APPENDIX A

GrSG STRUCTURAL HABITAT GUIDELINES

Greater Sage-Grouse Structural Habitat Guidelines

Guidelines for the maintenance of sage-grouse habitats were first provided by Braun et al. (1977). Subsequent research improved knowledge about the seasonal habitat use, movements, and migratory patterns of sage-grouse across their range. Connelly et al. (2000*c*) built upon those findings and developed more specific habitat guidelines for the structural characteristics of the overstory and understory of sagebrush communities used by sage-grouse. As Connelly et al. (2000*c*:275) mentioned, "…judgment of local biologists and quantitative data from population and habitat monitoring are necessary to implement the guidelines correctly." Connelly et al. (2000*c*) only referenced 1 Colorado study (a total of 16 studies across the west) for breeding habitat, and 3 (a total of 9) for winter habitat guidelines. Although Connelly et al. (2000*c*) improved the 1977 recommendations (Braun et al. 1977), information was lacking regarding habitat requirements for Colorado GrSG.

GrSG in Colorado inhabit the Wyoming Basin and Colorado Plateau floristic provinces. These provinces are distinctly different from a majority of the floristic provinces where data reported in Connelly et al. (2000*c*) were collected. Connelly et al. (2000*c*) reported grass and big sagebrush cover values from floristic provinces other than the Colorado Plateau and Wyoming Basin including the Columbia Basin, Northern Great Basin, Snake River Plain, and Silver Sagebrush provinces. Each floristic province has sometimes slightly, and sometimes significantly, different soils with differing geologic origins and precipitation patterns, which can impact a province's productivity and resulting plant community. Connelly et al. (2000*c*) used some habitat data from Colorado for breeding (Peterson 1980) and winter (Beck 1977, Schoenberg 1982, Hupp 1987), although Hupp's data (1987) were specific to the Gunnison Basin and GuSG winter habitat. Since Connelly et al. (2000*c*) developed the guidelines, additional information (Gill 1965, Peterson 1980, Schoenberg 1982, Remington 1983) has been identified and new reports (Hagen 1999, Hausleitner 2003, Graham and McConnell 2004, Graham and Jones 2005, Rossi and Jones 2007) have been developed. In addition, some of the information is so new (spring and summer 2006) the data have only been recently summarized for this plan and have not been included in a formal report (A.D. Apa, CDOW, personal communication).

In developing these habitat guidelines, we summarized only Colorado GrSG habitat use data that spanned 41 years (1965 – 2006). Breeding habitat information includes nest and brood-rearing habitat data. None of the studies divided brood-rearing habitat into early or late-brood-rearing, therefore all of the brood habitat information was included into breeding habitat. Summer/late-brood-rearing data included non-brooding female and male habitat use data. None of the studies was separated by annual precipitation. Some studies were conducted during very wet periods (mid-1980s) and some were conducted during very dry periods (2001-2003).

Seasonal Habitat Definitions

Until seasonal GrSG habitats are mapped in a given population area (see "Habitat Monitoring" strategy, pg. 354) the following definitions of seasonal habitats should be used (see Appendix B, "GrSG Disturbance Guidelines"). For additional limiting criteria, such as slope or aspect, consult with local biologists.

Breeding Habitat – sagebrush communities delineated within 4 miles of an active strutting ground (Appendix B, Fig. B-1). Breeding habitat includes active strutting grounds, and nesting and early brood-rearing habitat (Connelly et al. 2000*c*), usually in use from March through July.

None of the studies we reviewed for GrSG breeding habitat structural guidelines divided brood-rearing habitat into early- or late-brood-rearing, so all of the brood habitat information was included in breeding habitat. The data summary to develop the guidelines for breeding habitat was done without respect to nest success, so data from both successful and unsuccessful nests were used. Although data have been presented that suggest herbaceous vegetation might differ between successful and unsuccessful GrSG nests (Connelly et al. 2004), no consistent differences have been reported. There is, in fact, more conclusive and consistent evidence that shrub structure characteristics (i.e., horizontal and vertical cover values) differ between successful and unsuccessful nests (Connelly et al. 2004). For the breeding structural habitat guidelines we used habitat use data from Gill (1965), Peterson (1980), Schoenberg (1982), Hausleitner (2003), Graham and McConnell (2004), Graham and Jones (2005), Beck et al. (2006), Rossi and Jones (2007), and A.D. Apa (CDOW, personal communication).

Summer-Fall Habitat: vegetation communities including sagebrush, agricultural fields, and wet meadows (Connelly et al. 2000*c*) that are within 4 miles of an active strutting ground.

For summer-fall guidelines we used habitat use data from Schoenberg (1982), Hagen (1999), Graham and McConnell (2004), Graham and Jones (2005), Rossi and Jones (2007), and A.D. Apa (CDOW, personal communication).

Winter Habitat: sagebrush areas (Connelly et al. 2000*c*) within currently occupied habitat that are available (i.e., not covered by snow) to sage-grouse in average winters. These areas either have sufficient shrub height to be above average snow depths, or are exposed due to topographic features (e.g., windswept ridges, south-facing slopes). Winter habitat data were summarized from Schoenberg (1982), Remington (1983), and Hagen (1999).

Habitat Guideline Development

Where possible, study areas in the studies evaluated were categorized as arid or mesic. As per Connelly et al. (2000*c*), arid and mesic sites can be determined locally, using precipitation and soil characteristics (Tisdale and Hironaka 1981, Hironaka 1983, Winward 2004, Monsen 2005). We classified data from North Park and parts of Moffat County (excluding Cold Springs Mountain) as arid. We classified data from Cold Springs Mountain of Moffat County, NESR, and PPR as mesic. Most of the data reported were in the form of means and standard errors. The mean and standard error for each structural variable were summarized for arid or mesic sites across the entire range of GrSG in northwestern Colorado. The means were bounded by the standard errors to create a variable "distribution range" and the guideline was developed using the distribution range. Numerical maximum and minimum data points were considered but not included. The guideline range is compared with Connelly et al. (2000*c*).

Eight overstory and understory vegetation structural characteristic guidelines for GrSG breeding and summer-fall habitats are reported: (1) sagebrush canopy cover; (2) non-sagebrush canopy cover; (3) total shrub cover; (4) sagebrush height; (5) grass cover; (6) forb cover; (7) grass height; (8) forb height. Only 2 overstory vegetation structural characteristics guidelines were developed for winter habitat: (1) sagebrush cover, and (2) sagebrush height.

The use of "big sagebrush" is used generically in this guideline. Refer to Winward (2004) for the species or subspecies of big sagebrush for a specific location. Many species of shrubs were included in non-sagebrush canopy cover portion of the guideline. In more arid locations, the non-sagebrush shrubs can include, but are not limited to, horsebrush (*Tetradymia canescens*), rabbitbrush (*Chrysothamnus* spp.), bitterbrush (*Purshia tridentata*), snakeweed (*Gutierrezia sarothae*), greasewood (*Sarcobatus vermiculatus*), and winterfat (*Ceratoides* spp.). In mesic locations the aforementioned shrub species can occur but the shrub community can be augmented by Gambel oak (*Quercus gambelii*), snowberry (*Symphoriocarpus oreophilus*), serviceberry (*Amelanchier* spp.), and chokecherry (*Prunus* spp.). In addition, understory and overstory plant species may have a varying degrees of value as cover and/or food for sage-grouse (Appendix D, Table D-6).

Using the Guidelines

The vegetation structure guidelines we present (Tables A-1, A-2, and A-3) should be interpreted as minimum standards, and managers should strive to meet the full potential of any given site. These habitat guidelines should be considered adaptive, and interim in nature. The guidelines were developed from actual grouse use sites, but should be considered as guidance and not absolute values. We encourage the development of a rigorous mapping protocol so that these guidelines can be refined and used in specific breeding, summer-fall, and winter habitats. These guidelines are intended to represent a variety of landscape situations. Landscapes are diverse; some areas on the landscape will not meet theses guidelines, some areas will meet the guidelines, and some areas will exceed the guidelines. As new information is collected, these guidelines, as well as this plan are meant to be adaptable. Understories and overstories can include many plant species that have value as cover and/or food to GrSG (see Table D-6 in Appendix D).

Table A-1. GrSG structural habitat guidelines: breeding habitat.

GREATER SAGE-GROUSE STRUCTURAL HABITAT GUIDELINES

BREEDING HABITAT[a]				
	Greater Sage-Grouse (Colorado)		Connelly et al. (2000*c*)	
Vegetation Variable	**Arid[b]**	**Mesic[b]**	**Arid**	**Mesic**
Sagebrush Canopy (%)[c]	15 – 30	20 – 30	15 - 25	15 – 25
Non-sagebrush Canopy (%)[c]	5 – 10	5 – 10	-	-
Total Shrub Canopy (%)[c]	20 – 40	25 – 40	-	-
Sagebrush Height (cm)	30 – 60 [11.8 – 23.6 inches]	40 – 60 [15.7 – 23.6 inches]	30 – 80 [11.8 – 31.5 inches]	40 – 80 [15.7 – 31.5 inches]
Grass Cover (%)[d]	10 – 20	20 – 40	-	-
Forb Cover (%)[d]	5 – 15	15 – 30	≥ 15	≥ 25
Grass Height (cm)[e]	15 – 20 [5.9 – 7.9 inches]	15 – 25 [5.9 – 9.8 inches]	> 18 [> 7.1 inches]	> 18 [> 7.1 inches]
Forb Height (cm)[e]	5 – 15 [2.0 – 5.9 inches]	10 – 15 [3.9 – 5.9 inches]	-	-

[a]Breeding habitat is defined as sagebrush communities delineated within 4 miles of a strutting ground. Breeding habitat includes strutting, nesting and early brood-rearing habitat usually from mid-March through late-June.
[b]Arid or mesic communities are as defined by Winward (2004).
[c]Canopy cover measured according to Canfield (1941) and further described by Connelly et al. (2003*b*).
[d]Understory cover measured according to Daubenmire (1959).
[e] Measured as the tallest vertical point where the bulk of the plant mass occurs regardless if the mass occurs in the leafy portion of the plant or in the inflorescence (see Appendix C, "Sage-grouse Habitat Monitoring Protocol").

Table A-2. GrSG structural habitat guidelines: summer-fall habitat.

SUMMER-FALL HABITAT[a]				
	Greater Sage-Grouse (Colorado)		Connelly et al. (2000*c*)	
Vegetation Variable	**Arid[b]**	**Mesic[b]**	**Arid**	**Mesic**
Sagebrush Canopy (%)[c]	10 – 25	10 – 25	10 – 25	10 – 25
Non-sagebrush Canopy (%)[c]	5 – 10	5 – 15	-	-
Total Shrub Canopy (%)[c]	20 – 35	20 – 40	-	-
Sagebrush Height (cm)	30 – 65 [11.8 – 25.6 inches]	35 – 70 [13.8 – 27.6 inches]	40 – 80 [15.7 – 31.5 inches]	40 – 80 [15.7 – 31.5 inches]
Grass Cover (%)[d]	10 – 30	15 – 40	-	-
Forb Cover (%)[d]	5 – 15	10 – 25	> 15	> 15
Grass Height (cm)[e]	10 – 15 [3.9 – 5.9 inches]	10 – 20 [3.9 – 7.9 inches]	variable	variable
Forb Height (cm)[e]	5 – 10 [2.0 – 3.9 inches]	5 – 15 [2.0 – 5.9 inches]	variable	variable

[a]Summer-fall habitat is defined as those habitats that provide food and cover late in the summer when breeding habitat desiccates. These habitats include higher elevation mixed shrub communities, wet meadows, riparian areas and irrigated pasture crops that grouse inhabit from July through September. Grouse can move several kilometers to these habitats.
[b]Arid or mesic communities are as defined by Winward (2004).
[c]Canopy cover measured according to Canfield (1941) and further described by Connelly et al. (2003*b*).
[d]Understory cover measured according to Daubenmire (1959).
[e] Measured as the tallest vertical point where the bulk of the plant mass occurs regardless if the mass occurs in the leafy portion of the plant or in the inflorescence (see Appendix C, "Sage-grouse Habitat Monitoring Protocol").

Table A-3. GrSG structural habitat guidelines: winter habitat.

WINTER HABITAT[a]				
	Greater Sage-Grouse (Colorado)		**Connelly et al. (2000*c*)**	
Vegetation Variable	**Arid[b]**	**Mesic[b]**	**Arid**	**Mesic**
Sagebrush Canopy (%)[c]	20 – 40	25 – 40	10 – 30	10 – 30
Sagebrush Height (cm)[d]	20 – 40 [7.9 – 15.7 inches]	25 – 40 [9.8 – 15.7 inches]	25 – 35 [9.8 – 13.8 inches]	25 – 35 [9.8 – 13.8 inches]

[a]Winter habitat is defined as sagebrush communities that are inhabited by grouse from October through February.
[b]Arid or mesic communities are as defined by Winward (2004).
[c]Canopy cover measured according to Canfield (1941) and further described by Connelly et al. (2003*b*).
[d]Measured from ground level to the tallest stem (excluding inflorescence).

APPENDIX B

GrSG DISTURBANCE GUIDELINES

GUIDELINES FOR GREATER SAGE-GROUSE PROTECTION FROM POPULATION AND HABITAT DISTURBANCE

These guidelines are designed to protect GrSG populations and habitat from human-influenced activities. They should be used in conjunction with the "Conservation Strategy" section of this plan (pg. 306), which is designed to provide strategies and approaches to address the issues in GrSG conservation. For instance, a strategy may state that a particular habitat should be avoided during a certain period, and then may refer the reader to the disturbance guidelines to clarify the season and area to be avoided. The strategy may also state that the habitat should be avoided *when technically feasible*, but the guidelines may state specifically that habitat should be avoided. This example highlights the crux of the problem when human activities must occur (from a societal perspective), and the activities can't avoid impacting sage-grouse. The guidelines indicate how to avoid or minimize impact, using the current best available science. The strategies take into account technical reality; the ideal is to follow the guidelines, but the reality is that in some cases, that may not be possible, and the strategies provide guidance for those situations. These guidelines should be updated and modified as new information about GrSG, GrSG habitat, and human-caused impacts, becomes available. **As with all guidelines, adaptive approaches should be used and the best available science should be applied when implementing these guidelines.**

We recommend readers review the entire set of guidelines to assure an understanding of how the issues and topics are addressed, especially because they may be organized differently from other guidance documents or approaches. These Disturbance Guidelines are organized into 2 relatively distinct types of disturbance. The first type of disturbance is categorized as "Habitat Disturbance", and the second is "Functional Bird Disturbance".

Habitat Disturbance includes, but is not limited to, any actions that modify or change the quality, quantity, and/or or juxtaposition of habitat (see "Habitat: Fragmentation, Quality, and Quantity", pg. 151) at the local, regional, or landscape level. Habitat Disturbance can include the modification of or change in the horizontal or vertical structure (e.g., sagebrush height or cover) of the habitat. Although new water developments and ponds in GrSG habitat are not discussed in this section, note that they should be designed to discourage mosquito production in order to minimize WNV risk to GrSG.

Functional Bird Disturbance refers to actions or features that can directly influence the survival or behavior of GrSG individuals or local populations. This type of disturbance can be illustrated by activities that may have a direct influence on bird survival (e.g., fence collision), or that may impact bird behavior, even to the point where grouse are displaced from habitat (e.g., natural gas compressor stations near leks, recreational lek viewing). These types of anthropogenic disturbances would be above and beyond normal disturbance from predators or weather. Guidelines for this type of disturbance are intended to reduce the level of disturbance of males and females attending leks. There are perceived consequences to GrSG of increased disturbance during all seasons. For instance, because GrSG are a lekking species, disturbances that interfere with mating activities include (1) a shift in the particular males breeding, including males breeding with females away from the lek; or (2) increased disturbance that eventually causes birds to abandon the lek. During nesting season, female GrSG are extremely vulnerable to disturbance at nests, which can lead to nest abandonment. There are also concerns that disturbed birds may increase their movements, resulting in physiological consequences such as the expenditure of energy reserves during periods of high energy consumption (e.g., lekking period and winter). Physiological effects of disturbance and displacement to less suitable habitat can include chronic stress, reduced immunocompetence, reduced growth, greater susceptibility to predation and disease, and reduced body size.

The guidelines for each type of disturbance ("Habitat Disturbance" and "Functional Bird Disturbance") are organized first by whether the seasonal habitats in question (e.g., breeding, summer-fall, winter) are mapped, or unmapped (and thus, designated by the circles in Fig. B-1). Within those categories the guidelines are then organized by the issue related to the disturbance (e.g., sagebrush manipulation, anthropogenic features, herbivory, oil and gas development).

Successful implementation of these guidelines for protecting GrSG from disturbance requires the identification and delineation (e.g., mapping, ground validation of mapping efforts) of breeding, summer-fall, and winter habitats (see "Designation of Seasonal Habitats", following). All anthropogenic features (e.g., powerlines, roads, fences, gas wells, etc.) should also be identified and delineated. Colorado GrSG habitat use and movement data were used to develop these guidelines, but if local data were not available, guidelines are consistent with Connelly et al. (2000*c*). As new or local information becomes available through research or monitoring, these guidelines may be adjusted to more effectively manage GrSG.

For the purpose of these guidelines, we primarily adopt the Connelly et al. (2000*c*) definition of an active lek as an open area that has been attended by $\geq$ 2 male sage-grouse in $\geq$ 2 of the previous 5 years. However, this definition is derived mainly from observations of leks in large, stable populations and may not be appropriate for small populations with reduced numbers of males attending leks in fragmented sagebrush communities. Therefore, for smaller populations (i.e., Meeker - White River and Laramie River) that are isolated or disjunct from larger, more stable populations, an active lek is defined as an open area where 1 or more sage-grouse have been observed on more than 1 occasion, engaging in courtship or breeding behavior. An area used by displaying males in the last 5 years is considered an active lek. Buffers for protection from disturbance (described in following text) need to be measured from the perimeter of the open area defining the lek, not from a center point within the lek area. This is because in some situations, leks can span several acres.

If habitat disturbances that will require habitat restoration occur, the potential community needs to be identified (Winward 2004) and a diverse seed mixture of native shrubs, grasses, and forbs should be used with standard restoration or reclamation techniques (Monsen 2005).

Designation of Seasonal Habitats

If seasonal habitats have been mapped, see the section "Mapped Seasonal Habitats". If habitats have not been mapped, see "Unmapped Seasonal Habitats".

Unmapped Seasonal Habitats

Breeding Habitat and Summer-Fall Habitat - If these seasonal habitats are not mapped and field-validated, they should be designated by 2 concentric circles around active leks (Fig. B-1). The first circle has a radius of 0.6 miles ("Lek Habitat" portion of the Breeding Habitat), and the second has a radius of 4.0 miles, which encompasses the nesting and early-brood-rearing habitat and summer–fall habitat (Fig. B-1). Generally, breeding habitat is considered to be sagebrush communities within the 4-mile radius. Summer-fall habitat includes sagebrush communities, wet meadows, and agricultural fields within the 4-mile radius.

On federal lands, the 0.6 mile radius area around a lek in breeding habitat could be defined as an area of No Surface Occupancy (NSO) or Avoidance Area (AA). Every possible opportunity to avoid or minimize the impact should be exhausted to prevent development in this area, but allowances are provided in these guidelines. The 4-mile radius is **not** an NSO or AA. It is an area of consideration where the disturbance guidelines should be applied when, and if, possible.

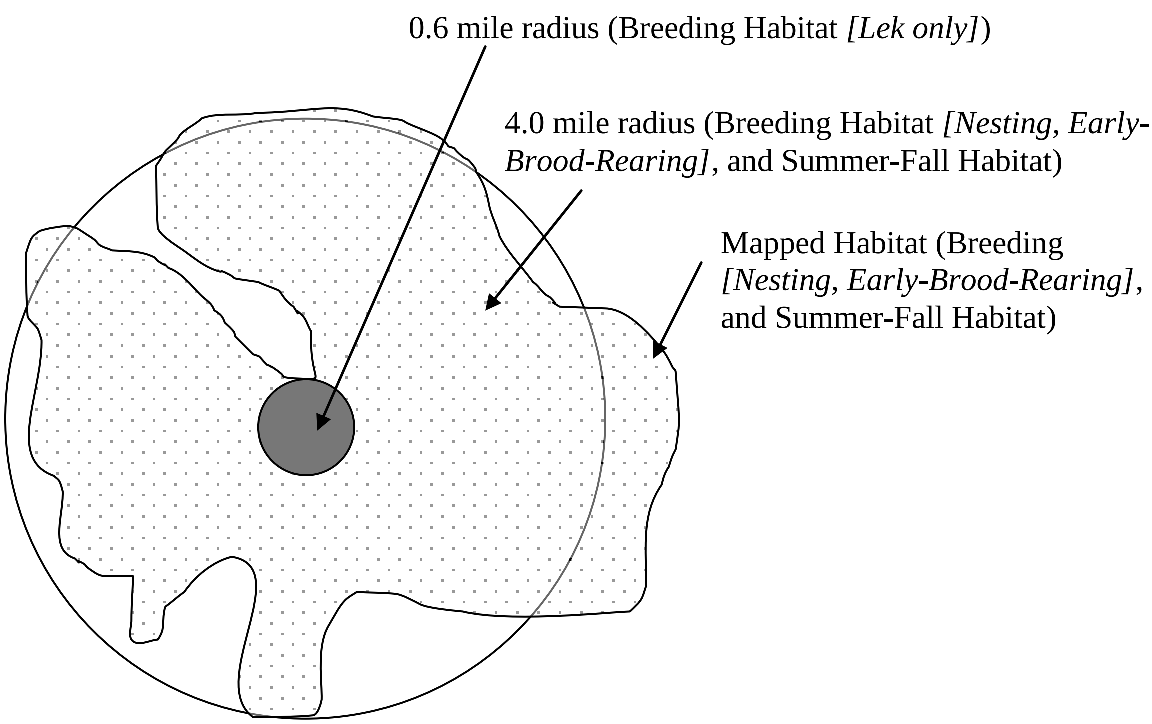

Fig. B-1. Illustration of GrSG seasonal habitat designation where habitat has been mapped, and where it is unmapped. The 2 concentric circles are to be used when seasonal habitat has not been mapped (see text for additional explanation). The irregular polygon represents seasonal habitats that have been mapped.

