

Figure 2. Categories of environmental index values for Greater Sage-Grouse on all lands within the species' historical range in the basin for historical and current time periods and 100 years in the future under proposed management and two restoration scenarios. Environmental index values ranged from 0 to 2 and were classified as follows: >1, high; >0.1 but ≤1, low; and ≤0.1, zero. Results for historical, current, and proposed management are from Raphael et al. (2001).

in the high environmental index class, which identified areas of high environmental quality, was greater under both restoration scenarios than under proposed management (Fig. 3). The number of subwatersheds in the high environmental index class under the restoration scenarios, however, was still below that estimated for the current period (Fig. 3).

Similarly, mean environmental index values for sage grouse on FS-BLM lands for scenarios 1 and 2 were 0.67 and 0.72, resembling that for the current period (0.70) but greater than the mean value of 0.46 for proposed management. These values were expressed on a scale from 0 to 2, with values at or near 0 associated with areas of extirpation, and values closer to or above 1.0 associated with areas currently occupied by sage grouse. Mean environmental index values on all lands also were higher under scenarios 1 and 2 (0.45 and 0.48) than under proposed management (0.34) but were lower than the mean value for the current period (0.52).

Environmental and Population Outcomes

The environmental outcome projected for sage grouse on FS-BLM lands was class C under both restoration scenarios, indicating a moderate risk of extirpation, the same as that projected for the current period (Fig. 4). In contrast, the environmental outcome projected under proposed management was class D (Fig. 4), indicating a higher risk of extirpation on FS-BLM lands than the moderate risk projected for the restoration scenarios and current period.

Population outcome on all lands was class D under both scenarios, the same as that projected for proposed management and the current period, indicating a high risk of extirpation associated with the large percentage of lands not targeted for restoration (Fig. 4). Despite the

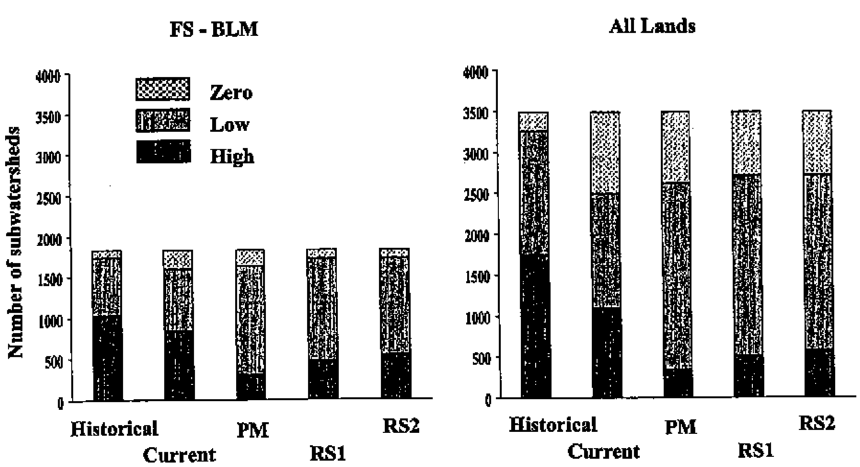

Figure 3. Number of subwatersheds on lands of the U.S. Forest Service (FS) and U.S. Bureau of Land Management (BLM) and all lands (basin) with zero, low, and high categories of environmental index for Greater Sage-Grouse within the species' historical range in the basin for historical and current periods and 100 years in the future under proposed management (PM) and two restoration scenarios (RS1 and RS2). Environmental index values ranged from 0 to 2 and were classified as follows: >1, high; >0.1 but ≤1, low; and ≤0.1, zero. Historical, current, and PM results are from Raphael et al. (2001).