Winter Habitat – If winter habitat is not delineated, then the following guidance should be used. Winter habitat is highly variable from year to year, depending upon winter conditions (especially snow depth). Because winter habitat use data is regionally specific, this plan defines winter habitat as sagebrush areas (Connelly et al. 2000*c*) within currently occupied habitat that (1) have sagebrush available above the snow for GrSG to use in average and extreme winters; and (2) meets the structural habitat guidelines for winter habitat in Appendix A, "GrSG Habitat Structural Guidelines".

Mapped Seasonal Habitats

If seasonal habitats have been mapped (Fig. B-1), the following guidelines should be followed in, and relative to, the mapped habitat. If there is overlap among different seasonal mapped habitats, whichever seasonal recommendations are the most restrictive should be applied. Recognize that although suitable breeding, summer-fall, and winter habitat may fall within 4 miles of a lek, these seasonal habitats may also fall outside 4 miles due to vegetation mosaics on the landscape (e.g., Fig. B-1), and this should be considered in all management decisions. This is because GrSG can be migratory (1- or 2-stage), or non-migratory (Connelly et al. 2000*c*). Consult your local biologist to determine the designation of the population of concern.

Rationale for Seasonal Habitat Distance Designation (Used when Habitat is Unmapped)

There is a long history of using guidelines or stipulations within a 1/4-mile buffer around leks to protect sage-grouse from adverse impacts of human activities. We have been unable to document any scientific literature that served as the basis for the establishment of this buffer, and new data suggest that this buffer size is inadequate to prevent impacts to breeding populations (Walker et al. 2007*a*). The buffers we recommend for unmapped seasonal habitats (following the "History of the '1/4-mile Buffer'") are based on actual data on GrSG habitat use.

History of the "1/4-mile Buffer"

Following is a description of how the 1/4-mile buffer appears to have come into use (paraphrased from a 1998 Affidavit by Dave A. Roberts, Wyoming Wildlife Program Leader, BLM, in response to Jonah oil and gas field development appeal).

> "We suspect that the following is the way the 1/4 mile distance came into use, however there is no written record of how the 1/4 mile buffer was derived for use:
>
> During the late 1950's and early 1960's, the land management agencies of the Federal government (especially the BLM and Forest Service) were doing a lot of sagebrush eradication (vegetation control) as a form of 'range improvement'. Most biologists at the

> time recognized this practice could be quite detrimental to sage grouse populations. As a result, the Western States Sage Grouse Committee was formed [in part] to address some of these impact issues. By the mid 1960's, the committee had developed some initial sagebrush management guidelines. The amount of impacts information was small at that point, however, so the initial guidelines were largely a guess [i.e., professional opinion] at what would be appropriate protection for sage grouse. The 1/4 mile distance was mutually, though not scientifically, accepted as a buffer distance from sage grouse leks to protect them from vegetation manipulations. Several editions of the guidelines were created from their initiation in the mid 1960's until their final publication in The Wildlife Society Bulletin in 1977. The 1/4 mile distance apparently dropped out somewhere along the way, or simply was never adopted in the published guidelines.
>
> The BLM started using the 1/4 mile distance, for lack of anything better, along with the rest of the published guidelines, back in the late 1960's. Over a period of time (now, over 3 decades) the 1/4 mile distance just evolved into a de facto 'guideline', or standard, through routine, everyday usage, even though there was not any real, empirical, scientific evidence to either support or refute its usage. Some more recent (within the last 5-8 years) studies and anecdotal observations would suggest that a greater distance (possibly 1/2 mile) would be a more appropriate protective buffer around sage grouse leks. Even these more recent studies, however, have not really been designed to empirically ascertain an appropriate setback distance."

The lack of supporting data for the 1/4-mile buffer is evident. We have used recent data from multiple studies to derive alternative buffers, for use when GrSG habitats have not been mapped.

<u>Breeding Habitat (March through July)</u>

Lek Habitat (March through mid-May) - The basis and rationale for the first radius, 0.6 miles from a lek (Fig. B-1), is developed by summarizing data from 5 separate studies of daytime movements of adult male sage-grouse during the breeding season (Carr 1967, Wallestad and Schladweiler 1974, Rothenmaier 1979, Emmons 1980, Schoenberg 1982), because daytime movements of adult male GrSG during the breeding season do not vary greatly. Wallestad and Schladweiler (1974) found daily movements of adult males ranged between 0.2 and 0.8 miles from leks, with a maximum cruising radius of 0.9 - 1.2 miles. Ellis et al. (1987) reported that dispersal flights of male GrSG (to day-use areas) ranged from 0.3 – 0.5 miles, with the longest flights ranging from 1.2 – 1.3 miles. Carr (1967) recorded a cruising radius for male GrSG that ranged from 0.9-1.1 miles. Rothenmaier (1979) found that 60-80% of male GrSG locations were within 0.6 - 0.7 miles of a lek. Emmons (1980) reported that male dispersal distances to day-use areas of 0.1 miles were common and that 67% of all use areas were greater than 0.3 miles from the lek. In addition, Schoenberg (1982) found that male daily movements averaged 0.6 miles, but ranged from 0.02 - 1.5 miles.

Male GrSG activity patterns during the breeding season include strutting during the early morning hours, feeding and loafing during the day, and roosting on the lek during the night. Grouse attending the lek do not always roost on the exact location where the strutting occurs the next morning. Occasionally (this is lek-dependent), grouse roost in adjacent sagebrush cover. Ultimately, male GrSG require an open area for strutting, and sagebrush immediately adjacent for feeding and loafing. Sagebrush adjacent to the lek is also used as escape cover from predators or other types of disturbance. Female GrSG that attend the lek also use the area in this zone in the same fashion as do males (Patterson 1952, Barnett and Crawford 1994, Coggins 1998).

Nesting (April through June) and Early Brood-Rearing Habitat (mid-May through July) - The second circle (Fig. B-1) encompasses nesting and early-brood-rearing habitat, and includes habitat within 4.0 miles from the lek. This is based on 6 research projects from Colorado, Idaho, and Wyoming (Peterson 1980; Autenrieth 1981; Giesen 1995; Holloran and Anderson 2005; A.D. Apa, CDOW, unpublished data). Data from these studies indicate that for 1,164 nests located by radio-telemetry, 79.0% of nests (n = 920/1,164; Table B-1) were located within 4 miles of the active lek where the females were captured.

The 4-mile radius differs from breeding habitat designations in previously published guidelines. Braun et al. (1977) considered the breeding complex to be within a 1.9-mile radius of an occupied lek, although in some circumstances they suggested that the breeding complex could exceed this distance. The 1.9-mile radius was based upon 2 research studies in which nests were located by ground-searching a 2-mile radius from active leks (Gill 1965, Martin 1970), and upon 2 radio-telemetry studies (Wallestad and Pyrah 1974, Autenrieth 1981). Later, Connelly et al. (2000c) suggested that breeding habitat exists within 2.0 miles of occupied leks when the habitat is uniform and the population is non-migratory. In addition, Connelly et al. (2000*c*) further recommended that breeding habitat should be protected within 3.1 miles of an occupied lek in non-uniform habitat where the population is non-migratory. In migratory populations, breeding habitat can occur up to 11.2 miles from occupied leks (Connelly et al. 2000*c*).

Previously, a 2-mile radius was thought to protect 80% of GrSG nesting habitat. Only 52% of the sample we used from multiple states (n = 605/1,164; Table B-1) would have been located within breeding habitat as identified by a 2-mile radius. Data from strictly Colorado GrSG populations follow a similar pattern. Of Colorado research summarized to date (based on data from telemetered GrSG females in Colorado), 52% of females (n = 271/518) nest within 2 miles of the lek they were captured on, while 80.5% (n = 417/518) nest within 4 miles of the lek upon which they were captured (Table B-1). The 2-mile radius is inadequate because it only protects approximately 50% of nests, whereas a 4-mile radius protects 80% of nests. Identifying the 4.0-mile radius circle is a good example of the continuous adaptive process of using more recent and local data to update guidelines, and to make them more appropriate for local situations. As mentioned earlier, the 4.0-mile radius is intended to be used only when breeding habitat has not been mapped.

<u>Summer–Fall (July through September) and Winter Habitat (October through February)</u>

Summer–Fall Habitat (July through September) - In general, all sagebrush stands within a 4-mile radius of an active lek can be considered sage-grouse habitat, although summer-fall habitat can also include riparian areas and agricultural fields within this radius. As sagebrush communities continue to dry out and many forbs complete their life cycles, sage-grouse typically respond by moving to a greater variety of habitats, and generally more mesic habitats (Patterson 1952). Sage-grouse begin movements in late June and into early July (Gill 1965, Klebenow 1969, Savage 1969, Connelly and Markham 1983, Gates 1983, Connelly et al. 1988, Fischer 1994). By late summer and into the early fall, females with broods, non-brood females, and groups of males become more social, and flocks are more concentrated (Patterson 1952). This is the period of time when GrSG can be observed in atypical habitat such as farmland and irrigated habitats (Connelly and Markham 1983, Gates 1983, Connelly et al. 1988).

From mid-September into October, GrSG prefer areas with more dense sagebrush (>15% canopy cover) and late green succulent forbs before moving to early transitional winter range where sexual segregation of flocks becomes notable (Wallestad 1975, Beck 1977, Connelly et al. 1988). During periods of heavy snow cover in late fall and early winter, use of mountain and Wyoming big sagebrush stands is extensive.

Winter Habitat (October through February) - GrSG winter habitat use depends upon snow depth and availability of sagebrush, which is used almost exclusively for both food and cover. Used sites are typically characterized by canopy cover >25% and sagebrush >12-16 inches tall (Schoenberg 1982), and are associated with drainages, ridges, or southwest aspects with slopes < 15% (Gill 1965, Wallestad 1975, Beck 1977, Robertson 1991). In Colorado, <10% of sagebrush habitat is used by GrSG during deep snow conditions (Beck 1977) because most of the sagebrush is buried under the snow. When snow deeper than 12 inches covers over 80% of the winter range, GrSG in Idaho have been shown to rely on sagebrush greater than 16 inches in height for foraging (Robertson 1991). Doherty et al. (2008) found that females preferred landscapes with extensive sagebrush habitat and gentle to flat terrain, and avoided areas with conifers, woody riparian zones, and rough terrain. Females also avoided areas with coal-bed natural gas development, and were 30% less likely to use an area with coal-bed natural gas development even if it contained suitable habitat.

Lower flat areas and shorter sagebrush along ridge tops provide roosting and feeding areas. During extreme winter conditions, GrSG will spend nights and portions of the day (when not foraging) burrowed into "snow roosts" (Back et al. 1987). When snow has the proper texture, snow roosts are dug by wing movements or by scratching with the feet.

Hupp and Braun (1989*b*) found that most GuSG feeding activity during the winter occurred in drainages and on slopes with south or west aspects in the Gunnison Basin. In years with severe winters resulting in heavy accumulations of snow, the amount of sagebrush exposed above the snow can be severely limited. Hupp and Braun (1989*b*) investigated GuSG feeding activity during a severe winter in the Gunnison Basin in 1984, where they estimated <10% of the sagebrush was exposed above the snow and available to sage-grouse. In these conditions, the tall and vigorous sagebrush typical in drainages were an especially important food source for GuSG.

Colorado GrSG Disturbance Guidelines

Whether seasonal habitats are unmapped or mapped, if there is overlap among the designated different seasonal habitats, whichever seasonal recommendations are the most restrictive should be applied.

<u>Habitat Disturbance</u>

In the course of all of the following activities, when seasonal habitats overlap, if possible, efforts should be made to avoid activities during the designated time periods. If not possible, then conduct the activities during the summer-fall period when grouse are more mobile and less energy is expended (versus, e.g., winter and nesting periods) so they can move and could avoid any activities. Generally speaking, the following timelines apply throughout the year for GrSG biology requisites in these habitats:

Breeding Habitat (March through July)
- *Lek Habitat (March through mid-May)*
- *Nesting Habitat (April through June)*
- *Early-Brood Rearing Habitat (mid-May through July)*

Summer-Fall Habitat (July through September)
Winter Habitat (October through February)

In all cases discuss the timelines on site-specific cases with a local biologist.

Breeding Habitat – *Lek Habitat*

a. Sagebrush Alteration – Any sagebrush manipulation should be extremely limited or prohibited within 0.60 mi of an active lek. Exceptions include sagebrush manipulations that are conducted to reduce shrub or vegetation height and density to improve the character of the actual lek.

b. Anthropogenic Features (also consult "a. Sagebrush Alteration" above, if feature construction will result in removal of any sagebrush):

1. Short-term ($\leq$ 1 year) – Restore lek habitat to the original sagebrush community (according to site capability; see Winward 2004, Monsen 2005, and Appendix A, "GrSG Structural Habitat Guidelines"), following feature removal.
2. Long-term (> 1 year) – Anthropogenic features are strongly discouraged due to the long-term loss of lek habitat (if unavoidable, minimize the footprint (area disturbed by feature construction) and see "Functional Bird Disturbance").

Breeding Habitat – *Nesting and Early-Brood-Rearing Habitat*

a. Sagebrush Alteration

1. Uniform and Unfragmented Breeding Habitat - sagebrush removal and/or treatment projects should be limited and not exceed 20-30% (Connelly et al. 2000*c*) of the total mapped habitat. Treatments need

recovery objectives that achieve the structural habitat guidelines identified in this plan (according to site capability; see Winward 2004, Monsen 2005, "Habitat Enhancement" strategy [pg. 349], and Appendix A, "GrSG Structural Habitat Guidelines"). Treatment blocks should be small (< 50 acres) and interspersed across the landscape in irregular configurations and shapes. Treated areas should not be systematic or predictable (e.g., a ratio of treated to untreated strips) across the landscape.

2. Fragmented Breeding Habitat – If the mapped original breeding habitat area has >40% loss (Connelly et al. 2000*c*) to other factors, all remaining habitat should be protected from disturbance.

b. Anthropogenic Features (also consult "a. Sagebrush Alteration" above, if feature construction will result in removal of any sagebrush). These include any human-made structures or features that are present on the landscape for 1 year or less (short-term) and greater than 1 year (long-term).

1. Short-term (≤ 1 year; e.g., fire-fighting camps, temporary corrals) – Restore nesting and early-brood-rearing habitat to the original sagebrush community (according to site capability; see Winward 2004, Monsen 2005, and Appendix A, "GrSG Structural Habitat Guidelines"), following feature removal.
2. Long-term (> 1 year) – Anthropogenic features should be limited if possible, due to the long-term loss of nesting and early-brood-rearing habitat (if unavoidable, minimize the footprint and see "Functional Bird Disturbance").

Summer–Fall Habitat

a. Sagebrush Alteration

1. Maintain sagebrush communities (Hausleitner 2003) within 0.20 miles (Connelly et al. 2000*c*) of known or suspected brood foraging areas. Sagebrush manipulations must be carefully planned to achieve the structural habitat guidelines (according to site capability; see Winward 2004, Monsen 2005, "Habitat Enhancement" strategy [pg. 349], and Appendix A, "GrSG Structural Habitat Guidelines").

b. Anthropogenic Features (also consult "a. Sagebrush Manipulation" above, if feature construction will result in removal of any sagebrush)

1. Short-term (≤ 1 year) – Restore summer-fall habitat to the original sagebrush community (Winward 2004, Monsen 2005) following feature removal.
2. Long-term (> 1 year) – Anthropogenic features should be limited if possible, due to the long-term loss of summer-fall habitat (if unavoidable, minimize the footprint and see "Functional Bird Disturbance").

Winter Habitat

a. Sagebrush Alteration

1. Sagebrush manipulations need to be limited or prohibited in winter habitat. Any manipulations should be small (< 10 acres) in size and not exceed 20% (Connelly et al. 2000*c*) of the delineated winter

habitat. Treatments should be irregular in shape and not predictable or systematic (e.g., ratio of treated and untreated strips) on the landscape. Treatments in the shape of rows or strips should be avoided.

b. Anthropogenic Features (also consult “a. Sagebrush Manipulation” above, if feature construction will result in removal of any sagebrush)

1. Short-term (< 1 year) – Restore winter habitat to the original sagebrush community (according to site capability; see Winward 2004, Monsen 2005, and Appendix A, “GrSG Structural Habitat Guidelines”), following feature removal.
2. Long-term (> 1 year) – Anthropogenic features should be limited if possible, due to the long-term loss of winter habitat (if unavoidable, minimize the footprint and see “Functional Bird Disturbance”).

Functional Bird Disturbance

In the course of all of the following activities, when seasonal habitats overlap, if possible, efforts should be made to avoid activities during the designated time periods. If not possible, then conduct the activities during the summer-fall period when grouse are more mobile and less energy is expended (versus, e.g., winter and nesting periods) so they can move and could avoid any activities. Generally speaking, the following timelines apply throughout the year for GrSG biology requisites in these habitats:

Breeding Habitat (March through July)
- *Lek Habitat (March through mid-May)*
- *Nesting Habitat (April through June)*
- *Early-Brood Rearing Habitat (mid-May through July)*

Summer-Fall Habitat (July through September)
Winter Habitat (October through February)

In all cases discuss the timelines on site-specific cases with a local biologist.

Breeding Habitat – *Lek Habitat:* Any activities associated with the following anthropogenic features, or any other bird-disturbing activities, should be limited between sunset and 2 hours after sunrise (modified from Lyon and Anderson 2003, A.D. Apa, CDOW, personal communication). There should be complete exclusions or significant restrictions from 2 hours before sunrise to 2 hours after sunrise during this time of year.

1. Anthropogenic Features or Human Activities
    a. Fences – Any fences planned within 0.60 miles of an active lek should be avoided whenever possible, but if avoidance is not possible, fences should be retro-fitted with devices that increase their visibility in areas of suspected or confirmed grouse collision mortalities. This effort is an attempt to reduce potential grouse collisions. Similar devices should be applied to existing fences in areas of suspected or confirmed collisions. In addition to visual devices, where possible, place fences in areas where topographic features can be used that will deter collisions (e.g., not on ridges).
    b. Powerlines (transmission, service lines) – Whenever possible, avoid the construction of powerlines in lek habitat. If impractical, powerlines within lek habitat should be retro-fitted to deter raptor perching. If practical, powerlines should be constructed to reduce the likelihood of grouse-wire collisions. Similar adjustments should be applied to existing powerlines where grouse mortality issues have been identified.
    c. Oil and Gas Exploration and Production – These anthropogenic features should not be constructed within lek habitat. If unavoidable, all activities should have minimal noise. Compressors, vehicles and other sources of noise should be equipped with effective mufflers or noise suppression to make the sounds emanating from these devices as

quiet as technologically possible. As a guideline, grouse vocalizations are less than 20 dBA (Dantzker et al. 1999).

d. Roads and Trails – Avoid constructing roads and trails within lek habitat. If unavoidable, roads should be placed so they, and their associated traffic, are not in direct line-of-sight of strutting males. Vehicles should not exceed 30 - 40 mph (adapted from Tessman et al. 2004) during the strutting period to avoid grouse-vehicle collisions. Roads should be minimally developed and seasonal closures should be developed.

e. Ex- urban Housing Development – No housing developments should occur within lek habitat.

f. Wind Power Generation and Communication Tower Sites – These sites should not be constructed within lek habitat.

g. Recreational Activities – Recreational activities should be excluded or strictly coordinated to accommodate the aforementioned timeframes. Lek viewing opportunities should be strictly controlled and emphasized during time periods before and after peak female attendance and breeding to avoid interrupting breeding activities. Once protocols are produced, lek viewing protocols should be monitored for compliance.

h. Herbivory – In situations where animals can be controlled (i.e., domestic sheep beds), avoid bedding sheep on or within 100 feet of active leks during the strutting period. Numerous anecdotal observations have documented sheep being bedded directly on lek and male and female GrSG fail to roost on the leks. Male display activity and roosting on leks is dramatically reduced or not present (A.D. Apa, CDOW, personal communication).

i. Research Activities – Research and management activities that could have detrimental impacts to individuals or populations must have Animal Care and Use Committee approval as well as the appropriate trapping and handling permits issued by CDOW. In addition, ethical handling guidelines will be in conformance with Gaunt and Oring (1997).

j. Surface Mining or Similar Activities – These anthropogenic features should not be constructed within lek habitat. If unavoidable, all activities should have minimal noise. Compressors, vehicles and other sources of noise should be equipped with effective mufflers or noise suppression to make the sounds emanating from these devices as quiet as technologically possible. As a guideline, grouse vocalizations are less than 20 dBA (Dantzker et al. 1999).

Breeding Habitat – *Nesting and Early-Brood-Rearing Habitat*,
Summer-Fall Habitat, *and*
Winter Habitat

1. Anthropogenic Features or Human Activities
    a. Fences - If, in the course of other activities, it is determined that fences in a particular area in these seasonal habitats are causing collisions, avoid constructing new fences in that area, and/or move, and/or retrofit existing fences to increase visibility and decrease possibility of collisions.
    b. Powerlines - If possible, powerlines should be avoided in these seasonal habitats. If not possible, consider burying powerlines, placing raptor perching deterrents, and avoiding areas where sage-grouse concentrate, riparian areas, or areas where collisions or predatory events from perching raptors have been documented.
    c. Oil and Gas Exploration and Production – Any necessary equipment should produce minimal noise; all compressors, vehicles, and other sources of noise should be equipped with effective mufflers or noise suppression devices to provide the quietest conditions technologically possible. Encourage remote monitoring to minimize disturbance of grouse during this period.
    d. Roads and Trails – Local (generally, unpaved) roads and trails should be excluded when possible, and when not, road and trail length and width should be minimized to the extent possible. Vehicles should not exceed 30 - 40 mph (adapted from Tessman et al. 2004) on local or unpaved roads.
    e. Ex- urban Housing Development - Housing developments should be discouraged in all GrSG habitats. When this is not practical, houses should be clustered as much as possible and domestic pets should be controlled to reduce predation or harassing events.
    f. Wind Power Generation and Communication Tower Sites – These sites should be avoided if possible. If not possible, retrofit all aspects of turbines and towers to deter raptor perching, and to decrease the possibility of GrSG collisions in identified or potential collision areas.
    g. Recreational Activities – Recreational activities should be localized and confine activities to established and approved roads and trails. In winter habitat, activities should be dramatically reduced in documented winter habitat.
    h. Surface Mining or Similar Activities – Any necessary equipment should produce minimal noise; all compressors, vehicles, and other sources of noise should be equipped with effective mufflers or noise suppression devices to provide the quietest conditions technologically possible. Encourage remote monitoring to minimize disturbance of grouse during this period.

Table B-1. Data and recommendations regarding GrSG nest location and delineation of GrSG breeding habitat.

DATA: DISTANCE OF GrSG NESTS FROM LEK OF CAPTURE				
% Nests within 2-mi. radius	**% Nests Within 4-mi. radius**	**Telemetry Research**	**Location**	**Study**
86.9 (n = 20/23)	N/A	No – ground searches for nests	North Park, CO	(A) Gill (1965)
80.0 (n = 4/5)	N/A	No – ground searches for nests	Montana	(B) Martin (1970)
59.5 (n = 182/306)	85 (n = 260/306)	Yes	Idaho	(C) Autenrieth (1981)
46.4 (n = 13/28)	85.7 (n = 24/28)	Yes – estimates made from a Figure in thesis	North Park, CO	(D) Peterson (1980)
71.8 (n = 51/71)	90.1 (n = 64/71)	Yes	North Park, CO	(E) Giesen (1995)
49.5 (n = 192/388)	77.1 (n = 299/388)	Yes	Moffat County, CO	(F) Thompson et al. 2005, Thompson 2006
48.4 (n = 15/31)	96.8 (n = 30/31)	Yes	Eagle and South Routt Counties, CO	(G) Graham and McConnell 2004, Graham and Jones 2005
44.7 (n = 152/340)	74.4 (n = 243/340)	Yes	Wyoming	(H) Holloran and Anderson (2005)
SUMMARIES OF DATA SETS				
52.3 (n = 271/518)	80.5 (n = 417/518)	Yes	All CO studies since 1980	(D) - (G)
52.0 (n = 605/1,164)	79.0 (n = 920/1,164)	Yes	All telemetry studies outlined in this table (CO, WY)	(C) - (H)

RECOMMENDATIONS: **Connelly et al. (2000*c*) Guidelines for delineation GrSG breeding habitat if no local information is available**		
Population Type	**Habitat Uniform?**	**Distance from Lek**
Non-migratory	Uniform sagebrush habitat	≤ 2 mi
Non-Migratory	Non-uniform sagebrush habitat	≤ 3.1 mi
Migratory	No designation	≤ 11.2 mi

APPENDIX C

SAGE-GROUSE HABITAT MONITORING PROTOCOL

MINIMUM STRUCTURAL VEGETATION DATA COLLECTION GUIDELINES FOR SAGE-GROUSE SPECIES IN COLORADO

Gunnison Sage-grouse Rangewide Steering Committee

February 2007

The following protocol was originally designed to assess suitability of vegetation conditions for the Gunnison sage-grouse as documented in the Gunnison sage-grouse Rangewide Conservation Plan (RCP; Gunnison Sage-grouse Rangewide Steering Committee 2005; "Appendix H, GUSG Structural Habitat Guidelines"). It is applicable to both Gunnison (GuSG and greater sage-grouse (GrSG) in Colorado.

- This protocol is intended to provide guidance in measuring minimum vegetation characteristics to evaluate site-specific structure as described by the "GrSG Structural Habitat Guidelines" (Appendix A in the CCP), and the "Gunnison sage-grouse Structural Habitat Guidelines" (Appendix H of the RCP). If additional vegetation data are needed, consult the BLM Technical Reference 1734-4 or other agency technical manuals.
- This protocol can be used to document current suitability of site-specific conditions, monitor changes in condition over time, and evaluate impacts of habitat and restoration treatments.
- Vegetation data need to be collected during the season of use by sage-grouse. For Breeding Habitat, measurements start around the end of May after the first nest hatches, and continue through June to encompass nesting and early-brood-rearing habitat. Summer Habitat measurements start around mid-June (after the chicks are about 4 weeks old), and continue through mid-August to include late-brood-rearing habitat. Winter structural habitat variables (sagebrush canopy cover and sagebrush height) may be collected at any time of the year because these variables do not change substantially on a seasonal basis.
- To maintain consistency in data collection, use of this protocol is recommended. If an alternate methodology is used, techniques must be reported for future reference.

General Guidance

- To measure sagebrush and other shrub canopy cover, use the line intercept method developed by Canfield (1941). For other canopy cover estimates use Daubenmire (1959) plots.
- Take a minimum of 1 photo per transect at the starting point of the transect line. Attempt to take the photo at a height and angle that will provide a good representation of the general condition of the site.
- Frequency, density, and composition are additional types of information that could be collected but are not required by these guidelines to assess sage-grouse habitat structural condition. If this type of data is needed consult the Technical Reference 1734-4 (http://www.blm.gov/nstc/library/pdf/samplveg.pdf).

Specific Measurements

Transect Line Placement

- Line -transects should be 30 m in length and placement of transects should be random within representative range sites.
- Collect UTM coordinates at the start pointing of the transect line, using a GPS unit.
- Transects placement should be stratified by community types and soils.

Shrub Canopy Cover

- Measure all shrubs and trees that intersect the line transect. The species of sagebrush that intersect the line should be documented; all others non-sagebrush shrubs can be lumped into one category.
- Large spaces in the foliage cover (>5 cm) should be excluded from the canopy cover measurement.
- Do not measure overlap of canopy of species; i.e., if two sagebrush plants overlap along the transect, the length of the transect covered from a vertical vantage point is the percent canopy cover regardless of how may individual plants makeup that coverage. Canopy cover should never exceed 100%.

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General Guidelines for Application of Daubenmire (1959)

- See Daubenmire (1959) or Bureau of Land Management (1996) for additional details
- Note: cover classes indicated for Daubenmire (1959) have been modified per discussion regarding Table C-1
- Five other vegetation variables will be collected along line transects within a Daubenmire frame:
    - Sagebrush Height
    - Grass Height
    - Forb Height
    - Grass Cover
    - Forb Cover
- Collect data in 10 Daubenmire frames along each 30-m transect
- Select a consistent systematic method for placement of the Daubenmire frame along each transect. Record the method used on the field form so future transects can be completed in the same way.

Sagebrush Height

- Take one height measurement per sampling point (Daubenmire frame) by selecting the sagebrush closest to the lower left corner of the Daubenmire frame, based on its canopy and not its root. The closest sagebrush could be within the frame, in front of the frame, behind the frame, and on either side of the transect. Choose the sagebrush closest to the lower left corner of the frame regardless of its direction from that corner.

- Note on the data sheet whether the shrub measured is a seedling (no woody base) or a very young plant
- Exclude seed heads (inflorescences) from height measurement
- Do not re-measure the same shrub even if it is the closest sagebrush for a subsequent plot. Instead select the next nearest sagebrush within 10 meters of the plot. If there is no other sagebrush within 10 meters, do not take that height measurement for that plot.

Understory Cover

To the extent possible, plants should be identified to the species level, but training and time limitations may prevent this. The important habitat variables to be collected include:

- Grasses: at a minimum, distinguish between perennials and annuals. Identify dominant species to the extent possible in comments section of form. Identify cheat grass and other non-native species to the extent possible.
- Sedges are included in the grass category.
- Forbs: at a minimum, list the number of different forb species per plot, even if you cannot identify the species. Identify species to the extent possible.
- Measure the live and residual foliar cover of grasses and forbs.

Understory Height

Height measurements are conducted to characterize the vertical and horizontal structure of the understory. Sage-grouse select habitat based on vertical (how tall it is) and horizontal (how thick it is) structure. Both aspects contribute to a diversity of structure and provide a sense of security for birds. These aspects contribute to nest, chick and adult concealment from predation events. That is why these measurements are relatively consistent, but not absolutely consistent.

- Measure 1 grass and 1 forb in each Daubenmire frame. The plants must be rooted in the frame, and if there are no grasses or forbs in the frame, record as not present.
- Measure height of the nearest grass and forb from the bottom left corner of the Daubenmire frame.
- Grass height only includes the current year's growth. There are no criteria or guidelines for previous years' growth (e.g., residual grass height).
- Grass height can include annual or perennial grass. If annual grass (e.g. *Bromus tectorum*) is measured, it should be documented on the datasheet. It is preferable to measure perennial grasses.
- Additional grass heights can be measured, but at a minimum grass height should be measured in the following manner:
    - Measure grass height (leaf or inflorescence) at the tallest vertical point (do not straighten up the plant; i.e., droop height) where the bulk of a plant's mass occurs. If the plant has only 1 inflorescence and the bulk of the mass occurs in the leafy portion of the plant, measure the tallest leaf height. If the inflorescence provides a bulk of the mass, then the tallest portion of the inflorescence is measured.
    - This protocol does not provide guidelines for every species of grass. The individual conducting the sampling will have to make a judgment for each plot

and each species along a plot. Consistency by following this protocol is key, as well as collecting an adequate number of measurements.

- The same protocol should be followed for forbs.

All cover estimates should be placed in the categories noted in Table C-1. The standard Daubenmire method uses 6 cover classes, but the specific ranges lump too much in the 5-25% class to detect understory habitat conditions when compared to the Gunnison or greater sage-grouse vegetation variables, this category was split into 2 cover classes below.

Table C-1. Modified cover classes for sage-grouse habitat variable estimation.

Cover Class	Range of Coverage	Midpoint of Range
1	0-5%	2.5
2	5-15%	10
3	15-25%	20
4	25-50%	38
5	50-75%	63
6	75-100%	88

Examples of where grass and forb heights should be taken (ignore horizontal blue line in photos).

APPENDIX D

RECOMMENDATIONS REGARDING PLANT SPECIES

for USE in GrSG HABITAT MANAGEMENT and RESTORATION

(from MONSEN 2005)

The content in the following tables is from Monsen (2005), but the format is in some cases altered from Monsen (2005). The tables are numbered for use in this appendix; the corresponding table numbers found in Monsen (2005) are provided in the table descriptions.

Table D-1. Ecological status, use index, competitiveness, seeding rates, and natural spread index of species adapted for seeding mountain brush and juniper-pinyon sites that receive over 15 – 20 in of annual precipitation (from Monsen, Stevens USDA, RMRS – GTR – 2004 in press). This is "Table 1" in Section II of Monsen (2005).

		Use index for:		Competitiveness[b] as a seedling, in the presence of:			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Grasses							
Bluegrass, big	P,E,L	X	X	ME	ME	ME	3
Bluegrass, Canada	P,E,L		X	ME	ME	ME	3
Bluegrass, Sandberg	P,E,L	X	X	ME	ME	ME	4
Brome, mountain	P,E,L	X		ME	ME	ME	5
Brome, nodding	P,E,L	X		ME	ME	ME	5
Brome, Regar	P,E,L		X	EX	EX	ME	4
Brome, smooth, northern	P,E,L		X	EX	EX	EX,NC	5
Brome, smooth, southern	P,E,L		X	EX	EX	EX,NC	5
Fescue, Sulcata sheep	P,E,L	X		ME	EX	EX	3
Junegrass, prairie	P,E,L	X		ME	ME	ME	3
Muttongrass	P,E,L	X		ME	ME	ME	4
Needle-and-thread	P,E	X	X	ME	ME	EX	4
Needlegrass, green	P,E,L	X	X	ME	ME	EX	3
Orchardgrass "Paiute"	P,E,L		X	EX	EX	EX	5
Ricegrass, Indian	P,E,L	X		ME	ME	EX	3
Rye, mountain	P,E		X	EX	EX	PO	5
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME	4
Trisetum, spike	P,E,L	X		ME	ME	ME	3
Wheatgrass, bluebunch	P,E,L	X		EX	EX	EX	3
Wheatgrass, fairway	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, standard	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, slender	P,E,L	X	X	ME	ME	ME	4
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX	4
Wheatgrass, western	P,E,L	X	X	ME	ME	EX	4
Forbs							
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME	3
Aster, blueleaf	P,E,L	X	X	EX	EX	EX	4
Aster, Pacific	P,E,L	X	X	EX	EX	EX	4
Balsamroot, arrowleaf	E,L	X		PO	PO	EX	2
Balsamroot, cutleaf	E,L	X		PO	PO	EX	2
Balsamroot, hairy	E,L	X		PO	PO	EX	2
Burnet, small	P,E,L		X	EX	EX	ME	4
Crownvetch	P,E,L		X	ME	ME	ME	4
Eriogonum, cushion	P,E,L	X	X	ME	ME	ME	3
Flax, Lewis	P,E,L	X	X	ME	ME	ME	5
Goldeneye, showy	P,E,L	X	X	ME	ME	ME	3
Goldenrod, Parry	P,E,L	X		ME	ME	ME	3
Helianthella, oneflower	P,E	X		ME	ME	ME	4
Lupine, Nevada	E,L	X		PO	PO	EX	2
Lupine, silky	E,L	X		PO	PO	ME	2
Lomatium, Nuttall	P,E,L	X		ME	ME	ME	3
Milkvetch, cicer	P,E,L		X	ME	ME	ME	4

Table D-1. Ecological status, use index, competitiveness, seeding rates, and natural spread index of species adapted for seeding mountain brush and juniper-pinyon sites that receive over 15 – 20 in of annual precipitation (from Monsen, Stevens USDA, RMRS – GTR – 2004 in press). This is “Table 1” in Section II of Monsen (2005).

		Use index for:		Competitiveness[b] as a seedling, in the presence of:			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Penstemon, Eaton	P,E,L	X		EX	EX	ME	5
Penstemon, low	P,E,L	X		EX	EX	ME	5
Penstemon, Palmer	P,E	X	X	EX	EX	PO	5
Penstemon, Rocky Mtn.	P,E,L	X	X	ME	ME	PO	5
Penstemon, sidehill	P,E,L	X		ME	ME	ME	5
Penstemon, thickleaf	P,E,L	X		ME	ME	ME	5
Penstemon, toadflax	P,E,L	X		PO	ME	ME	5
Penstemon, Wasatch	P,E,L	X		EX	EX	ME	5
Sainfoin	P,E,L		X	ME	ME	ME	4
Sage, Louisiana	P,E,L	X	X	PO	PO	ME	4
Sage, tarragon	P,E,L	X		PO	PO	ME	5
Salsify, vegetable	P,E		X	EX	EX	ME	5
Sweetvetch, Utah	P,E,L	X		PO	ME	ME	3
Yarrow, western	P,E,L	X	X	ME	ME	ME	4
Shrubs							
Ash, singleleaf	P,E,L	X		PO	PO	ME	2
Bitterbrush, antelope	P,E,L	X	X	ME	EX	EX	4
Buckwheat, Wyeth	P,E,L	X		EX	EX	ME	4
Ceanothus, Martin	P,E,L	X		ME	ME	EX	3
Chokecherry, black	P,L	X		PO	ME	EX	2
Cliffrose, Stansbury	P,E,L	X		ME	ME	EX	3
Elderberry, blue	P,E,L	X		PO	ME	EX	2
Ephedra, green	P,E,L	X		ME	ME	EX	2
Kochia, forage	P,E	X		EX	EX	ME	5
Mahogany, curlleaf	P,E	X		PO	ME	EX	2
Mahogany, true	E,L	X		PO	ME	EX	2
Maple, Rocky Mountain	E,L	X		ME	ME	EX	2
Rabbitbrush, mountain rubber	P,E,L	X	X	EX	EX	ME	5
Rabbitbrush, mountain and basin white stem rubber	P,E,L	X	X	ME	ME	ME	5
Rose, Woods	P,E,L	X	X	PO	ME	EX	1
Sagebrush, mountain big	P,E,L	X	X	ME	EX	EX	4
Saltbush, fourwing	P,E,L	X	X	ME	ME	ME	2
Serviceberry, Saskatoon	P,E,L	X	X	PO	PO	EX	2
Snowberry, longflower	E,L	X		PO	PO	EX	1
Snowberry, mountain	P,E,L	X		PO	ME	EX	1
Squawapple	P,E,L	X		PO	ME	EX	1
Sumac, Rocky Mountain	P,E,L	X	X	PO	ME	EX	2
Sumac, skunkbush	P,E,L	X	X	PO	ME	EX	2
Winterfat	P,E,L	X	X	ME	ME	EX	3
Seeding Rate							
Growth Form	Lbs/Acre[d]						
Grasses	4 - 7						
Forbs	5 - 6						
Shrubs	3 - 4						

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Natural spread: 1 = poor; 2 = fair; 3 = moderate; 4 = good; 5 = excellent.
[d] Drill rate—broadcast seeding requires 1/4 - 1/3 additional seed.

Table D-2. Ecological status, use index, competitiveness, and seeding rates of species adapted for seeding juniper-pinyon intermixed with mountain big sagebrush or black sagebrush sites that receive 11 - 15 in of annual precipitation. (From Monsen and Stevens RMRS - GTR - 2004. In press). This is "Table 4" in Section II of Monsen (2005).

		Use index for:		Competitiveness[b] as a seedling, in the presence of:			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Grasses							
Bluegrass, big	P,E,L	X	X	ME	ME	ME	3
Bluegrass, Canada	P,E,L		X	ME	ME	ME	3
Bluegrass, Sandberg	P,E,L	X	X	ME	ME	ME	4
Brome, nodding	P,E,L	X	X	ME	ME	ME	4
Brome, Regar	P,E,L		X	ME	ME	ME	4
Brome, smooth, southern	P,L		X	EX	EX	EX,NC	5
Dropseed, sand	P,E,L	X		EX	ME	ME	4
Fescue, hard sheep	P,E,L		X	ME	ME	ME,NC	4
Fescue, Sulcata sheep	P,E,L	X	X	ME	ME	EX	3
Grama, blue	P,E,L	X		ME	ME	EX	4
Junegrass, prairie	P,E,L	X		ME	ME	ME	3
Muttongrass	P,E,L	X		ME	ME	ME	4
Needle-and-thread	P,E	X		ME	ME	ME	4
Needlegrass, green	P,E,L	X	X	ME	ME	EX	3
Orchardgrass, "Paiute"	P,E,L		X	EX	EX	EX	5
Ricegrass, Indian	P,E,L	X		ME	ME	EX	3
Rye, mountain	P,E		X	EX	EX	PO	5
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME	4
Trisetum, spike	P,E,L	X		ME	ME	ME	3
Wheatgrass, bluebunch	P,E,L	X	X	ME	ME	EX	3
Wheatgrass, fairway	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, standard	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX	3
Wheatgrass, streambank	P,E,L	X	X	EX	EX	EX	4
Wheatgrass, thickspike	P,E,L	X	X	ME	EX	EX	4
Wheatgrass, western	P,E,L	X	X	ME	ME	EX	4
Wildrye, Great Basin	E,L	X		PO	ME	EX	2
Wildrye, Russian	P,E,L		X	PO	ME	EX	3
Forbs							
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	EX	3
Aster, Pacific	P,E,L	X	X	PO	ME	ME	4
Balsamroot, arrowleaf	E,L	X		PO	PO	EX	2
Burnet, small	P,E,L		X	EX	EX	ME	4
Flax, Lewis	P,E,L	X	X	EX	EX	ME	5
Globemallow, gooseberryleaf	E,L	X	X	ME	ME	EX	2
Goldeneye, showy	P,E,L	X	X	ME	ME	ME	3
Penstemon, Palmer	P,E	X	X	EX	EX	PO	5
Sainfoin	E,L		X	ME	ME	ME	4
Salsify, vegetable	P,E		X	EX	EX	ME	4
Sweetvetch, Utah	P,E,L	X		ME	ME	ME	3
Yarrow, western	P,E,L	X	X	ME	ME	ME	4
Shrubs							
Apache-plume	E,L	X		PO	ME	EX	3
Ash, singleleaf	E,L	X		PO	PO	EX	2

Table D-2. Ecological status, use index, competitiveness, and seeding rates of species adapted for seeding juniper-pinyon intermixed with mountain big sagebrush or black sagebrush sites that receive 11 - 15 in of annual precipitation. (From Monsen and Stevens RMRS - GTR - 2004. In press). This is “Table 4” in Section II of Monsen (2005).

		Use index for:		**Competitiveness[b] as a seedling, in the presence of:**			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Bitterbrush, antelope	P,E,L	X	X	EX	EX	EX	4
Buckwheat, Wyeth	P,E,L	X	X	ME	EX	ME	4
Ceanothus, Fendler	E,L	X		ME	ME	EX	3
Cliffrose, Stansbury	E,L	X		ME	ME	EX	2
Elder, blueberry	E,L	X		PO	ME	EX	2
Ephedra, green	E,L	X		ME	ME	EX	2
Kochia, forage	P,E		X	EX	EX	ME	5
Mahogany, curlleaf	E,L	X		ME	ME	EX	2
Mahogany, littleleaf	E,L	X		ME	ME	EX	2
Mahogany, true	E,L	X		ME	ME	EX	2
Peachbrush, desert	L	X		PO	PO	EX	2
Rabbitbrush, mountain rubber	P,E,L	X	X	ME	ME	ME	3
Rabbitbrush, mountain and basin white stem rubber	P,E,L	X	X	ME	ME	ME	5
Sagebrush, basin big	P,E,L	X	X	ME	ME	EX	5
Sagebrush, black	P,E,L	X	X	ME	ME	EX	5
Sagebrush, mountain	P,E,L	X	X	ME	ME	EX	4
Saltbush, fourwing	E,L	X	X	ME	ME	ME	2
Serviceberry, Saskatoon	P,E,L	X	X	PO	PO	EX	2
Serviceberry, Utah	E,L	X	X	PO	PO	EX	2
Snowberry, mountain	E,L	X	X	PO	PO	EX	2
Squawapple	E,L	X		PO	PO	EX	2
Sumac, Rocky Mountain smooth	E,L	X	X	PO	ME	EX	2
Sumac, skunkbush	E,L	X	X	PO	ME	EX	2
Winterfat	P,E,L	X	X	ME	ME	EX	3
Seeding Rate							
Growth Form	Lbs/Acre[d]						
Grasses	4 - 6						
Forbs	4 - 6						
Shrubs	3 - 4						

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Natural spread: 1 = poor; 2 = fair; 3 = moderate; 4 = good; 5 = excellent.
[d] Drill rate—broadcast seeding requires 1/4 - 1/3 additional seed.