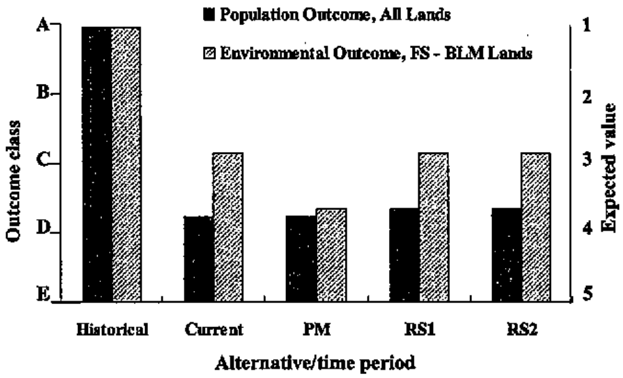

Figure 4. Expected values and classes of environmental outcomes and population outcomes projected for Greater Sage-Grouse for historical and current periods and 100 years in the future under proposed management (PM) and two restoration scenarios (RS1 and RS2). Results for environmental outcomes are for lands of the U.S. Forest Service (FS) and U.S. Bureau of Land Management (BLM). Results for population outcomes are for all lands. Historical, current, and PM results are from Raphael et al. (2001).

lack of improvement in class of population outcome under the restoration scenarios compared with proposed management, the probability of a class C population outcome was 0.35 under the restoration scenarios versus 0.23 under proposed management and the current period (on a probability scale from 0.0 to 1.0).

Improvements in environmental outcome for sage grouse under the restoration scenarios were due primarily to improvements to the input node of habitat capacity, which reflected the composite effect of increased environmental index values across the subwatersheds compared with those of proposed management. Habitat capacity on FS-BLM lands increased to 43% and 47% under scenarios 1 and 2, respectively, as opposed to 30% under proposed management (on a scale from 0 to 100%).

Discussion

Restoration Effects

Our results indicate that an extensive and sustained combination of passive and active restoration, as outlined under the two restoration scenarios, would minimize further degradation and loss of habitat for sage grouse on FS-BLM lands in the future. As a result, the restoration scenarios would constrain the increased risk of population extirpation associated with proposed management of FS-BLM lands, as evidenced by the environmental outcome of class C for the restoration scenarios versus a class D for proposed management.

Our results also indicate that areas not targeted for restoration would not recover in the future, or would continue to undergo degradation (also see Hemstrom et al. 2002 [this issue]). For example, a large percentage (37%) of potential sage-grouse habitat was not targeted for restoration under our scenarios. In the absence of restoration, these areas will continue to be overrun by cheatgrass (*Bromus tectorum*) and other exotic plants (Hemstrom et al. 2002 [this issue]) or continue to be used for agriculture or other land-management activities that do not provide habitat.

Continued degradation of lands not targeted for restoration resulted in a population outcome of class D for both the restoration scenarios and proposed management. A major implication of this finding is that restoration efforts must be applied to a larger land base than was targeted under our restoration scenarios if the objective is to reduce future risks posed by a variety of habitat threats across the species' range (for a summary of threats, see Wisdom et al. 2002 [this issue]). Additional restoration, however, would need to target portions of sage grouse range that are of mixed ownership (federal and nonfederal lands), posing logistical challenges that could inhibit success. The benefits and feasibility of this additional restoration on mixed ownership would require new analysis beyond that conducted under our restoration scenarios.

Another implication is the possibility that habitat improvements under restoration may require more than 100 years (Knick 1999). This implication may be particularly relevant to lower-elevation, drier habitats dominated by Wyoming big sagebrush, which do not respond quickly to restoration activities (Miller & Eddleman 2000) and which compose >60% of current sage grouse habitat in the basin (Hemstrom et al. 2002 [this issue]).

Our assumptions about the effectiveness of restoration treatments were deliberately conservative (Hemstrom et al. 2002 [this issue]). With a refined analysis, using more liberal modeling assumptions and more area treated, additional restoration benefits would be realized. Nonfederal lands, which represent approximately 50% of the historical habitat for sage grouse within its historical range in the basin, could also be included as part of additional restoration analysis, along with the FS-BLM habitat that was not included as part of our restoration scenarios. This additional analysis would provide insight into the potential to improve population outcome under dual restoration of federal and nonfederal lands.

Local variation in the potential to restore desired attributes of sage grouse habitat must also be considered at smaller scales than the regional scale used for our analysis (Hemstrom et al. 2002 [this issue]). This local variation could not be addressed as part of our scenarios, owing to the coarse spatial resolution of our data. Effective consideration of local variation in plant response to restoration activities may also improve the prospects for successful restoration beyond that modeled in our projections.

Although additional analyses would provide further insight into restoration potential, our scenarios represent one of the largest, most intensive combinations of restoration treatments ever modeled and evaluated for sagebrush steppe, and far exceed the restoration occurring or planned in this ecosystem. An important question that remains, however, is the degree to which the ecological potential for restoring sagebrush steppe has been reduced by establishment of exotic plants.