Table D-3. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding mountain big sagebrush sites receiving over 15 in annual precipitation. (From Monsen and Stevens RMRS - GTR - 2004. In press). This is "Table 5" in Section II of Monsen (2005).

		Use index for:		Competitiveness[b] as a seedling, in the presence of:			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Grasses							
Bluegrass, big	P,E,L	X	X	ME	ME	ME	3
Bluegrass, Canada	E,L		X	ME	ME	ME	3
Bluegrass, Sandberg	P,E,L	X		ME	ME	ME	4
Brome, Regar	P,E,L		X	EX	EX	ME	4
Brome, smooth, southern	P,E,L		X	EX	EX	EX,NC	5
Dropseed, sand	P,E,L	X		EX	ME	ME	4
Fescue, hard	P,E,L		X	ME	ME	EX,NC	3
Fescue, Idaho	E,L	X		PO	ME	ME	3
Fescue, sheep	P,E,L	X	X	ME	ME	ME	3
Galleta	P,E,L	X		ME	ME	ME	4
Grama, blue	P,E,L	X		ME	ME	EX	4
Junegrass, prairie	P,E,L	X		ME	ME	ME	3
Muttongrass	P,E,L	X		ME	ME	ME	4
Needle-and-thread	P,E	X		ME	ME	ME	4
Needlegrass, green	P,E,L	X	X	ME	ME	ME	4
Needlegrass, Letterman	P,E,L	X		ME	ME	ME	3
Oatgrass, tall	P,E		X	ME	ME	ME	4
Orchardgrass, 'Paiute'	P,E,L		X	EX	EX	EX	5
Ricegrass, Indian	P,E,L	X		ME	EX	ME	3
Rye, Mountain	P,E		X	EX	EX	ME	5
Squirreltail, bottlebrush	P,E	X	X	EX	EX	ME	4
Wheatgrass, bluebunch	P,E,L	X		EX	EX	ME	3
Wheatgrass, fairway	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, standard	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, slender	P,E,L	X		EX	EX	ME	4
Wheatgrass, streambank	P,E,L	X	X	ME	ME	ME	4
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX	4
Wheatgrass, western	P,E,L	X	X	PO	ME	EX	4
Wildrye, Great Basin	E,L	X		PO	ME	ME	2
Wildrye, Salina	E,L,	X		PO	ME	EX	4
Forbs							
Agoseris, pale	P,E,L	X		EX	ME	ME	5
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME	3
Aster, Pacific	P,E	X	X	ME	ME	ME	4
Balsamroot, arrowleaf	E,L	X		PO	PO	EX	2
Burnet, small	P,E,L		X	EX	EX	ME	4
Crownvetch	P,E,L		X	ME	ME	ME	4
Hawksbeard, tapertip	P,E,L	X		ME	ME	ME	4
Flax, Lewis	P,E,L	X	X	EX	EX	ME	5
Goldeneye, showy	P,E,L	X	X	ME	ME	PO	3
Lupine, mountain	E,L	X		PO	ME	ME	2
Lupine, silky	E,L	X		ME	ME	ME	2
Milkvetch, cicer	P,E,L		X	ME	ME	ME	4
Penstemon, Eaton	P,E,L	X		EX	EX	ME	5

Table D-3. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding mountain big sagebrush sites receiving over 15 in annual precipitation. (From Monsen and Stevens RMRS - GTR - 2004. In press). This is "Table 5" in Section II of Monsen (2005).

		Use index for:		**Competitiveness[b] as a seedling, in the presence of:**			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Penstemon, low	P,E,L		X	EX	EX	EX	5
Penstemon, Palmer	P,E	X		EX	EX	PO	5
Penstemon, Rocky Mtn	P,E,L	X	X	ME	ME	ME	5
Penstemon, Wasatch	P,E,L	X		EX	EX	ME	5
Sainfoin	P,E		X	ME	ME	ME	5
Sweetvetch, Utah	P,E,L	X		ME	ME	ME	3
Trefoil, birdsfoot	P,E		X	ME	ME	ME	3
Yarrow, western	P,E,L	X	X	EX	EX	ME	4
Shrubs							
Bitterbrush, antelope	P,E,L	X	X	ME	EX	EX	4
Buckwheat, sulfur	P,E,L	X	X	ME	ME	ME	4
Buckwheat, Wyeth	P,E,L	X	X	ME	ME	ME	4
Ceanothus, Martin	E,L	X		PO	ME	EX	3
Ceanothus, snowbush	E,L	X		ME	ME	EX	3
Chokecherry, black	E,L	X		PO	PO	EX	2
Cliffrose, Stansbury	E,L	X		ME	ME	EX	2
Elderberry, blue	E,L	X		PO	ME	EX	2
Ephedra, green	E,L	X		ME	ME	ME	2
Kochia, forage	P,E		X	ME	EX	ME	5
Mahogany, curlleaf	E,L	X	X	PO	ME	EX	2
Mahogany, true	E,L	X	X	PO	ME	EX	2
Rabbitbrush, mountain low	P,E,L	X	X	EX	EX	EX	5
Rabbitbrush, mountain rubber	P,E,L	X	X	EX	EX	EX	5
Rabbitbrush, mountain and basin white stem rubber	P,E,L	X	X	EX	EX	EX	5
Rose, Woods	E,L	X	X	PO	PO	EX	2
Sagebrush, low	P,E,L	X		EX	EX	ME	5
Sagebrush, mountain big	P,E,L	X	X	EX	EX	EX	5
Sagebrush, silver	P,E,L	X		EX	EX	ME	5
Saltbush, fourwing	P,E	X	X	ME	ME	ME	2
Serviceberry, Saskatoon	E,L	X		PO	PO	EX	2
Snowberry, mountain	E,L	X		PO	PO	EX	2
Squawapple	E,L	X		PO	PO	EX	2
Sumac, skunkbush	E,L	X		PO	ME	EX	2
Sumac, Rocky Mountain smooth	E,L	X		PO	ME	EX	2

Seeding Rate	**Precipitation**	
Growth form	**12 - 17 inches**	**17+ inches**
	Lbs/Acre[d]	
Grasses	4 - 6	4 - 5
Forbs	4 - 6	3 - 5
Shrubs	3 - 4	3 - 4

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Natural spread: 1 = poor; 2 = fair; 3 = moderate; 4 = good; 5 = excellent.
[d] Drill rate—broadcast seeding requires 1/4 - 1/3 additional seed.

Table D-3. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding silver sagebrush, timberline sagebrush, and subalpine big sagebrush sites. (From Monsen and Stevens RMRS - GTR - 2004. In press). This is "Table 6" in Section II of Monsen (2005).

		Use index for:		**Competitiveness[b] as a seedling, in the presence of:**			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Grasses							
Barley, meadow	P,E,L	X	X	EX	EX	ME	4
Bluegrass, big	E,L	X	X	ME	ME	ME	4
Bluegrass, Canada	E,L		X	ME	ME	ME	4
Brome, meadow	P,E,L		X	ME	ME	ME	4
Brome, mountain	P,E,L	X	X	EX	EX	EX	5
Brome, nodding	P,E,L	X		EX	EX	EX	5
Brome, smooth, northern	P,E,L		X	EX	EX	EX,NC	5
Brome, smooth, southern	P,E,L	X		EX	EX	EX	5
Brome, subalpine	E,L		X	ME	EX	EX,NC	5
Fescue, hard sheep	P,E,L		X	ME	ME	EX,NC	3
Fescue, sheep	P,E,L	X	X	ME	ME	EX,NC	3
Foxtail, creeping	P,E,L		X	ME	EX	EX	5
Foxtail, meadow	P,E,L		X	ME	ME	EX	5
Needlegrass, green	P,E,L	X		ME	ME	ME	3
Needlegrass, Letterman	P,E,L	X	X	ME	ME	ME	3
Oatgrass, tall	P,E		X	ME	EX	ME	5
Orchardgrass	P,E,L		X	EX	EX	ME	5
Hair-grass, tufted	P,E	X	X	PO	ME	ME	5
Sedge, ovalhead	P,E,L	X		PO	ME	EX	2
Timothy	P,E		X	EX	EX	PO	5
Timothy, alpine	P,E,L	X		EX	EX	ME	5
Wheatgrass, slender	P,E,L	X	X	EX	EX	ME	4
Forbs							
Alfalfa (non-irrigated type)	P,E		X	EX	EX	ME	3
°Aster, blueleaf	P,E,L	X		ME	ME	EX	4
Aster, Englemann	P,E,L	X		PO	ME	EX	4
Crownvetch	E,L		X	ME	ME	EX	4
Geranium, sticky and Richardson	P,E,L	X	X	ME	ME	EX	4
Goldeneye, showy	P,E	X		ME	EX	EX	3
Goldenrod, Canada	P,E,L	X		ME	ME	EX	4
Groundsel, butterweed	P,E	X		PO	ME	EX	4
Lupine, mountain	E,L	X		ME	ME	EX	2
Lupine, silky	E,L	X		ME	ME	EX	2
Milkvetch, cicer	E,L		X	ME	EX	ME	4
Penstemon, Eaton	P,E	X	X	ME	ME	ME	5
Penstemon, low	P,E	X	X	ME	ME	ME	5
Penstemon, Rocky Mountain	P,E	X	X	ME	ME	ME	5
Penstemon, Wasatch	P,E	X	X	ME	ME	EX	5
Sage, Louisiana	P,E	X	X	ME	ME	PO	5
Sainfoin	E		X	ME	EX	ME	4
Sweetanise	E,L	X	X	ME	ME	ME	4
Yarrow, western	P,E,L	X	X	ME	ME	ME	4
Shrubs							
Chokecherry, black	E,L	X	X	PO	PO	EX	2

Table D-3. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding silver sagebrush, timberline sagebrush, and subalpine big sagebrush sites. (From Monsen and Stevens RMRS - GTR - 2004. In press). This is "Table 6" in Section II of Monsen (2005).

		Use index for:		Competitiveness[b] as a seedling, in the presence of:			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Cinquefoil, bush	E,L	X	X	ME	ME	EX	2
Elderberry, red	L	X	X	PO	ME	EX	2
Rabbitbrush, mountain low	P,E	X	X	ME	ME	ME	5
Sagebrush, silver	P,E,L	X	X	ME	ME	EX	5
Sagebrush, timberline	P,E,L	X	X	ME	ME	EX	5
Snowberry, mountain	P,E,L	X	X	PO	PO	EX	5

Seeding Rate

Growth Form	Lbs/Acre[d]
Grasses	4 - 5
Forbs	3 - 4
Shrubs	3 - 4

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Natural spread: 1 = poor; 2 = fair; 3 = moderate; 4 = good; 5 = excellent.
[d] Drill rate—broadcast seeding requires 1⁄4 - 1⁄3 additional seed.

Table D-4. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding basin big sagebrush sites. (From Monsen and Stevens RMRS – GTR - 2004. In press). This is "Table 7" in Section II of Monsen (2005).

		Use index for:		Competitiveness[b] as a seedling, in the presence of:			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Grasses							
Bluegrass, Sandberg	P,E,L	X		ME	ME	ME	4
Dropseed, sand	P,E,L	X		EX	ME	ME	4
Fescue, hard sheep	P,E,L		X	ME	ME	EX,NC	3
Fescue, Idaho	E,L	X		PO	ME	ME	3
Fescue, sheep	P,E,L	X		ME	ME	ME	3
Galleta	P,E,L	X		ME	ME	ME	4
Grama, blue	P,E,L	X		ME	ME	ME	4
Needle-and-thread	P,E	X		ME	ME	ME	4
Needlegrass, Thurber	P,E,L	X		ME	ME	EX	4
Orchardgrass,' Paiute'	P,E,L		X	ME	ME	ME	5
Ricegrass, Indian	P,E,L	X		ME	EX	EX	3
Rye, mountain	P,E		X	EX	EX	ME	5
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME	4
Trisetum, spike	P,E,L	X		ME	ME	ME	3
Wheatgrass, bluebunch	P,E,L	X		ME	ME	EX	3
Wheatgrass, fairway	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, standard	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, streambank	P,E,L	X	X	ME	ME	ME	4
Wheatgrass, tall	P,E		X	ME	ME	ME	2
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX	4
Wheatgrass, western	P,E,L	X	X	PO	ME	EX	4
Wildrye, Great Basin	E,L	X		PO	ME	EX	2
Wildrye, Russian	P,E,L		X	PO	ME	EX	2
Forbs							
Agoseris, pale	P,E,L	X		EX	ME	ME	5
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME	3
Aster, Pacific	P,E	X	X	ME	ME	ME	4
Burnet, small	P,E,L		X	EX	EX	ME	4
Flax, Lewis	P,E,L	X	X	ME	EX	ME	5
Goldeneye, showy	P,E,L	X	X	ME	ME	PO	3
Globemallow Gooseberryleaf and scarlet	E,L	X	X	ME	ME	EX	2
Hawksbeard, tapertip	P,E,L	X		ME	ME	ME	4
Lupine, Nevada	E,L	X		ME	ME	EX	2
Penstemon, Eaton	P,E,L	X		EX	EX	ME	5
Penstemon, low	P,E,L	X		EX	EX	EX	5
Penstemon, Palmer	P,E	X	X	EX	EX	PO	5
Salsify, vegetable	P,E,L	X		ME	ME	ME	4
Sweetvetch, Utah	P,E,L	X		ME	ME	ME	3
Yarrow, western	P,E,L	X	X	EX	EX	ME	4
Shrubs							
Bitterbrush, antelope	P,E,L	X		ME	EX	EX	4
Ephedra, green	E,L	X		PO	ME	EX	2
Hopsage, spiny	E,L	X		ME	ME	EX	2

Table D-4. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding basin big sagebrush sites. (From Monsen and Stevens RMRS – GTR - 2004. In press). This is "Table 7" in Section II of Monsen (2005).

		Use index for:		**Competitiveness[b] as a seedling, in the presence of:**			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Kochia, forage	P,E,L		X	EX	EX	ME	5
Rabbitbrush, mountain low	P,E,L	X	X	EX	EX	ME	5
Rabbitbrush, mountain and basin white stem rubber	P,E,L	X	X	EX	EX	ME	5
Sagebrush, basin big	P,E,L	X	X	ME	EX	EX	5
Sagebrush, Wyoming big	P,E,L	X		ME	EX	EX	4
Sagebrush, low	P,E,L	X		ME	EX	EX	5
Saltbush, fourwing	E,L	X	X	ME	ME	ME	2
Winterfat	P,E,L	X	X	ME	ME	ME	3

Seeding Rate	**Precipitation**	
Growth form	**9-13 inches**	**13+ inches**
	Lbs/Acre[d]	
Grasses	4 - 5	4 – 5
Forbs	4 - 5	5 – 6
Shrubs	3 - 4	4 – 5

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Natural spread: 1 = poor; 2 = fair; 3 = moderate; 4 = good; 5 = excellent.
[d] Drill rate—broadcast seeding requires 1⁄4 - 1⁄3 additional seed.

Table D-5. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding Wyoming big sagebrush sites. (From Monsen and Stevens RMRS-GTR - 2004. In press). This is "Table 8" in Section II of Monsen (2005).

		Use index for:		Competitiveness[b] as a seedling, in the presence of:			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Grasses							
Bluegrass, Sandberg	P,E,L	X		ME	ME	EX	4
Dropseed, sand	P,E,L	X	X	EX	ME	EX	4
Fescue, hard sheep	P,E,L		X	ME	ME	EX	3
Fescue, Idaho	P,E,L	X		PO	ME	ME	3
Galleta	P,E,L	X		ME	ME	ME	4
Grama, blue	P,E,L	X		ME	ME	EX	4
Needle-and-thread	P,E	X		ME	ME	ME	4
Needlegrass, Thurber	P,E,L	X		ME	ME	EX	4
Ricegrass, Indian	P,E,L	X		ME	ME	EX	3
Rye, mountain	P,E		X	EX	EX	ME	5
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	EX	4
Trisetum, spike	P,E,L	X		ME	ME	ME	3
Wheatgrass, bluebunch	P,E,L		X	EX	EX	EX	3
Wheatgrass, fairway	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, standard	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC	5
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX,NC	3
Wheatgrass, streambank	P,E,L	X		ME	ME	ME	4
Wheatgrass, thickspike	P,E,L	X		ME	ME	EX	4
Wheatgrass, western	P,E,L	X		PO	ME	EX	4
Wildrye, Great Basin	E,L	X		PO	ME	EX	2
Wildrye, Russian	P,E,L		X	PO	ME	EX	3
Wildrye, Salina	E,L	X	X	ME	ME	EX	4
Forbs							
Agoseris, pale	P,E,L	X		EX	ME	ME	5
Alfalfa	P,E,L		X	ME	ME	PO	3
Alfileria	P,E		X	EX	EX	ME	5
Balsamroot, arrowleaf	E,L	X		ME	ME	EX	2
Burnet, small	P,E,L		X	ME	ME	PO	4
Flax, Lewis	P,E,L	X	X	ME	ME	PO	5
Goldeneye, showy	P,E,L	X	X	ME	ME	PO	3
Globemallow, gooseberryleaf	E,L	X	X	PO	ME	EX	2
Globemallow, scarlet	E,L	X	X	PO	ME	EX	2
Hawksbeard, tapertip	P,E,L	X		ME	ME	ME	4
Lupine, Nevada	E,L	X		ME	ME	ME	2
Penstemon, littlecup	P,E,L	X		ME	ME	ME	5
Penstemon, low	P,E,L,	X		ME	ME	ME	5
Penstemon, Palmer	P,E,L	X	X	ME	ME	PO	5
Yarrow	P,E,L	X		ME	ME	ME	4
Shrubs							
Ephedra, green	E,L	X		PO	PO	PO	2
Hopsage, spiny	E,L	X		PO	ME	EX	2
Kochia, forage	P,E,L		X	EX	EX	ME	5
Peachbrush, desert	E,L	X		PO	PO	EX	2

Table D-5. Ecological status, use index, competitiveness, seeding rate, and natural spread index of species adapted for seeding Wyoming big sagebrush sites. (From Monsen and Stevens RMRS-GTR - 2004. In press). This is "Table 8" in Section II of Monsen (2005).

		Use index for:		**Competitiveness[b] as a seedling, in the presence of:**			
Species	**Ecological Status[a]**	**Restoration Planting**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**	**Natural spread[c]**
Rabbitbrush, mountain low	P,E,L	X	X	EX	EX	ME	5
Rabbitbrush, mountain and basin white stem rubber	P,E,L	X	X	EX	EX	EX	5
Saltbush, fourwing	E,L	X	X	ME	ME	ME	2
Winterfat	P,E,L	X	X	ME	ME	ME	3
Seeding Rate							
Growth Form	Lbs/Acre[d]						
Grasses	5 – 6						
Forbs	4 – 5						
Shrubs	2 – 3						

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Natural spread: 1 = poor; 2 = fair; 3 = moderate; 4 = good; 5 = excellent.
[d] Drill rate—broadcast seeding requires 1⁄4 - 1⁄3 additional seed.

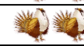
Table. D-6: Food and cover value for sage-grouse. This is "Appendix I" in Monsen (2005).

FORBS			
Common Name	**Scientific Name**	**Cover Value[1]**	**Food Value[1]**
Western yarrow	*Achillea millefolium*	2	5
False dandelion	*Agoseris glauca*	1	5
Everlasting	*Antennaria spp.*	1	4
Pacific aster	*Aster chilensis*	3	4
Blueleaf aster	*A. glaucodes*	3	4
Hairy balsamroot	*Balsamorhiza hookeri*	4	4
Cutleaf balsamroot	*B. macrophylla*	4	4
Arrowleaf balsamroot	*B. sagittata*	4	4
Sego lily	*Calochortus spp.*	1	4
Indian paintbrush	*Castillega spp.*	1	3
Tiny trumpet	*Collomia linearis*	1	5
Hawksbeard	*Crepis spp.*	2	5
Fleabane	*Erigeron spp.*	2	5
Sulfur eriogonum	*E. umbellatum*	2	3
Wyeth eriogonum	*Eriogonum hereleoides*	2	3
Prairiesmoke	*Gayophytum spp.*	1	4
Curlcup gumweed	*Grindelia squarrosa*	2	4
Utah sweetvetch	*Hedysarum boreale*	3	5
Prickley lettuce	*Lactuca serriola*	2	5
Pea	*Lathyrus spp.*	2	4
Pepperweed	*Lepidium spp.*	1	4
Gilia	*Linanthus spp.*	1	4
Lewis flax	*Linum perenne*	3	4
Desertparsley	*Lomatium spp.*	1	5
Lupine	*Lupinus spp.*	4	4
Alfalfa	*Medicago sativa*	5	5
Monkey flower	*Minulus spp.*	1	5
Broomrape	*Orobanche spp.*	1	5
Firecracker penstemon	*Penstemon eatonii*	2	3
Palmer penstemon	*P. palmeri*	2	3
Phlox	*Phlox spp.*	2	5
Cinquefoil	*Potentilla spp.*	1	3
Small burnet	*Sanquisorba minor*	3	3
Groundsel	*Senecio spp.*	1	3
Globemallow	*Sphaeralcea spp.*	2	3

Table. D-6: Food and cover value for sage-grouse. This is "Appendix I" in Monsen (2005).

FORBS			
Common Name	**Scientific Name**	**Cover Value[1]**	**Food Value[1]**
Common dandelion	*Taraxacum officinale*	🦃	🦃🦃🦃🦃🦃
Salsify	*Tragopogon spp.*	🦃🦃	🦃🦃🦃🦃🦃
Clover	*Trifolium spp.*	🦃🦃	🦃🦃🦃🦃🦃
GRASSES			
Thickspike wheatgrass	*Agropyron dasytachyum*	🦃🦃🦃	-
Standard/desert wheatgrass	*A. desertotum*	🦃🦃	-
Intermediate wheatgrass	*A. intermedium*	🦃	-
Fairway crested wheatgrass	*A. cristatum*	🦃🦃	-
Siberian crested wheatgrass	*A. fragile*	🦃🦃	-
Western wheatgrass	*A. smithii*	🦃🦃	-
Bluebunch wheatgrass	*A. spicatum*	🦃🦃🦃🦃🦃	-
Slender wheatgrass	*A. trachycaulum*	🦃🦃🦃🦃🦃	-
Blue gramma	*Bouteloua gracilis*	🦃🦃	-
Mountain brome	*Bromus carinatus*	🦃🦃🦃	-
Smooth brome	*B. inermus*	🦃	-
Orchard grass	*Dactylis glomerata*	🦃🦃🦃	-
Great Basin wildrye	*Elymus cinereus*	🦃🦃🦃	-
Russian wildrye	*E. junceus*	🦃🦃🦃	-
Junegrass	*Koeleria macrantha*	🦃🦃🦃🦃🦃	-
Indian ricegrass	*Oryzopsis hymenoides*	🦃🦃🦃🦃🦃	-
Mutton bluegrass	*Poa fendleriana*	🦃🦃🦃🦃🦃	-
Sandberg bluegrass	*P. secunda*	🦃🦃🦃🦃	-
Squirreltail	*Sitanion hystrix*	🦃🦃🦃🦃🦃	-
Sand dropseed	*Sporobolus cryptandrus*	🦃🦃🦃🦃🦃	-
Needle-and-threadgrass	*Stipa comata*	🦃🦃🦃🦃🦃	-
Green needlegrass	*S. lettermanii*	🦃🦃🦃🦃🦃	-

Table. D-6: Food and cover value for sage-grouse. This is "Appendix I" in Monsen (2005).

SHRUBS			
Common Name	**Scientific Name**	**Cover Value**[1]	**Food Value**[1]
Saskatoon serviceberry	*Amelanchier alnifolia*		-
Utah serviceberry	*A. utahensis*		-
Low sagebrush	*Artemisia arbuscula*		
Silver sagebrush	*A. cana*		
Black sagebrush	*A. nova*		
Basin big sagebrush	*A. tridentata ssp. tridentata*		
Mountain big sagebrush	*A. t. spp. vaseyana*		
Wyoming big sagebrush	*A. t. spp. wyomingensis*		
Fourwing saltbush	*Atriplex canescens*		-
Shadscale	*A. confertifolia*		-
Rubber rabbitbrush	*Chrysothamnus nauseosus*		-
Winterfat	*Ceratoides lanata*		
Chokecherry	*Prunus virginiana*		-
Antelope bitterbrush	*Purshia tridentata*		-
Mountain snowberry	*Symphoricarpos oreophilus*		-

[1]- No value

 **Low**

 **Low-Medium**

 **Medium**

 **Medium-High**

 **High**

APPENDIX E

GRAZING MANAGEMENT OPTIONS FOR GrSG

Grazing Management Options for GrSG

If habitat assessments and monitoring indicate forage use and habitat guidelines are being met with the current grazing system, changes may not be needed. Use by wild ungulates may limit or alter the effectiveness and design of grazing management alternatives (see "Grazing" strategy, Objective 6.2.2, pg. 346). Consult with local range conservationists and local work groups to assess local site conditions and capability.

1. If habitat assessments and monitoring indicate a change in forage or other habitat element use may be needed, consider changing the distribution of livestock, duration of use, and time of year that livestock graze a particular location by using grazing systems such as rest-rotation, deferred rotation, or high intensity/short duration. Allow for growth or re-growth in each pasture during each growing season to provide quality vegetation and vegetation height requirements during periods of sage-grouse seasonal use (refer to "GrSG Structural Habitat Guidelines", Appendix A).

2. Develop grazing banks to provide alternative forage and facilitate adaptive management for situations discussed within this list of alternatives.

3. When alternative forage is available and/or other incentives can facilitate changes, consider delaying spring grazing of occupied breeding habitat and/or avoid using sage-grouse seasonal use areas during or immediately before important use periods.

4. Where possible, do not graze the same pasture at the same time of year for consecutive years. If not possible, develop smaller grazing units within large pastures using salting, supplements, water, herding, or fencing to facilitate desired grazing management.

5. Consider the impact to sage-grouse when locating and constructing new fences and livestock watering and handling facilities. Consider moving existing facilities and fences if they are affecting (increasing) grouse mortality, especially near leks.

6. If sage-grouse mortality due to collision with fences is documented or likely to occur, consider marking the appropriate fence section with permanent flagging or other suitable material that will increase visibility of the fence for GrSG.

7. Water developments, placement of supplements, fencing, and season of use are just some of the tools that can be used to discourage over-utilization around riparian areas, water sources, bottoms and draws.

8. If needed, defer livestock use from pastures or allotments in occupied GrSG habitat, or change management plans when abnormal environmental events occur (e.g., drought, heavy snow fall, flooding) and stress vegetation.

9. As necessary, periodically graze lek sites moderate to heavy in late fall, to maintain site openness that GrSG require. Note: temporary fencing, herding, or increased stocking rate could be used, but needs to be limited to specific lek site, and avoid overgrazing surrounding area.

10. Avoid placing salt, minerals or supplements near leks and use them as tools to achieve desired livestock distribution and use in GrSG habitat.

11. The timing and location of livestock turnout and trailing should be adjusted to avoid livestock concentrations and other livestock associated disturbances in lek areas during the breeding season (March through May). Work with local wildlife personnel to locate and map lek sites.

12. Develop, when needed, alternative water sources to distribute livestock and improve water availability for wildlife and GrSG. Ensure wildlife accessibility to water and install escape ramps in all new and existing water troughs. Consider water development design to minimize WNV risk to GrSG.

13. Spring developments (both new and old) can be constructed and/or modified to maintain their free-flowing and wet meadow characteristics. Consider project design to minimize WNV risk to GrSG.

14. If monitoring data indicate forb vigor is not at proper condition or is declining, defer spring grazing periodically to increase forb vigor and occurrence. Lightly or moderately graze deferred areas following nesting or in the fall. Monitor to determine actual growth of grass during spring and summer deferment.

15. For late-successional sagebrush stands that don't meet habitat objectives for GrSG seasonal habitats, use mechanical, chemical, or grazing treatments that will rejuvenate new sagebrush growth and improve sagebrush quality and age diversity, as well as understory forbs and grasses.

16. Treat sagebrush (e.g., mechanical, grazing, or chemical treatments) and manage grazing in historic riparian areas to increase riparian zone and raise the water table to reestablish riparian grasses and shrubs for brood-rearing habitat.

17. To improve vegetation composition and forage, plant forb seed in rangelands that lack forbs and have enough moisture and the soil characteristics to establish and support forbs.

18. Defer grazing in wildfire and treatment areas until desired understory and overstory are established.

APPENDIX F

AVAILABLE FUNDING OPPORTUNITIES

FOR GrSG HABITAT CONSERVATION

Table F-1. Specific funding opportunities identified for GrSG habitat conservation.

Colorado Division of Wildlife (CDOW)						
Grant / Program	**What land is eligible?**	**Length of Agreement**	**Easements**	**Cost Share**	**Applicant obligations**	**Contact Information**
Colorado Species Conservation Partnership Program (CSCP)	Any land where an easement or management plan are needed to benefit sage-grouse.	Variable	one-time, up-front payment	Variable	Develop a conservation plan and comply with the terms of the easement, or develop a plan and assist with the cost, establishment, and maintenance of conservation practices.	Ken Morgan (303)291-7404 http://wildlife.state.co.us/
Habitat Partnership Program (HPP)	All land is eligible where wildlife/human interactions occur.	Variable	N/A	Variable	Contact local District Wildlife Manager and develop proposal. Must be able to evaluate the success of project based on objectives.	Local District Wildlife Manager http://wildlife.state.co.us/
Cooperative Habitat Improvement Program (CHIP)	All private land for which the habitat improvement has been approved by the area habitat biologist	10 years	N/A	85%	Applicant must provide 15% of cost of habitat improvement and must ensure practice is maintained through the term of the contract.	CDOW (970)255-6185 http://wildlife.state.co.us/
Habitat Stamp Program	All land – primarily for deer/elk winter range and hunting and fishing opportunities	Variable	N/A	variable	N/A	Ken Morgan (303)291-7404 http://wildlife.state.co.us/

Table F-1 (con't). Specific funding opportunities identified for GrSG habitat conservation.

Natural Resources Conservation Service (NRCS)							
Grant / Program	**What land is eligible?**	**Length of Agreement**	**Rental Payments**	**Easements**	**Cost Share**	**Applicant obligations**	**Contact Information**
Conservation Security Program (CSP)	Private agriculture operation lands	5-10 years	Flat rates - based on Conservation work applied to land	N/A	50—65%	Record keeping of past and present conservation efforts	Local NRCS office www.nrcs.usda.gov
Conservation Reserve Program (CRP)	Highly erodible cropland that has been planted for 4 of the 6 years preceding enactment of the 2002 law. Marginal pastureland is also eligible.	10-15 years	Payment based on length of agreement and average rental rates for the county.	N/A	50%	Develop and follow a plan for the conversion of cropland to a less intensive use. Also, assist with the cost, establishment, and maintenance of conservation practices.	Local FSA or NRCS office. www.nrcs.usda.gov
Conservation Reserve Program Continuous Sign-up	Highly erodible cropland that has been planted for 4 of the 6 years preceding enactment of the 2002 law. Marginal pastureland is also eligible.	10-15 years	Payment based on length of agreement and average rental rates for the county	N/A	50% to 90%	Develop and follow a plan to implement riparian buffers, wildlife habitat buffers, wetland buffers, filter strips, grass waterways, shelterbelts, living snow fences, contour grass strips, salt tolerant vegetation, or shallow water areas for wildlife. Also, assist with the cost, establishment, and maintenance of conservation practices.	Local FSA or NRCS office www.nrcs.usda.gov
Environmental Quality Incentives Program (EQIP)	All private land in agricultural production is eligible ; includes cropland, grassland, pastureland and non-industrial private forestland.	1-10 years	N/A	N/A	up to 75%	Develop and follow an EQIP plan that describes the conservation and environmental purposes to be achieved; assist with installation costs.	Local NRCS office www.nrcs.usda.gov
Farm and Ranchland Protection Program (FRPP)	Private land that contains prime farmland or other unique resources and is subject to a pending easement from an eligible entity.	Perpetual	N/A	one-time, up-front payment	N/A	Continue to use the land for agricultural purposes. Develop a conservation plan and comply with the terms of the easement.	Local NRCS office www.nrcs.usda.gov
Grassland Reserve Program (GRP)	Private land that includes grassland, forbs, or shrubs (including rangeland and pastureland); and land that historically was dominated by grasses, forbs, and shrubs and has significant value for plants and animals.	10-30 year agreement, or perpetual	annual payment based on length of agreement	one-time, up-front payment on perpetual	up to 100%	Develop and follow a plan for the restoration and maintenance of grasslands. If necessary, assist with the cost of restoration. Can maintain agricultural use with development of a conservation plan.	Local NRCS office www.nrcs.usda.gov

Table F-1 (con't). Specific funding opportunities identified for GrSG habitat conservation.

Natural Resources Conservation Service (NRCS)							
Grant / Program	**What land is eligible?**	**Length of Agreement**	**Rental Payments**	**Easements**	**Cost Share**	**Applicant obligations**	**Contact Information**
Wetlands Reserve Program (WRP)	Most private wetlands converted to agricultural use prior to 1985 are eligible. Wetland must be restorable and suitable for wildlife benefits.	10 years, 30 years, or perpetual	N/A	one-time, up-front payment	up to 100%	Develop and follow a plan for the restoration and maintenance of the wetland. If necessary, assist with the cost of restoration. Also, must give up agriculture production rights.	Local NRCS office www.nrcs.usda.gov
Wildlife Habitat Incentives Program (WHIP)	All private land is eligible, unless it is currently enrolled in CRP, WRP, or a similar program	5-15 years	N/A	N/A	up to 75%	Prepare and follow a wildlife habitat development plan; assist with installation costs.	Local NRCS office www.nrcs.usda.gov

Table F-1 (con't). Specific funding opportunities identified for GrSG habitat conservation.

U.S. Fish and Wildlife Service (USFWS)							
Grant / Program	**What land is eligible?**	**Length of Agreement**	**Rental Payments**	**Easements**	**Cost Share**	**Applicant obligations**	**Contact Information**
Landowner Incentive Program (LIP)	All private and tribal land	Variable	Yes	Short and long term	up to 75%	Personnel from state agency will need to submit application, USFWS will approve, and CDOW will administer grant in cooperation with the landowner.	Ken Morgan (303)291-7404 http://wildlife.state.co.us/
Intermountain West Joint Venture Partnership	Projects considered acceptable for funding include long-term protection, restoration, or enhancement of any bird habitat. Joint Venture emphasis is centered upon on-the ground conservation.	Up to 30 years	N/A	Yes	50%	N/A	David Klute – Colorado Representative (303)291-7320 www.iwjv.org
North American Wetland Conservation Act	State, private, Tribal, Federal?	Variable	No	Long-term	50%	Work with local USFWS office, but grant is administered through USFWS Migratory Bird Office	Local USFWS office or http://www.iwjv.org/
North American Wetland Conservation Act, Small Grants	State, private, Tribal, Federal	Variable	No	Long-term	50%	Work with local USFWS office, but grant is administered through USFWS Migratory Bird Office (Up to $50K/grant)	Local USFWS office or http://www.iwjv.org/
Partners for Fish and Wildlife	All private land, wetland and riparian habitat has been a primary focus along with some treatment of sagebrush.	Variable, most projects delivered in 1-3 months	N/A	N/A	75-100%	Work with USFWS Biologist to develop project plan. Follow management actions for duration of wildlife extension agreement.	Bob Timberman (970) 723 4926 www.coloradopartners.fws.gov
Private Stewardship Grants Program	Private land	Variable	Yes	No	Variable	The contract and plan must provide quantifiable measures to evaluate the success of the project. The grant is administered through USFWS Ecological Services.	Local USFWS office http://grants.fws.gov/ (applications due 12/03 or 1/04)
Section 6 Conservation Grants	State, private, Tribal, Federal	Variable	N/A	N/A	up to 75%	Work with local USFWS office, but grant is administered through USFWS Ecological Services	Local USFWS office http://grants.fws.gov/

Table F-1 (con't). Specific funding opportunities identified for GrSG habitat conservation.

U.S. Fish and Wildlife Service (USFWS)							
Grant / Program	**What land is eligible?**	**Length of Agreement**	**Rental Payments**	**Easements**	**Cost Share**	**Applicant obligations**	**Contact Information**
State Wildlife Grants	State, private, Tribal, Federal	Variable	Yes	Short term and long term	75% planning, 50% impleme n-tation	States, but not Tribes, must develop comprehensive wildlife management plans	Jim.Guthrie@co.state.us or local USFWS office http://grants.fws.gov/
Tribal Wildlife Grants	Tribal	Variable	N/A	N/A	100%	Up to $250,000 / tribe	Local USFWS office http://grants.fws.gov/

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Table F-1 (con't). Specific funding opportunities identified for GrSG habitat conservation.

Non-Governmental Organizations (NGOs)							
Agency / Organization	**Grant / Program**	**What land is eligible?**	**Length of Agreement**	**Easements**	**Cost Share**	**Applicant obligations**	**Contact Information**
Audubon Society	N/A	Stress bird habitat and ecosystem restoration	Variable	N/A	Variable	N/A	www.audubon.org
Pheasants Forever	N/A	Mostly private lands do acquire lands for public use.	Variable	N/A	Variable	N/A	www.pheasantsforever.org
Great Outdoors Colorado (GOCO)	Legacy Initiative/ Open Space/ Wildlife Grants	All private and public land where state agencies, non-profit conservation organizations, local governments, or private land owners are interested in conservation and land protection.	Variable	Possible	Variable, usually requires a minimum 25% match	Personnel from local governments, non-profit land conservation organizations, CDOW, and Colorado State Parks need to be submit proposal and manage contract.	www.goco.org (303)863-7522 info@goco.org
Mule Deer Foundation	N/A	All land that is critical to wildlife	Variable	Possible	Variable	Must go through USFS, BLM or one of their corporate partners	www.muledeer.org 1-888-375-3337
Quail Unlimited	N/A	All land that potentially provides habitat for quail and (sometimes) sage grouse	Variable	Possible	Variable	Must go through USFS, BLM or one of their corporate partners	www.qu.org
Rocky Mountain Elk Foundation	N/A	All land that is critical to wildlife	Variable	Possible	Variable	Must go through USFS, BLM or one of their corporate partners	www.rmef.org
National Fish and Wildlife Foundation	N/A	Special grants for research on all land that potentially provides habitat for fish and wildlife.	Variable	Possible	Minimum 1:1	Non-federal partners, community-based organizations, tribes, educational institutions, and other non-profit organizations.	www.nfwf.org

Table F-1 (con't). Specific funding opportunities identified for GrSG habitat conservation.

Non-Governmental Organizations (NGOs)							
Agency / Organization	**Grant / Program**	**What land is eligible?**	**Length of Agreement**	**Easements**	**Cost Share**	**Applicant obligations**	**Contact Information**
National Forest Foundation	N/A	On or adjacent to National Forests or Grasslands	Variable	N/A	1:1 ratio with private	Non-federal partners, community-based organizations, tribes, educational institutions, and other non-profit organizations.	www.natlforests.org
North American Grouse Partnership	N/A	All land that provides habitat to sage or other grouse	Variable	N/A	Variable	Non-federal partners, community-based organizations, tribes, educational institutions, and other non-profit organizations.	www.grousepartners .org
The Nature Conservancy	N/A	All private and public land where agencies, non-profit conservation organizations, local governments, or private land owners are interested in conservation and land protection.	Variable	Possible	Variable	Federal and non-federal partners, community-based organizations, tribes, educational institutions, and other non-profit organizations.	www.nature.org
National Wildlife Turkey Federation	N/A	All private and public land where agencies, non-profit conservation organizations, local governments, or private land owners are interested in conservation and land protection.	Variable	Possible	Variable	Federal and non-federal partners, community-based organizations, tribes, educational institutions, and other non-profit organizations.	www.nwtf.org

APPENDIX G

ENERGY AND MINING LEASING AND DEVELOPMENT: PROCESS

Oil and Natural Gas

The BLM is responsible for managing oil and gas development on federal lands as well as those lands where the federal government retained the minerals and patented the surface. For National Forest System lands, BLM coordinates with the USFS, which is responsible for identifying lands available for leasing through their land use planning process. If a nominated lease is in conformance with the appropriate Forest Plan, the USFS will provide BLM with the terms and conditions to be made part of the leases offered. BLM cannot lease USFS lands without the consent of the USFS. BLM does not offer USFS lands on its own initiative. And BLM cannot issue a lease on USFS lands over the objection of the USFS.

The Minerals Leasing Act of 1920, and its subsequent amendments, make federal lands available for oil and gas leasing. Both the BLM and USFS identify the lands open to oil and gas leasing in their Land Use Plans (LUPs) and outline the impacts that will occur from reasonably foreseen oil and gas development. To minimize impacts to other resource values and land-uses, the LUPs identify any stipulations to mitigate these impacts, which are attached to the lease and modify the lease terms. Federal policy allows for leasing decisions to be revisited when significant new scientific information becomes available.

For federal lands, BLM has regulatory responsibility for managing oil and gas leasing, exploration, development and production. This management responsibility generally entails issuance of a site-specific permit. Dependent upon the activity proposed, analysis of the proposed action under the National Environmental Policy Act (NEPA) may be required. In those cases where the surface was patented and the BLM retained the minerals, the same processes apply except the mineral lessee or owner is required to obtain a surface use agreement from the surface owner prior to permit approval. On non-federal lands, these processes are managed by the Colorado Oil and Gas Conservation Commission (COGCC). The NEPA analysis process is not applicable to the COGCC process on state or private minerals / non-federal land development.

Typically, oil and gas development occur in a sequential process. This process can be summarized as the following:

(1) Geophysical Exploration occurs (more detail follows). During this phase, the reservoir target is delineated. Geophysical exploration may occur before or after the leasing stage as well.

(2) Leasing Stage. An LUP or associated amendment is developed using the NEPA process. Land that is available for oil and gas leasing is identified and stipulations are developed to mitigate impacts. Once a lease is granted, the oil and gas operator has a legal right to reasonable use of the surface within the lease for exploration and development, within the stipulation attributed to each parcel.

(3) Drilling Operations (more detail follows). An Application for Permit to Drill (APD) is submitted, and if approved, an exploratory well is drilled. If the result is a "dry hole", the well is plugged and reclamation occurs. If the well is successful, production operations

occur. If the geologic prospect warrants additional development, other APDs are submitted and if approved, more exploratory wells are drilled until the limits of the geologic prospect are defined. Additional development drilling can occur at this point. These are development wells and fall under “Production Operations” (see (4)).

(4) Production Operations (more detail follows). If a gas well is completed, rights-of-way for pipelines, powerlines, etc., are obtained and installed. Production equipment is installed on the wellpad and production begins. Interim reclamation of the well pad occurs. The operator makes visits to the wellpad to make sure operations proceed properly and to adjust equipment. Operator submits sundry notices for other operations requiring approval, along with additional APDs. As a well becomes depleted, the operator obtains approval to plug the well and conduct reclamation operations.