Ecological Potential for Restoration

West (1999) estimated that up to 50–60% of the historical sagebrush steppe in western North America may have been changed to vegetative states dominated by undesirable exotic plants, which cannot be altered to desired native states with current knowledge and technology. The state and transition models used to project sage-grouse habitats for our analysis also reflect a conservative view of restoration potential (Hemstrom et al. 2002 [this issue]), but our model projections appear more optimistic than the views of West (1999).

For example, our projections indicate that a substantial reduction in the stocking rate of livestock, coupled with active fire suppression and exotic weed management, would restore native grasses and forbs to the understory of sagebrush steppe in 30–50 years (Hemstrom et al. 2002 [this issue]). This improvement is reflected in the substantial decline in HRV departure and uncharacteristic grazing projected by Hemstrom et al. (2002 [this issue]) and in the subsequent improvement in environmental index values under the two restoration scenarios compared with those of proposed management. Restoration of native grasses and forbs to the understory of sagebrush steppe is notable because this understory is a key requirement for successful nesting and brood rearing by sage grouse (Edelmann et al. 1998; Schroeder et al. 1999; Connelly et al. 2000).

Despite the success projected for restoring native grasses and forbs in the understory of sagebrush stands, the formidable challenge of restoring areas dominated by exotic plants may limit the success of future efforts to restore sagebrush steppe at regional scales (Knick 1999; West 1999). This limit, or the degree to which the ecological potential for restoration of sagebrush steppe has been reduced by exotic plants, is perhaps the most compelling research topic in need of further attention at regional scales at which the requirements of sage grouse population viability must be considered.

Model Reliability and Implications

Raphael et al. (2001) identified sources of uncertainty and issues of reliability associated with the use of Bayesian belief network models to assess conditions for upland vertebrates in the basin. Although validation tests suggest that our sage-grouse models provide reliable predictions for current conditions (Wisdom et al. 2002 [this issue]), future projections under our restoration scenarios and proposed management cannot be validated. Consequently, the sources of uncertainty and issues of reliability listed by Raphael et al. (2001) must be considered in the careful and appropriate interpretation of our future projections. These sources of uncertainty point to the need for landscape research on populations and habitats of sage grouse to improve the reliability of future projections at regional scales of the species' range.

Despite questions about future conditions, our estimates of environmental and population outcomes for the current period indicate that sage grouse habitats and populations in the basin are substantially degraded. Extensive habitat and population declines have occurred, resulting in fragmented, isolated environments and populations. These modeled effects agree with empirical data about the status and trends of sage grouse populations in western North America (Connelly & Braun 1997; Schroeder et al. 1999) and the associated widespread loss of habitat (Braun 1998). Moreover, the many causes of extensive habitat decline include the invasion of exotic plants, grazing by livestock, changes in fire regimes, and lack of rehabilitation with native vegetation (Braun 1998; Schroeder et al. 1999). These particular causes are especially pertinent for FS-BLM managers because such causes continue to play key roles on federal rangelands (Hann et al. 1997).

Restoration Experiments and Management Implications

Restoration management is a relatively new field, fraught with uncertainties of knowledge and challenges to effective implementation (McIver & Starr 2001). Restoration of sagebrush steppe is particularly uncertain and challenging, given the slow and varied response of vegetation to positive treatments under such arid conditions (Tausch et al. 1995). These uncertainties and challenges can be addressed through regional experiments, designed as an adaptive management process between scientists and managers (e.g., as described by Walters 1986). Local restoration efforts, without coordination and implementation across large areas as an adaptive management experiment, appear to have a low probability of improving population outcomes for sage grouse in the basin; this is due to the vast areas over which restoration must occur and the comprehensive, integrated manner in which a suite of restoration treatments must be implemented (Knick 1999).

Extensive and sustained restoration of sagebrush steppe is fundamental to improving landscape conditions for sagebrush obligates such as sage grouse. Long-term restoration strategies, developed at regional scales and designed and implemented as restoration experiments, would provide a reliable basis for improving the probability of effective recovery of sagebrush steppe. Our results provide a framework and starting point for designing such landscape strategies to restore habitat for sage grouse and other species that depend on the sagebrush-steppe ecosystem.

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