To help with development of the conservation strategies, more detailed descriptions of typical oil and gas development stages follow, including clarification of which types of activities require various government leases and approvals.

“Geophysical exploration” is a general term used for various indirect exploration methods that use geophysical instruments and methods to determine subsurface condition (i.e., the potential for oil and gas) by analysis of such properties as specific gravity, electrical conductivity, or magnetic susceptibility. A geophysical survey is the use of one or more geophysical techniques in geophysical exploration, such as earth currents, electrical, infrared, heat flow, magnetic, radioactivity and seismic activity. Most modern seismic exploration is based on the collection of data over a 2- or 3-dimensional grid. This requires thousands of geophones (instruments that detect Earth motions) placed on the ground and recording systems capable of recording ground motion from as many sites. The seismic wave is typically generated by either using a surface vibrator, i.e., a Vibroseis truck, or by an explosive source.

When a Vibroseis truck is used as the source, it travels to a pre-determined location where it stops, lowers a metal plate, and vibrates for a specific time. This process is repeated throughout the project area. The Vibroseis trucks travel to the source locations via existing roads and/or trails, or cross county.

When an explosive source is used, explosive materials are placed at pre-determined locations and exploded. They are either placed in a drilled shot hole and exploded, or placed on the surface and exploded. When placed in a drilled shot hole, a small portable drill rig is utilized. The portable drill rig can be driven to the pre-determined locations via existing roads and/or trails or cross county or alternatively for inaccessible locations, it is delivered via helicopter.

Federal approval to perform geophysical operations is required on surface lands administered by BLM or Forest Service. However, an oil and gas lease is not required to perform geophysical operations on federal lands. There are 2 ways in which to request approval of geophysical operations on federal lands: (1) via filing of a Notice of Intent (NOI) to perform geophysical operations; or (2) via a sundry notice if requested under the terms of an oil and gas lease. The NOI process doesn't apply to private surface while a sundry notice may. Either way, the procedures for processing a NOI or sundry notice are similar. Onsite inspections will be scheduled, appropriate natural resource/cultural clearances will be performed and mitigation measures or avoidance alternatives will be developed. The appropriate level of NEPA document will be prepared dependent upon the proposal. Any approval of the NOI will incorporate the mitigation measures identified at the onsite inspections.

Drilling and production operations include all actions/phases associated with drilling and producing an oil or gas well. There are multiple sequential steps which occur. A detailed discussion follows.

Drill Pad Construction

An oil or gas well requires the construction of a level, structurally competent location for placement of the drilling rig and associated equipment. Typical drill pads require an average of between 2 acres for single wells and 5 acres where multiple wells are drilled from 1 surface location. Drill pads are cleared of all vegetation using a bulldozer or other earth-moving equipment. Topsoil is usually removed and stored for use in reclaiming the site. An access road to the drilling location will also be constructed to transport the drilling rig, materials, and well servicing equipment to the site. These roads have a driving surface that is usually 16 - 18 feet wide, and an assumed total disturbed width of 35 feet. Gross vehicle weights of vehicles using these roads may exceed 80,000 lbs. One or two earthen pits will be constructed for storing drill cuttings and drilling mud reserves during drilling. Pits are usually unlined but may be lined with plastic or bentonite clay to prevent fluid loss or contamination of subsurface water resources. Pitless or self-contained drilling systems are sometimes called for in areas of high ground water or sensitive resource values. These systems substitute portable tanks of water and drilling mud reserves and may include a centrifuge system to remove solids from drilling fluids. The site preparation process may last from a few days to several weeks, depending upon the length of access road and size of drilling pad that will be constructed.

Drilling Operations

Oil and gas wells are drilled primarily with rotary drilling rigs. In the rotary method, a hole is drilled by means of a rotating bit to which a downward force is applied. The bit is attached to, and rotated by, a drill string composed of drill pipe and drill collars, with new sections of pipe being added as drilling progresses. Drill cuttings are lifted from the hole by the drilling mud, which is continuously pumped down the drill string through nozzles in the bit and upward through the annular space between the drill pipe and the hole. At the surface, the drilling mud is diverted to tanks or pits for cleaning and treatment. Drilling mud typically has several additives that are used to enhance the properties of the fluid. Typical mud additives include:

• weighting materials to increase the density of the mud
• corrosion inhibitors to protect metal components from corrosion
• dispersants to break up solid clusters of clay particles
• flocculants to cause suspended particles to group together for removal by settling
• surfactants, such as fatty acids and soaps, to defoam and emulsify the mud
• biocides to kill bacteria that may be inhabiting the mud
• fluid loss reducers such as starch and polymers to limit the loss of drilling fluid to subsurface formations

As the hole is drilled, casing is placed in the hole to prevent caving, and to isolate water- and hydrocarbon-bearing zones. Three or four separate casing strings may be used in wells. Casing is secured in place by pumping cement down the inside of the casing, which travels to the bottom of the borehole, then upward into the annular space between the casing and the hole. Following setting of the casing and any surface equipment, the drilling rig is moved from the well location. Drill cuttings are usually allowed to dry, and are then buried in the pit where they accumulated during well completion.

Directional drilling, where geologically and technically feasible, may be employed to reduce the amount of surface disturbance necessary to drill wells or to reach bottom-hole locations that may not be accessible from the surface with a straight hole. More than 1 well can be drilled from a single surface location using this technology, with the objective of effectively accessing the producing horizon beneath areas where surface disturbance is not permitted. A directionally drilled well is more costly to drill than a vertical well to the same depth. Following setting of the casing and any surface equipment, the drilling rig is moved from the well location. Drill cuttings are usually buried in the pit where they were accumulated during well drilling.

Well Completion

After drilling the well, several steps are required to start production. Well completion operations are generally performed by a completion rig (a small, truck-mounted rig used to complete the well and install downhole equipment). The casing and cement must be perforated to enable gas to enter the well bore. Several producing zones may be perforated by means of small, shaped explosive charges that create holes in the casing and cement. Most reservoirs in northwestern Colorado are considered low-permeability reservoirs and require hydraulic fracturing in order to produce at economic flow rates. Hydraulic fracturing is accomplished by pumping a water-based viscous fluid and sand down the well at high pressures and flow rates. After the fracture gradient (the pressure where the formation begins to break down) for the zone is reached and exceeded, the formation fractures and begins taking the fluid and remains propped open after pumping stops and pressure is released. The propped fracture provides a high-permeability channel for gas to enter the well bore. In some wells, hydrochloric or hydrofluoric acid may be pumped into the producing formation to enhance permeability. Gas production from the well is controlled using an assembly of pipes, valves, and fittings at the surface (called the “Christmas tree”). Following completion, a well is allowed to flow back to the pit, which removes any excess fracturing fluid, spent acid, and remaining sand in the well bore. Any gas and oil that comes to the surface is burned off, or "flared." Some operators use specialized separation equipment, referred to as a super separator, to decrease the need for flaring. The well is then shut-in until connected to a gas flowline.

Production Operations

Produced fluid flows from the wellhead into an onsite separator that removes water and condensate from the flow line. Natural gas is directed from the separator into a flowline, a 2- to 4-inch-diameter pipeline leading to a trunk line or natural gas compressor. Flowlines are usually buried but can be laid on the ground surface. Within the field area, flowlines will primarily be built along the existing access road to minimize surface disturbance. Water and condensate are stored in onsite tanks and are periodically removed by truck. The condensate is sold and the water is transported to an approved disposal facility. Trunk lines gather gas from a number of producing wells and are usually 6 to 8 inches in diameter and buried. Compressors are used to move gas from flowlines and trunk lines into transmission lines. Compressor stations range in size from one acre to as much as 20 acres, depending upon the number of compressors required and the need for additional support infrastructure. Transmission lines range from 10 to 36 inches in diameter and transport natural gas to a facility to be conditioned for ultimate sale to a purchaser.

Natural gas wells may periodically require maintenance procedures called workovers. Workovers are performed using a completion rig and may include (1) repairing leaks in the casing, tubing, or other downhole equipment; (2) re-completing the well in additional producing formations; (3) stimulating the well with supplemental fracturing or acid treatments; or (4) removing scale and other accumulated deposits. Workovers may take one day to several days to complete, depending upon the complexity of the tasks to be undertaken. Surface equipment may also require periodic maintenance. Valves, piping, tanks, and separators may require repair, cleaning, and adjustment. Each well is visited on a regular basis by the operator, who checks on the performance of the well, gas condensate and water tanks, and is responsible for the proper functioning of the production equipment. The frequency of these visits may range from once per day to once per week. Some operators use solar-powered remote telemetry facilities to monitor well performance, reducing the number of visits to the well site. Oil wells have operations similar to gas wells, although they typically require a pumping unit such as a pump jack.

Reclamation and Abandonment

Disturbed areas are partially reclaimed following well completion, based on a BLM-approved reclamation plan. This includes reclamation on that portion of disturbed areas which is not considered necessary during well production. Abandoned well locations are reclaimed. Reclamation requirements are contained in the Conditions of Approval (COAs) applied by BLM during the permitting process. Well abandonment involves placing cement plugs in the well bore to prevent fluid migration. Surface facilities are removed and the well is capped below the ground surface. Buried pipelines are usually left in place but plugged at intervals as a safety precaution.

Approvals

Drilling operations on federal oil and gas leases require an approved APD. The operating regulations used to permit an oil and gas well are found in 43 CFR Part 3160. These regulations are implemented and supplemented with a set of Onshore Oil and Gas Orders. The Orders are also regulations and carry the full force and effect of regulation. A well must be drilled in order to produce oil and/or gas from the lease. There are 2 ways to initiate permitting of a well, either via a Notice of Staking (NOS), followed by the submittal of an APD, or directly through submittal of an APD.

Before drilling a well, the lessee, or an operator for the lease, must file an APD. The operator must file an application with the BLM Field Office in which the action will take place. The application must include, in part, a plan for the drilling of the well and a plan for the protection of the surface and environment. The drilling plan contains information as to the depth of the well, how it will be constructed, how ground water and other mineral resources will be protected, and how blowouts and other emergencies will be prevented or dealt with. The surface use plan describes the access road, drill pad and construction methods. It also includes proposed reclamation and mitigation of impacts to wildlife, cultural resources, vegetation, soils, surface water, and other land-uses and values. For wells on National Forest System lands, the USFS approves the surface use plan. If the appropriate information and mitigation is not incorporated into the APD, the application may be modified or rejected. RMP decisions are incorporated by attaching stipulations to the lease and COAs to the APD. Onshore Oil and Gas Order No. 1 requires a field (onsite) inspection as part of the review of an APD. The inspection is a meeting between the parties to explain and clarify the proposed action.

The NEPA process provides written documentation of the environmental review for an APD and the development of mitigation (COAs; see below). The NEPA process also serves as the vehicle to check for conformance with the RMP. At the site-specific level, Environmental Assessments (EAs) are prepared for a majority of APDs in Colorado. In cases where the proposed well is obviously part of a larger field development, and such development has not already been analyzed by a NEPA document other than the RMP, a Field Development EA can be prepared.

Another component of the review process is the technical review of the drilling plan portion of the APD. The APD review by the field office (FO) geologist includes the following items: (1) geological markers and formation tops; (2) oil, gas, and mineral-bearing zones; (3) potential hazards such as abnormal pressure; (4) casing set points; and (5) cement tops. A geologic review report documents the review and is incorporated into the APD case file. The APD review by the FO petroleum engineer includes the following items: (1) casing and cement program; (2) drilling fluid program; (3) pressure control system; and (4) testing, coring, and logging.

When all of the resource specialists have accumulated all of the information about the proposed well operation, they determine requirements for site-specific environmental protection. As part of the impact analysis, each specialist must determine whether the APD needs to be supplemented with additional impact mitigation measures. These measures are called COAs. However, these mitigation measures are distinct from stipulations that are attached to the lease. COAs are developed through the NEPA compliance process for each APD. Stipulations which are attached to the lease are developed through the planning process. The COAs must be reasonable. This means they must be technically possible to accomplish, and they must allow the exercise of lease rights. They must also be plainly worded and justified by the NEPA process. A COA must not prevent an applicant from proceeding with development for either economic or technical reasons.

Once all of the BLM staff specialists have reviewed the APD and determined that the surface use plan and drilling plan are in compliance with BLM regulations, and all other impacts are addressed in the appropriate NEPA document, the APD is ready for approval, providing that the mandatory 30-day posting period has elapsed. At this point, COAs are attached to the APD, and the FO Manager signs and dates the APD. The approved APD is valid for one year, with a one-time extension of up to one year, if requested.

After the well is drilled, certain subsequent well operations require BLM approval via a sundry notice, Form 3160-5. Generally, any work on the wellbore, additional surface disturbance and changes to oil and gas measurement equipment require BLM approval prior to performing the work. During production, field operations are inspected by the BLM to assure accountability for royalties, compliance with the lease, permit safety, and environmental requirements.

The final stage in the life of an oil or gas well usually occurs when it is depleted and can no longer produce in paying quantities. At this stage, the operator submits a plug and abandonment plan which is reviewed and, if necessary, modified by the BLM petroleum engineer prior to approval. When the downhole plugging is completed, the operator submits a subsequent Report of Abandonment which is reviewed by the BLM. When surface reclamation is completed and vegetation has been reestablished, usually in 2 to 3 growing seasons, the operator will submit another subsequent report of a Final Abandonment Notice (FAN). The BLM will inspect the location to determine whether it was reclaimed properly, and if so, approve the FAN.

Coal Bed Methane

Coal bed methane (CBM), also known as natural gas from coal seams and coal bed natural gas, is one of the most important and valuable resources in the Western United States. The natural gas that results from CBM development is a clean burning fossil fuel.

CBM development follows a similar process for Oil and Gas (O&G) development in that reserves are first leased, and natural gas is extracted through the drilling of wells. Generally, water produced by CBM development in Colorado is either re-injected back into the well or hauled away via truck. CBM associated facilities and their potential impacts to GrSG are similar to those expected during O&G production. Potential areas for CBM development typically overlap with other O&G operations and are considered during the RFD process in LUPs.

Oil Shale

Recently enacted legislation (Energy Policy Act of 2005, H.R.6, Section 369) instructed the Department of Interior to make available for leasing (from lands already identified as being available for oil and gas leasing) federal oil shale lands within 6 months after enactment of HR6, for research and development of technologies for the recovery of liquid fuel from oil shale and tar sands on public lands.

The legislation also required the DOI to prepare a Programmatic Environmental Impact Statement (PEIS) for a commercial leasing program for oil shale and tar sands resources. This document will only allocate lands to make them available for the opportunity to lease. Additional NEPA will be required prior to leasing. The Draft PEIS is expected to be completed in late 2007/early 2008. The Record of Decision (ROD) is anticipated late in 2008. The Final Regulations are required 6 months after the draft PEIS is completed. The PEIS will examine 3 oil shale extraction technologies: underground and surface mining with surface retorting, as well as the in-situ retorting process. In-situ retorting involves heating the oil shale while it is still in the ground. One method involves electric heating elements, which would be placed in bore holes, heating the shale to approximately 700 degrees for 3-4 years. The released liquids are gathered in wells specifically designed for that purpose.

The majority of the high potential areas for oil shale development in Colorado are within the BLM's White River Resource Area (WRRA), in Rio Blanco County (S. Thompson, Bureau of Land Management, personal communication). The Resource Management Plan (RMP; Bureau of Land Management 1997) for the WRFO has Resource Decisions that cover the lands available for leasing and development of oil shale. A summary of those decisions are as follows:

1) A total of 223, 860 acres will be available for oil shale leasing;
2) 39,140 acres will be available for open pit development; and
3) 70,820 acres will be available for multi-mineral (oil shale, nahcolite, and dawsonite) leasing following development of acceptable multi-mineral recovery technology.

The above areas are generally considered to be the "high potential" oil shale areas within Colorado (see Fig. 22, pg. 114). The PEIS will amend the White River RMP, as well as the Little Snake RMP, Grand Junction RMP and GSRMP, so these numbers could change in the future.

Mining

Sodium (or trona) is produced by solution mining and consists of a group of wells for injection of hot water and retrieval of dissolved nahcolite, a collection pipeline, roads, and a processing plant. Coal, uranium, gravel, and other mineral mining activities may be conducted through surface mining, pit mining, strip mining or underground mining operations (see also “Energy and Mineral Development” issues section, pg. 109).

APPENDIX H

LITERATURE REVIEW
OF
OIL AND NATURAL GAS DEVELOPMENT IMPACTS
ON PRAIRIE GROUSE

Summary of Oil and Natural Gas Development Impacts on Prairie Grouse
September 2006

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Rising energy consumption and an increasing reliance on foreign energy sources in the United States has led the current presidential administration to institute 4 initiatives addressing these issues: (1) help the nation become more energy efficient, (2) create new sources of energy, (3) increase domestic production from existing resources, and (4) work with other nations on energy efficiency (American Gas Association 2005:2–3). To increase domestic production there has been a 60% increase in recent years in the number of permits for drilling in the Rocky Mountain West (American Gas Association 2005). From 1929 to 2004, 122,496 applications to drill were filed with federal agencies in 13 western states; 95.7% were authorized, 3.0% were pending, 1.2% were withdrawn, and <0.1% were rejected (Connelly et al. 2004). These statistics suggest oil and gas development is rapidly increasing in the West, propelled by national initiatives to increase energy supplies from federal lands (Connelly et al. 2004, American Gas Association 2005).

Oil and gas development may impact other resources including ground water, surface water, fish and wildlife habitat, and archaeological sites. Understanding the impacts of disturbances such as oil and gas development on prairie grouse populations is complex. Impacts can be quantified directly through habitat loss and direct mortalities or indirectly through measuring the avoidance of birds to disturbances, evaluating trends in population parameters such as lek counts, modeling changes in habitat selection, and estimating effect sizes in vital rates such as nest success and survival. Five geologic basins (Greater Green River, Montana Thrust Belt, Paradox-San Juan, Powder River, and Uinta-Piceance) contain the majority of onshore oil and natural gas on federal lands in the United States (U.S. Departments of Interior, Agriculture, and Energy 2003). Incidentally, each of these basins underlies current habitat for greater sage-grouse (*Centrocercus urophasianus*) or Gunnison sage-grouse (*C. minimus*; Schroeder et al. 2004). Rigorous research is essential to understand direct and indirect impacts to prairie grouse across this expansive landscape. Better understanding impacts can lead to improved mitigation measures to lessen impacts on grouse populations.

Here, I summarize the current knowledge on the effects of oil and gas development and production activities on prairie grouse, based on 12 papers that report empirical evidence about impacts on greater sage-grouse and lesser prairie-chickens (*Tympanuchus pallidicinctus*; Tables H-1 – H-3). It is important to understand the experimental or sampling designs of each study including use of control and treatment areas, sample sizes, and other factors to assess the strength of inference of each study. Environmental impact studies are typically designed as quasi experiments because the impacted or treatment areas are not randomized as in a manipulative experiment (Manly 2001). However, quasi experiments with replicated treatment and control areas with pre- and post- development data can provide strong inference because impacts can be inferred through temporal and spatial patterns (Green 1979). None of the identified studies was designed as a manipulative or quasi experiment (Table H-1), which may be symptomatic of the inability of researchers to establish studies before oil and gas field development begins. Reviewed studies were designed as (*i*) observational studies, where radio-marked birds were used to assess parameters of interest such as survival and nest success relative to impacts from oil and gas development or (*ii*) correlative studies evaluating cause and effect relationships such as lek counts and habitat selection in relation to development infrastructure such as well pad or road densities (Tables H-1 and H-2).

Despite the weaknesses of some study designs, corroboration of results from different studies even under different conditions provides support that biological patterns are not artifacts of study designs, methods, investigators, or limited to temporal or spatial extent of individual studies. Replicating entire studies even under different conditions and locales is termed *metareplication* (Johnson 2002). Similar conclusions from replicated studies provide support even for small studies with relatively poor study designs. For instance, lek abandonment caused by oil and gas field disturbances has been reported from studies of lesser prairie chickens in New Mexico and greater sage-grouse in Alberta, Colorado, Montana, Utah, and Wyoming. Each study occurred under different conditions and employed different methodology (Table H-2).

Most of the currently available information on impacts is focused on lek abandonment and changes in male lek attendance (Table H-2). Fewer studies have examined nest success, nest initiation, survival, other vital rates, or habitat selection (Table H-2). The mechanistic properties of disturbances such as noise, traffic volumes, and dust are not well understood in relation to oil and gas development and prairie grouse. For example, noise was 52.5 dB, 20 m from the center of a lek where 5 lesser prairie-chicken males displayed in New Mexico (Hunt 2004). It would be necessary for a drill rig to be 320 to 480 m from a lesser prairie chicken lek to avoid creating noise exceeding 52.5 dB; this region encompasses an area of 0.3–0.7 km^2 (Table H-3; Hunt 2004). Anecdotal evidence exists for visual, movement, and auditory disturbance by oil and gas development at several leks in Utah, which indicates that pump mufflers and strategic placement of well pads and associated infrastructure may alleviate lek abandonment (Addendum A).

Resource Management Plans prepared by field offices of the Bureau of Land Management typically apply 2 common stipulations to federal oil and gas leases occurring in habitats occupied by sage-grouse. The first stipulation calls for no surface occupancy (i.e., well pads, roads, compressor stations, etc.) within a 0.4 km (0.25 mi) region surrounding each lek. The second stipulation is a timing limitation that inhibits development activities within 3.2 km (2 mi) of leks during the breeding and nesting season (Bureau of Land Management 1997, Lyon and Anderson 2003). For example, to coincide with local breeding and nesting periods, the Resource

Management Plan for the White River Field Office of the Bureau of Land Management in northwestern Colorado stipulates that oil and gas field development activities are not permitted in sage-grouse habitats within 3.2 km of leks from April 15 through July 7 (Bureau of Land Management 1997). Results suggest that no surface occupancy within 0.4 km is not adequate to avoid lek abandonment or other negative influences on prairie grouse populations, and also indicates that surface occupancy may need to be at least 1.6 km from leks to avoid declines or abandonment (Tables H-2 and H-3). Empirical and anecdotal evidence also indicates that lessening noise and visual disturbance of oil and gas field infrastructure may make these features more compatible with lekking grouse at distances less than 1.6 km from leks; however, these relationships have not been rigorously evaluated (Tables H-2 and H-3; Addendum A).

Below, I list several topics that research should address to better understand the effects of oil and gas development on prairie grouse populations. My list suggests there is a great need for research to more clearly elucidate impacts of oil and gas development on prairie grouse and to provide suitable mitigation actions to offset these impacts.

- Effects of disturbance properties such as noise, visual obstruction, dust, and traffic volumes on habitat selection and vital rates
- Effects of disturbance properties on habitat effectiveness (quality). For example, Pitman et al. (2005) reported the presence of anthropogenic features including transmission lines, wellheads, buildings, roads, and center-pivot irrigation systems effectively eliminated 53% of otherwise suitable nesting habitat for lesser prairie chickens from 2 study areas totaling 13,380 ha in southwestern Kansas. Avoidance of anthropogenic features was believed to be related to properties of disturbances such as noise and visual obstruction
- Effects of oil and gas developments on predator communities and subsequent implications for predation rates on grouse
- Effects of weeds introduced along roads and other surface disturbances on habitat quality
- Interactions of development and climatic conditions on habitat selection and vital rates
- Effects of the timing of development and production on habitat selection and vital rates
- Effects of "phased" versus "complete" development on habitat selection and vital rates
- Effects of mitigation efforts to minimize impacts on prairie grouse. This is a very large area of research. For example, experimental studies of road and well pad densities, timing of construction activities, and habitat enhancement or rehabilitation efforts could be conducted to address specific questions relative to prairie grouse populations
- The scale of impacts on populations needs to be more clearly understood. Holloran (2005) and Naugle et al. (2006*b*) investigated this, but more needs to be done

Table H-1. Summary of study designs for research studies used to review impacts of oil and gas development and production on prairie grouse, August 2006.

Study	Design	Pretreatment data	Control area(s)	Sample size(s)	Peer-reviewed[a]	Type of publication
Aldridge and Boyce (2007)	Correlative	No	No	113 nests. 669 brood locations from 35 broods. 41 chicks from 22 broods	Yes	Scientific journal
Braun et al. (2002)	Descriptive and correlative	Yes and no, depending on application	Yes and no, depending on application	Variable	Yes	Conference transaction
Crompton and Mitchell (2005)	Observational	No	Yes	20 females captured on 4 leks	No	Completion report
Holloran (2005)	Correlative and observational	No	Yes	Lek counts from 21 leks 209 females captured from 14 leks. 162 nests within 3.2 km of the Pinedale Anticline Crest	No	PhD dissertation
Hunt (2004)	Correlative	No	No	33 active leks and 39 abandoned leks	No	PhD dissertation
Kaiser (2006)7	Correlative and observational	No	Yes	18 leks. 60 adult females, 23 yearling females, 20 yearling males	No	MS thesis
Lukas (2006)	Correlative	No	No	162 leks	No	Agency report

Table H-1. Summary of study designs for research studies used to review impacts of oil and gas development and production on prairie grouse, August 2006.

Study	Design	Pretreatment data	Control area(s)	Sample size(s)	Peer-reviewed[a]	Type of publication
Lyon and Anderson (2003)	Observational	No	Yes	48 females captured on 6 leks	Yes	Scientific journal
Naugle et al. (2006*a*)	Correlative	Yes	Yes	516 leks. 40 lek complexes were sufficient (>10 counts between 1988–2005) for trend analysis	No	Progress report
Naugle et al. (2006*b*)	Correlative	No	No	292 locations for 106 birds in 2005 and 241 locations for 94 birds in 2005–2006	No	Completion report
Pitman et al. (2005)	Observational	No	No	155 nests	Yes	Scientific journal
Robel et al. (2004)	Observational	No	No	187 nests, 18,866 locations	Yes	Conference transaction

[a]Peer review for theses and dissertations is conducted by graduate committees. These reviews are not considered to be as rigorous as peer review for scientific journals.

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
BROOD HABITAT SELECTION						
	GRSG	AB	P	Unknown	Oil and gas activity occurred on 1/3 of habitat area. Broods tended to be close to well sites, but at the same time they avoided areas with a greater density of visible well sites within 1 km (number of 30 m pixels within a 1 km radius from locations that were wells)	1
HATCHING DATE	GRSG	WY	D	Unknown	Nests of adult and yearlings breeding and nesting within a buffered region representing impacts of oil and gas development hatched an average of 5 days later than birds breeding and nesting outside the buffers	6
LEK ABANDONMENT						
Compressor stations	GRSG	WY	D	3.1/km^2	Nearly 200 compressor stations within 1.6-km (1 mi) from leks. Sage-grouse counts were consistently lower on these leks than leks >1.6-km to compressor stations	2

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
Noise	GRSG	UT	D	3.1/km^2	New well caused abandonment of a lek. Noise was 70 dB, 20 m from pumpjack and 45 dB at the lek, which was 200 m from pumpjack	3
	LPC	NM	P	unknown	Noise levels were about 4 decibels higher at abandoned leks than at active leks	5
	LPC	NM	P	unknown	Significant difference between ambient noise levels at active (30.4 dB) and inactive (34.8 dB) leks	5
Power lines	GRSG	WY	D	3.1/km^2	40 leks with an overhead power line within 0.4-km (0.25-mi). Growth rates based on counts were lower for leks near power lines compared to leks >0.4-km from power lines	2
	LPC	NM	P	unknown	18 of 40 (45%) abandoned leks were ≤800 m from at least 1 power line, whereas 1 of 33 (3%) active leks were ≤800 m from a power line	5

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	Species[a]	Location[b]	Stage[c]	Pad density (pads/km^2)	Results	Reference[d]
Roads	GRSG	AB	D	Active wells = 1.0/km^2, inactive wells = 2.0/km^2	Roads or well sites were developed within 200 m from 3 leks between 1983 and 1985. Since the development, these leks have become inactive	2
	GRSG	AB	D	Active wells = 1.0/km^2, inactive wells = 2.0/km^2	From 1973 to 2001, leks were active at 3 sites in and 8 sites around the periphery of an active oil and gas development. In 2001, 7 leks were active, with 2 within site of an active well or power line	2
	GRSG	WY	D	0.1–0.4/km^2 from 1999 to 2004	Male lek counts within 0.0–1.0, 1.1–2.0, and 2.1–3.0 km of a main haul road declined significantly compared to control leks (>6.1 km from a main haul road)	4
	LPC	NM	P	Unknown	Road density in 1.6-km buffers was 3.3 km/km^2 and 2.4 km/km^2 on abandoned and active leks	5

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
Well density	GRGS	WY	P	3.1/km^2	200 CBM wells within 0.4-km (0.25 mi) from 30 known leks. Significantly fewer males per lek and lower rate of growth for these leks than 200 leks that were >0.4-km from a well	2
	LPC	NM	P	unknown	Abandoned leks had more active and total wells, greater road length, and nearer to power lines than active leks within a 1.6-km (1-mi) buffer centered on leks	5
	LPC	NM	P	unknown	Mean number of active wells within 1.6 km (1-mi) from leks was 1 for active leks and 8 for abandoned leks during their last active year	5
LEK RECRUITMENT AND VISITS						
	GRSG	WY	D	unknown	Fewer males recruited on leks as distance to drill rigs decreased. No relationship between male recruitment and proximity of leks to main haul roads or producing wells	6

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
	GRSG	WY	D	unknown	Fewer males were recruited to leks as distance inside a region buffered to represent oil and gas development increased	6
	GRSG	WY	D	unknown	Fewer yearling females visited leks as distance to producing wells decreased. No relationship between adult female lek visits and distance to producing wells. No relationship for adult or yearling female lek visits relative to proximity to drill rigs or main haul roads	6
MALE LEK COUNTS						
	GRSG	UT	D	3.1/km^2	Mean annual declines were –44% for leks in developed areas, but increased 15% on undeveloped leks	3

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	Species[a]	Location[b]	Stage[c]	Pad density (pads/km^2)	Results	Reference[d]
	GRSG	WY	D	0.1–0.4/km^2 from 1999 to 2004	Control leks (<5 wells within 5 km of lek), lightly impacted leks (5–15 wells within 5 km of lek), and heavily impacted leks (>15 wells within 5 km of lek). Total males on heavily impacted leks declined 51% from the year prior to impact to 2004. Average annual declines were 16% on heavily impacted leks (excluding 3 centrally located leks that declined 89%), 19% on lightly impacted leks, and 2% on controls	4
	GRSG	WY	D	0.1–0.4/km^2 from 1999 to 2004	Negative change in annual lek counts within 5 km from drilling rigs, 3 km of producing wells, and 3 km of main haul roads	4
	GRSG	WY	P	0.1–0.4/km^2 from 1999 to 2004	Well densities exceeding 1/2.8-km^2 appeared to negatively affect male lek attendance	4

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
	GRSG	CO	P	NW CO: active wells = 0–2.1/km^2, inactive wells = 0–1.0/km^2 North Park: active wells = 0–3.3/km^2. inactive wells = 0–1.3/km^2 Middle Park: active and inactive wells = 0–0.1/km^2	Three populations (NW CO, North Park, and Middle Park) with limited oil and gas activity were considered from 1973–2005. High males counted were correlated with numbers of active and inactive wells within 3.2 km from leks. Best model included a year effect. Weak negative effect of active wells in NW CO, but this effect disappears when yearly variation was considered	7
	GRSG	MT, WY	D	Potentially 3.2/km^2	84% decline (1988–2005) in males counted on leks after coalbed methane development in Powder River Basin. Of leks counted in 2004 or 2005, remaining leks in coalbed methane areas were either inactive or had ≤20 males, whereas larger leks (>20 males on average) were outside coalbed methane areas	9

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
NEST INITIATION						
	GRSG	WY	D	unknown	65% for females from disturbed leks, 89% for females from undisturbed leks. Effect size is 24% less for females from disturbed leks. Traffic volumes of 1–15 vehicles/day during the breeding season may reduce nest initiation rates	8
NEST PLACEMENT						
	GRSG	WY	D	unknown	Distances from disturbed leks to nests declined from those reported in Lyon and Anderson (2003), which occurred before substantial oil and gas field development. Both studies occurred in the same area indicating development had reduced the availability of nesting habitat, which may have reduced the distance females placed nests from leks	6

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
	GRSG	WY	D	unknown	26% of females from disturbed leks (≤3 km from gas development) nested ≤3 km from lek of capture, while 91% of females from undisturbed leks (>3 km from gas development or ≤3 km from gas development but isolated from disturbances by topography) nested ≤3 km of lek of capture	8
	GRSG	WY	D	unknown	1–15 vehicles/day during breeding season may increase distances moved from leks to nests	8
	LPC	KS	P	0.7–1.1/km^2	Nest locations were influenced by transmission lines, oil and gas wellheads, buildings, improved roads, and center-pivots on a 7,770 ha sand-sagebrush prairie. This was determined because the nearest 10% of nests to each landscape feature were farther from the feature than would be expected at random	11
	LPC	KS	P	0.7–1.1/km^2	Mean distance to oil or gas wellheads was 85 ± 23 m (mean ± SE) for 90% of 187 nests	12

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	**Species**[a]	**Location**[b]	**Stage**[c]	**Pad density** (pads/km^2)	**Results**	**Reference**[d]
NEST SUCCESS						
	GRSG	AB	P	Unknown	Nest success was 39% from 2001 to 2004 and nest failure was not affected by human features	1
	GRSG	WY	D	0.1–0.4/km^2 from 1999 to 2004	Percentage of avian predation responsible for depredated nests increased from 13% in 2000 to 40% in 2004 as oil and gas field development increased	4
	GRSG	WY	D	Unknown	50% for females from disturbed and undisturbed leks over 2 years	8
SURVIVAL						
Chicks	GRSG	AB	P	Unknown	Chick survival to 56 days was 12%. Chick failure (death) increased in habitats with greater well site densities within 1 km and in riparian habitats	1
Females	GRSG	UT	D	3.1/km^2	Annual survival rate was 12.5% for 8 females captured in coalbed methane area and 73% for 11 females captured in undeveloped area	3

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	Species[a]	Location[b]	Stage[c]	Pad density (pads/km^2)	Results	Reference[d]
	GRSG	WY	D	0.1–0.4/km^2 from 1999 to 2004	Survival for nesting adult females was 73% pretreatment and 53% post treatment (20% effect size)	4
	GRSG	WY	D	Unknown	Females that bred or nested within natural gas development buffers had 10% lower survival during early brood rearing than females that bred or nested outside buffers. This corroborates earlier results of Holloran (2005) from the same area	6
WINTER HABITAT						
	GRSG	MT, WY	D	Potentially 3.2/km^2	Sage-grouse avoided coalbed methane development in suitable habitat after controlling for habitat quality. The addition of mean wells/km^2 within a 1–km buffer improved model fit by 12.4 ΔAIC, indicating energy development and habitat quality were the best models explaining winter habitat selection	10
YEAR-ROUND HABITAT						

Table H-2. Review of literature summarizing effects of oil and gas development and production on prairie grouse, August 2006. Well pad densities are reported because well pads provide an ecological indication of the associated infrastructure (roads, power lines, compressor stations, pipelines, settling ponds) within oil and gas fields (unpublished data reported in Naugle et al. [2006*b*]).

Response and effect	Species[a]	Location[b]	Stage[c]	Pad density (pads/km^2)	Results	Reference[d]
	LPC	KS	P	0.7–1.1/km^2	Mean distance to oil or gas wellheads was 72 ± 5 m (mean ± SE) in sagebrush prairie habitat not included in the area bounded by 95% of lesser prairie chicken locations	12

[a]GRSG = greater sage-grouse, LPC = lesser prairie-chicken.
[b]AB = Alberta, CO = Colorado, KS = Kansas, MT = Montana, NM = New Mexico, UT = Utah, WY = Wyoming.
[c]Development stage: D = development, P = production.
[d](1) Aldridge and Boyce (2007), (2) Braun et al. (2002), (3) Crompton and Mitchell (2005), (4) Holloran (2005), (5) Hunt (2004), (6) Kaiser (2006), (7) Lukas (2006), (8) Lyon and Anderson (2003), (9) Naugle et al. (2006*a*), (10) Naugle et al. (2006*b*), (11) Pitman et al. (2005), (12) Robel et al. (2004).

Table H-3. Mean decibels (dB) for sound sources in lesser prairie-chicken (*Tympanuchus pallidicinctus*) habitat, southeastern New Mexico. Adapted from Hunt (2004:147–148).

Source	***n***	**Mean dB**
Active leks	33	30.4
Inactive leks	39	34.8
Control points	60	32.2
5 displaying males–dB, 20 m to lek	1	52.5
Distance (m) from oil drilling rig		
20	10	74.7
160	10	61.1
320	10	54.7
480	10	48.6
640	10	45.9
800	10	43.9
960	10	41.7
1,120	10	40.6
1,280	10	39.5
1,440	10	38.3
1,600	10	37.9
Distance (m) from Propane-powered pumpjacks		
20	10	86.5
160	10	52.0
Distance (m) from Propane-powered pumpjacks (continued)		
320	10	44.4
480	10	39.7
640	10	38.0
800	10	36.4
960	10	36.5
1,120	10	36.1
1,280	10	36.2
1,440	10	35.9
1,600	10	35.3
Distance (m) from electric pumpjacks		
20	10	66.1
160	10	37.3
320	10	36.3
480	10	35.3
640	10	35.5
800	10	35.1
960	10	35.5

Table H-3. Mean decibels (dB) for sound sources in lesser prairie-chicken (*Tympanuchus pallidicinctus*) habitat, southeastern New Mexico. Adapted from Hunt (2004:147–148).

Source	***n***	**Mean dB**
1,120	10	35.4
1,280	10	35.4
Distance (m) from electric pumpjacks (continued)		
1,440	10	34.9
1,600	10	35.1
Distance (m) from compressor stations		
20	10	76.8
160	10	58.3
320	10	49.9
480	10	46.5
640	10	43.2
800	10	40.7
960	10	39.0
1,120	10	38.4
1,280	10	37.5
1,440	10	36.5
1,600	10	36.0
Vehicles on paved road, about 110 km/h, from 8 m		
Tanker trucks	10	90.0
Eighteen-wheelers	10	87.2
Motorcycles	2	85.6
Vehicles on paved road, about 110 km/h, from 8 m (continued)		
Work trucks/welding trucks	10	85.5
Pickup trucks with trailers	10	85.1
Bus	1	81.6
Automobiles	10	81.3
Pickup trucks	10	80.8

Addendum A. Sage-grouse Leks with Energy Development

Information from Brian Maxfield
Sensitive Species Biologist
Utah Division of Wildlife Resources
July 29, 2006

East Bench Area
East Bench 16 – Active Lek

Gas well – 540 m from lek. Well has associated methane pump used primarily during winter to keep liquefied gas/condensate from freezing. Pump is active during early lekking. Well drilled in 2005 and developed in 2006. Well placed on existing well pad built 4+ years prior. Well out of sight of strutting males because of small ridge.

Sand Wash Rim – Active Lek

Gas well – 1650 m from lek. Well placed prior to 2004 (exact time unknown). Well out of sight of strutting males. Another well was planned for closer but exact location is not known yet. New well will also be out of sight of strutting males but will be closer than 1000 m.

Deadman Bench Area
North Deadman – Active Lek

Oil well – 335 m. Well has active single piston pump with muffler attached. Moving pump arm is in view of strutting males. Not sure about year well was placed. Lek was discovered in 1995 and I believe well was placed prior to this time, probably during 1980s energy development.

Myton Bench Area
Myton Bench/Wells Draw – Inactive Lek

Compressor – 1440 m.
Gas well – 530 m
More wells nearby but I will need to go in field to measure distances. Lek went inactive after compressor and wells were placed.

Halfway Hollow Area
South 12 Mile – Inactive Lek

Oil well – 645 m. Well has active single piston pump with no muffler attached. Moving pump arm is in full view of strutting males. Lek went inactive after well was placed. No grouse have been observed in the area since.

South Slope Area
South Bonanza – Active Lek

Oil wells – 210 m, 860 m, 930 m. Wells do not have active pumps but have a battery of tanks and receive vehicular visits. The two closest wells are within view of strutting males. Other well is located across a deep draw and is not visible. This lek was first located in 2006 but the landowner indicated the lek has been there for 15-20 years (at least).

Monarch Bench – Active Lek?

Oil well – 0 m. Grouse strut on well pad. When pump is active (moving) grouse will strut off pad but nearby (within 50 m). Status of lek is not positive because lek is located on tribal ground and we are not allowed access. Tribe says lek has been active in past couple of years. Well and lek have been there for many years.

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APPENDIX I

SUGGESTED MANAGEMENT PRACTICES APPLICABLE FOR OIL AND GAS DEVELOPMENT, WITHIN LEASE RIGHTS

Suggested Management Practices (SMPs) Applicable for Oil and Gas Development, within Lease Rights

In addition to "GrSG Disturbance Guidelines" (Appendix B), and conservation strategies identified in this plan ("Conservation Strategy", pg. 306), this is a list of suggested management practices that may be applied to oil and gas operations, or other surface-disturbing activities, to aid in protecting GrSG and their habitat. These SMPs are not regulatory, but are options that could be applicable to all ownership situations; they are also *not* the BLM's Best Management Practices (BMPs) for public lands, which can be found at http://www.blm.gov/bmp. As new information becomes available, additional management practices will be developed.

1. Minimize impacts on habitat through road construction standards, design and placement in all occupied and vacant/unknown sage-grouse habitat (exploration, drilling and production).
   A. Minimize construction of new roads
   B. Utilize minimum construction and maintenance standards appropriate for the operation.
   C. Minimize visual/auditory impacts by placing roads below ridgelines or along topographic features.
   D. Place roads outside of riparian areas.
   E. Conduct exploration along existing roads where possible.
   F. Avoid construction of surface-disturbing activities within 0.6 miles of active leks.

2. Minimize impacts to sage-grouse through road use (patterns) and seasonal restrictions (exploration, drilling, and production).
   A. Sign roads to prevent off road travel.
   B. Set seasonal closures during critical sage-grouse use periods.
   C. Encourage remote monitoring.
   D. Develop travel plan to minimize vehicular traffic.
   E. Place speed bumps, dips etc. to slow traffic as needed.
   F. Construct or maintain any roads outside of critical seasonal use periods.
   G. Encourage road rehabilitation or realignment to minimize impacts to sage-grouse.

3. Overlay lease map with sage-grouse habitat to determine vacant and occupied leases (drilling and production).
   A. Add lease notice 'This lease may require a full development plan as determined by an interdisciplinary team.

4. Implement noise mitigation from research and/or state regulations.

5. Create an educational video about sage-grouse habitat and ecology to increase awareness for oil and gas employees (exploration, drilling, and production).

6. Avoid or minimize impacts to riparian, wetland, or wet meadow habitats to limit impacts to brood rearing areas (exploration, drilling, and production).

A. Locate equipment, facilities, and roads outside of riparian zones which may serve as late brood rearing habitat (1000-ft buffer where feasible).
B. Drive over woody vegetation at stream crossings rather than remove it wherever possible.
C. Bore pipeline crossings under perennial streams rather than trenching.

7. Avoid or minimize impacts to sagebrush habitats to limit impacts on GrSG breeding, summer/fall, and winter areas (exploration, drilling, and production.
   A. Site facilities in habitats other than sagebrush, wherever possible.

8. Use reclamation standards (interim and final) that are beneficial to restoring sage-grouse habitat. (drilling, and production)
   A. Incorporate sagebrush, desired forbs and grass species into seed mix. Use native species wherever possible or non-natives when approved via state or federal biologists.
   B. Replace soil manually for shot holes (exploration).
   C. Rip and/or recontour and reclaim operation sites, and access roads.
   D. Retain and “manage” topsoil as appropriate for reclamation.
   E. Reclaim riparian areas with native vegetation.
   F. Mimic vegetation patterns during reclamation.
   G. Develop a reclamation plan with CDOW and surface owner.
   H. Investigate opportunities to utilize suitable produced water in accordance with state water laws.

9. Prevent or minimize raptor perching on oil and gas facilities and structures in important sage-grouse habitat (drilling and production).
   A. Design power poles to discourage raptor perching, using the most current science.
   B. Minimize height of dry hole markers in SG habitat (flush with ground or < 1’).

10. Components of a Comprehensive Development Plan (production).
   A. Map all road infrastructure for area to be developed.
   B. Map seasonal sage-grouse habitat within area of development.
   C. Consider cumulative habitat loss to date in determining future development opportunities.
   D. Consider topographic features when recommending areas to protect for sage-grouse.
   E. Delineate maximum wellpad spacing (e.g., “No more than 1 wellpad per 'xx' acres”) for areas when research identifies that threshold.
   F. Establish incremental development thresholds where possible (e.g., no more than 10% breeding habitat impacted over 10 year period)
   G. Coordinate planning among companies operating in the same field.
   H. Cluster development where possible to minimize impacts.
   I. Encourage alternative drilling or production methods to minimize acres of habitat directly or indirectly affected (e.g., directional drilling).

   J. Encourage remote monitoring of production sites to reduce disturbance to birds during critical seasons.

11. Consider oil and gas development fields in preparation of local fire response plans within sage-grouse habitat.

12. Monitor mosquito production in produced water and control mosquitoes as needed. Use BTI (*Bacillus thurgensis israelsis*) for mosquito control in water pits associated with oil and gas operations where appropriate (production).

13. Implement measures to ensure water quality is maintained, and hazardous spills are minimized in sage-grouse habitat and associated riparian areas (drilling and production).
    A. Encourage use of water tanks instead of open pits.
    B. Line open water pits.
    C. Minimize SG contact with produced water.

14. Design well pad, storage facilities, and site locations to minimize degradation of sage-grouse habitat and visual/actual obstructions in the area (production).
    A. Use low profile storage tanks.
    B. Paint wells to camouflage in background.

15. Minimize impacts on local watersheds and local water sources during local drilling and reclamation activities in sage-grouse habitat (e.g., surface and sub-surface water depletion impacts on sage-grouse habitat).

16. Transport water and condensate by pipeline rather than truck whenever possible to minimize vehicle traffic, dust, noise, and disturbance.

APPENDIX J

GrSG GIS DATA:

HABITAT TYPE, LANDOWNERSHIP, EASEMENTS

Data in this appendix are derived from CoMAP 2006 (Wilcox et al. 2006).

Habitat Categories – All GrSG Populations

Table J-1. Areas of habitat categories in each GrSG population area (for category definitions see "GrSG Habitat Mapping Efforts", pg. 66).

GrSG Area	Occupied Habitat (acres)	Vacant / Unknown Habitat (acres)	Potentially Suitable Habitat (acres)	Total
Meeker – White River	41,160	6,810	116,515	164,485
Middle Park	259,019	5,168	6,441	270,628
North Park	413,915	0	0	413,915
Northern Eagle – Southern Routt Counties	95,388	11,436	126,490	233,314
Northwest Colorado	2,563,033	51,275	34,646	2,648,953
Parachute – Piceance - Roan	304,588	99,683	221,788	626,060
Total (acres)	3,677,103	174,372	505,880	4,357,354

Landownership in Each GrSG Population

Table J-2. Landownership data for Meeker – White River GrSG area.

Ownership	Occupied Habitat - Acres (% of total occupied)	Vacant/Unknown Habitat Acres (% of vacant/unknown)	Potentially Suitable Habitat Acres (% of total potential)	Total - Acres (% of total)
BLM	3,478 (8%)	291 (45%)	23,709 (20%)	27,477 (17%)
CDOW	401 (1%)	3,857 (57%)	93 (0%)	4,351 (3%)
Private	36,864 (90%)	2,663 (39%)	91,312 (78%)	130,838 (80%)
USFS	418 (1%)	0 (0%)	1,401 (1%)	1,819 (1%)
Total (acres)	41,160	6,810	116,515	164,465

Table J-3. Landownership data for Middle Park GrSG area.

Ownership	Occupied Habitat Acres (% of total occupied)	Vacant/Unknown Habitat Acres (% of vacant/unknown)	Potentially Suitable Habitat Acres (% of total potential)	Total Acres (% of total)
BLM	74,065 (29%)	0 (0%)	284 (4%)	74,349 (27%)
CDOW	4,719 (2%)	58 (1%)	0 (0%)	4,776 (2%)
City	10 (0%)	0 (0%)	0 (0%)	10 (0%)
County	729 (0%)	127 (2%)	0 (0%)	856 (0%)
NGO	4,411 (2%)	0 (0%)	0 (0%)	4,411 (2%)
Private	148,675 (57%)	3,905 (76%)	6,073 (94%)	158, 654 (59%)
SLB	21,106 (8%)	0 (0%)	0 (0%)	21,106 (8%)
USFS	5,305 (2%)	1,078 (21%)	84 (1%)	6,467 (2%)
Total (acres)	259,019	5,168	6,441	270,628

Table J-4. Landownership data for Northern Eagle – Southern Routt Counties GrSG area.

Ownership	Occupied Habitat Acres (% of total occupied)	Vacant/Unknown Habitat Acres (% of vacant/unknown)	Potentially Suitable Habitat Acres (% of total potential)	Total Acres (% of total)
BLM	26,189 (27%)	268 (2%)	64,231 (51%)	90,688 (39%)
CDOW	37 (0%)	81 (1%)	4,445 (4%)	4,563 (2%)
NGO	0 (0%)	206 (2%)	0 (0%)	206 (0%)
Private	67,480 (71%)	10,880 (95%)	52,256 (41%)	130,615 (56%)
SLB	1,596 (2%)	0 (0%)	1,267 (1%)	2,863 (1%)
USFS	86 (0%)	2 (0%)	4,291 (3%)	4,379 (2%)
Total (acres)	95,388	11,436	126,490	233,314

Table J-5. Landownership data for North Park GrSG area.

Ownership	Occupied Habitat Acres (% of total occupied)	Vacant/Unknown Habitat Acres (% of vacant/unknown)	Potentially Suitable Habitat Acres (% of total potential)	Total Acres (% of total)
BLM	140,025 (34%)	0 (0%)	0 (0%)	140,025 (34%)
CDOW	2,852 (1%)	0 (0%)	0 (0%)	2,852 (1%)
Private	216,671 (52%)	0 (0%)	0 (0%)	216,671 (52%)
SLB	31,335 (8%)	0 (0%)	0 (0%)	31,335 (8%)
USFS	377 (0%)	0 (0%)	0 (0%)	377 (0%)
USFWS	22,656 (5%)	0 (0%)	0 (0%)	22,656 (5%)
Total (acres)	413,915	0	0	413,915

Table J-6. Landownership data for Northwest Colorado GrSG area.

Ownership	Occupied Habitat Acres (% of total occupied)	Vacant/Unknown Habitat Acres (% of vacant/unknown)	Potentially Suitable Habitat Acres (% of total potential)	Total Acres (% of total)
BLM	1,277,070 (50%)	19,336 (38%)	5,799 (17%)	1,302,205 (49%)
CDOW	15,664 (1%)	0 (0%)	0 (0%)	15,664 (1%)
Other State	1,444 (0%)	0 (0%)	0 (0%)	1,444 (0%)
NPS	9,869 (0%)	0 (0%)	2 (0%)	9,869 (0%)
Private	1,046,147 (41%)	30,832 (60%)	16,742 (48%)	1,093,721 (41%)
SLB	197,562 (8%)	1,106 (2%)	4,847 (14%)	203,515 (8%)
USFS	3,311 (0%)	0 (0%)	7,256 (21%)	10,567 (0%)
USFWS	11,964 (0%)	0 (0%)	0 (0%)	11,964 (0%)
Total (acres)	2,563,032	51,275	34,646	2,648,953

Table J-7. Landownership data for Parachute – Piceance - Roan GrSG area.

Ownership	Occupied Habitat Acres (% of total occupied)	Vacant/Unknown Habitat Acres (% of vacant/unknown)	Potentially Suitable Habitat Acres (% of total potential)	Total Acres (% of total)
BLM	97,839 (32%)	80,470 (81%)	143,622 (65%)	321,931 (51%)
BOR	0 (0%)	0 (0%)	474 0(%)	474 0(%)
CDOW	6,272 (2%)	4,515 (5%)	667 (0%)	11,454 (2%)
U.S. Dept. Energy	1,264 (0%)	0 (0%)	193 (0%)	1,457 (0%)
Private	199,212 (65%)	14.698 (15%)	76,675 (35%)	290,585 (46%)
USFS	0 (0%)	0 (0%)	158 (0%)	158 (0%)
Total (acres)	304,588	99,683	221,788	626,060

Table J-8. Landownership data (acres) for occupied habitat in Zones 1, 2, 3a, 3b, 3c, and 7 of the Northwest Colorado GrSG area. In these zones there is no habitat that falls into the vacant/unknown or potentially suitable categories.

Ownership	Zone 1	Zone 2	Zone 3a	Zone 3b	Zone 3c	Zone 7
BLM	134,050	470,250	111,065	123,310	50,540	6,413
CDOW	2,230	50	4,810	0	0	0
Joint	0	0	0	0	25	0
NPS	971	988	0	0	0	777
Private	13,021	57,371	110,430	98,663	244,814	6,186
SLB	25,422	31,533	18,013	36,597	13,765	0
USFWS	11,964	0	0	0	0	0
Total (acres)	187,657	560,194	244,318	258,570	309,143	13,376

Table J-9. Landownership data for Zone 4a of the Northwest Colorado GrSG area.

Ownership	Occupied Habitat (Acres)	Vacant/Unknown Habitat (Acres)	Potentially Suitable Habitat (Acres)	Total (Acres)
BLM	18,047	0	0	18,047
Private	49,218	0	483	49,701
SLB	1,750	0	638	2,387
USFS	3,087	0	7,256	10,344
Total (acres)	72,102	0	8,377	80,479

Table J-10. Landownership data for Zone 4b of the Northwest Colorado GrSG area.

Ownership	Occupied Habitat (Acres)	Vacant/Unknown Habitat (Acres)	Potentially Suitable Habitat (Acres)	Total (Acres)
BLM	6,179	295	17	6,491
CDOW	16	0	0	16
Private	176,255	17,171	11,424	204,850
SLB	35,366	222	4,205	39,793
Unknown	9	0	0	9
USFS	224	0	0	224
Total (acres)	219,451	17,688	15,646	252,786

Table J-11. Landownership data for Zone 5 of the Northwest Colorado GrSG area.

Ownership	Occupied Habitat (Acres)	Vacant/Unknown Habitat (Acres)	Potentially Suitable Habitat (Acres)	Total (Acres)
BLM	168,614	124	1,157	169,895
CDOW	7,017	0	0	7,017
Other State	18	0	0	18
NPS	25	0	2	27
Private	215,621	5,911	1,032	222,563
SLB	23,746	0	0	23,746
Unknown	1,533	0	0	1,533
Total (acres)	416,574	6,034	2,191	424,798

Table J-12. Landownership data for Zone 6 of the Northwest Colorado GrSG area.

Ownership	Occupied Habitat (Acres)	Vacant/Unknown Habitat (Acres)	Potentially Suitable Habitat (Acres)	Total (Acres)
BLM	188,599	18,917	4,625	212,142
NPS	7,109	0	0	7,109
Private	74,567	7,751	3,803	86,121
SLB	11,371	884	4	12.259
Total (acres)	281,647	27,552	8,432	317,632

Easements in Each GrSG Population

Table J-13. Acreage of conservation easements currently held in each GrSG area.

GrSG Population	Occupied Habitat	Vacant/ Unknown Habitat	Potentially Suitable Habitat	Total
Meeker – White River	2,129	0	1,596	3,726
Middle Park	8,833	2,267	0	11,099
North Park	1,169	0	0	1,169
Northern Eagle – Southern Routt Counties	2,430	953	2,161	5,544
Northwest Colorado	18,683	922	240	19,846
Parachute – Piceance - Roan	1,355	0	1,808	3,163
Total	34,600	4,142	5,806	44,548

Table J-14. Acreage of conservation easements currently held in each management zone of the Northwest Colorado GrSG area.

Management Zone	Occupied Habitat	Vacant/ Unknown Habitat	Potentially Suitable Habitat	Total
1	3,129	0	0	3,129
2	7,765	0	0	7,765
3a	491	0	0	491
3b	0	0	0	0
3c	0	0	0	0
4a	2,035	0	0	2,035
4b	2,581	922	240	3,743
5	2,683	0	0	2,683
6	0	0	0	0
7	0	0	0	0
Total	18,683	922	240	19,846

Selected Habitat Classes in Habitat Categories – All GrSG Populations

The data from Table J-1 were refined for use in the "Habitat Model Analysis" (pg. 241) and "Population Management Zone Development" (pg. 28). Specifically, the vegetation classes of the areas falling with occupied, vacant/unknown, and potential categories were examined closely in regards to their usefulness to GrSG. Only those categories deemed as usable GrSG habitat are included in the selected habitat (Tables J-15 – J-20).

Table J-15. Meeker – White River: selected vegetation class data used for habitat model analysis and population target development. Note that, following this selection process, an additional refinement was made in defining the boundary between the NWCO and MWR populations, regarding potentially suitable habitat: a large polygon of potentially suitable habitat was moved from Zone 5 to the Meeker – White River. Thus, the data for MWR in this table differ markedly from the data in Tables J-1 and J-2, and that difference is not based solely on the vegetation class selection process.

Selected Vegetation Class	Occupied	Vacant/Unknown	Potential	Total
Aspen/Mesic Mountain Shrub Mix	1,697	45	616	2,358
Disturbed Rangeland	28	1	240	269
Dryland Ag	514	0	1,859	2,373
Gambel Oak	2,689	351	2,867	5,907
Grass Dominated	855	266	4,546	5,666
Grass/Forb Mix	323	155	1,006	1,485
Herbaceous Riparian	60	3	59	121
Irrigated Ag	3,157	272	2,602	6,030
Juniper/Mtn Shrub Mix	88	2	115	205
Juniper/Sagebrush Mix	26	0	254	280
Mesic Mountain Shrub Mix	2,578	75	1,224	3,877
PJ-Mtn Shrub Mix	461	280	435	1,176
PJ-Oak Mix	159	134	115	409
PJ-Sagebrush Mix	55	52	215	322
Riparian	4	2	4	9
Rock	103	1	143	246
Sagebrush Community	4,278	724	10,993	15,995
Sagebrush/Gambel Oak Mix	1,310	178	460	1,948
Sagebrush/Grass Mix	4,728	1,116	6,283	12,127
Sagebrush/Greasewood	4	0	115	119
Sagebrush/Mesic Mtn Shrub Mix	15,006	1,603	6,572	23,181
Serviceberry/Shrub Mix	12	18	88	119
Shrub Riparian	468	77	798	1,343
Snowberry/Shrub Mix	0	0	12	12
Soil	44	4	84	132
Sparse Juniper/Shrub/Rock Mix	6	0	167	173
Sparse PJ/Shrub/Rock Mix	914	352	3,527	4,793
Willow	44	0	6	50
Xeric Mountain Shrub Mix	16	0	10	26
TOTAL	**39,627**	**5,713**	**45,412**	**90,752**

Table J-16. Middle Park: selected vegetation class data used for habitat model analysis and population target development.

Selected Vegetation Class	Occupied	Vacant/Unknown	Potential	Total
Aspen/Mesic Mountain Shrub Mix	4	0	0	4
Barren Land	2,781	150	0	2,931
Grass Dominated	6,334	885	781	8,000
Grass/Forb Mix	5,440	0	427	5,867
Greasewood	1,316	0	7	1,323
Herbaceous Riparian	2,085	66	35	2,186
Irrigated Ag	18,450	460	467	19,377
Mesic Mountain Shrub Mix	221	0	0	221
PJ-Mtn Shrub Mix	140	0	0	140
PJ-Sagebrush Mix	27	0	0	27
Riparian	1,468	25	62	1,556
Rock	6,789	27	23	6,839
Sagebrush Community	130,925	2,330	2,774	136,029
Sagebrush/Grass Mix	38,273	229	782	39,283
Sagebrush/Mesic Mtn Shrub Mix	11,427	368	106	11,902
Sagebrush/Rabbitbrush Mix	73	0	0	73
Shrub Riparian	386	27	31	444
Shrub/Brush Rangeland	928	58	0	985
Shrub/Grass/Forb Mix	6,780	0	95	6,875
Soil	3,460	0	1	3,461
Sparse Grass (Blowouts)	73	0	0	73
Sparse PJ/Shrub/Rock Mix	5	0	0	5
Subalpine Grass/Forb Mix	2,062	115	133	2,310
TOTAL	**239,446**	**4,741**	**5,725**	**249,912**

Table J-17. North Park: selected vegetation class data used for habitat model analysis and population target development.

Selected Vegetation Class	Occupied	Vacant/Unknown	Potential	Total
Aspen/Mesic Mountain Shrub Mix	1	0	0	1
Bitterbrush Community	171	0	0	171
Disturbed Rangeland	204	0	0	204
Grass Dominated	32,045	0	0	32,045
Grass/Forb Mix	4,838	0	0	4,838
Greasewood	499	0	0	499
Herbaceous Riparian	3,402	0	0	3,402
Irrigated Ag	65,278	0	0	65,278
Sagebrush Community	247,058	0	0	247,058
Sagebrush/Grass Mix	37,964	0	0	37,964
Soil	1,930	0	0	1,930
Sparse Grass (Blowouts)	2,525	0	0	2,525
Willow	8,055	0	0	8,055
TOTAL	**403,972**	**0**	**0**	**403,972**

Table J-18. Northern Eagle – Southern Routt Counties: selected vegetation class data used for habitat model analysis and population target development.

Selected Vegetation Class	Occupied	Vacant/Unknown	Potential	Grand Total
Aspen/Mesic Mountain Shrub Mix	1,758	819	449	3,027
Dryland Ag	77	45	0	121
Forb Dominated	238	0	713	951
Gambel Oak	216	15	1,087	1,319
Grass Dominated	2,480	306	954	3,740
Grass/Forb Mix	459	24	815	1,299
Herbaceous Riparian	12	4	0	16
Irrigated Ag	10,768	957	4,390	16,115
Juniper/Mtn Shrub Mix	0	5	0	5
Juniper/Sagebrush Mix	108	0	278	386
Mesic Mountain Shrub Mix	4,417	1,623	8,188	14,229
PJ-Mtn Shrub Mix	477	0	2,599	3,076
PJ-Sagebrush Mix	616	0	2,509	3,125
Rabbitbrush/Grass Mix	0	0	28	28
Rock	391	12	235	638
Sagebrush Community	28,742	402	37,298	66,442
Sagebrush/Grass Mix	9,383	477	3,977	13,837
Sagebrush/Greasewood	0		375	375
Sagebrush/Mesic Mtn Shrub Mix	20,097	3,100	21,338	44,535
Sagebrush/Rabbitbrush Mix	976	4	304	1,284
Sedge	217	39	0	256
Serviceberry/Shrub Mix	0	0	30	30
Shrub Riparian	373	98	12	483
Shrub/Grass/Forb Mix	1,219	62	2,139	3,420
Snowberry/Shrub Mix	175	67	0	241
Soil	242	0	1,434	1,677
Sparse Juniper/Shrub/Rock Mix	18	1	240	259
Sparse PJ/Shrub/Rock Mix	339	0	3,842	4,181
Subalpine Grass/Forb Mix	378	3	907	1,287
Willow	523	93	133	748
Xeric Mountain Shrub Mix	764	0	1,960	2,724
TOTAL	**85,463**	**8,155**	**96,236**	**189,854**

Table J-19. Northwest Colorado: selected vegetation class data used for habitat model analysis and population target development. Note that, following this selection process, an additional refinement was made in defining the boundary between the NWCO and MWR populations, regarding potentially suitable habitat: a large polygon of potentially suitable habitat was moved from Zone 5 to the Meeker – White River. Thus, the data for Zone 5 in this table differ markedly from the data in Table J-11.

Northwest Colorado	Selected Vegetation Class	Occupied	Vacant/ Unknown	Potential	Total
Zone 1	Bitterbrush Community	461	0	0	461
	Bitterbrush/Grass Mix	102	0	0	102
	Grass Dominated	528	0	0	528
	Grass/Forb Mix	1,527	0	0	1,527
	Greasewood	3,866	0	0	3,866
	Herbaceous Riparian	4,238	0	0	4,238
	Irrigated Ag	420	0	0	420
	Mesic Mountain Shrub Mix	11,414	0	0	11,414
	Sagebrush Community	34,895	0	0	34,895
	Sagebrush/Grass Mix	65,130	0	0	65,130
	Sagebrush/Greasewood	1,822	0	0	1,822
	Sagebrush/Mesic Mtn Shrub Mix	1,145	0	0	1,145
	Salt Desert Shrub Community	10,781	0	0	10,781
	Saltbush Community	20,886	0	0	20,886
	Serviceberry/Shrub Mix	150	0	0	150
Zone 1 Total		**157,366**	**0**	**0**	**157,366**
Zone 2	Aspen	21	0	0	21
	Aspen/Mesic Mountain Shrub Mix	440	0	0	440
	Bitterbrush Community	4,105	0	0	4,105
	Bitterbrush/Grass Mix	405	0	0	405
	Cottonwood	86	0	0	86
	Douglas Fir	19	0	0	19
	Exotic Riparian Shrubs	293	0	0	293
	Forested Riparian	27	0	0	27
	Grass Dominated	1,381	0	0	1,381
	Grass/Forb Mix	2,641	0	0	2,641
	Greasewood	14,395	0	0	14,395
	Herbaceous Riparian	430	0	0	430
	Irrigated Ag	762	0	0	762
	Juniper	1,512	0	0	1,512
	Juniper/Sagebrush Mix	12,790	0	0	12,790
	Mesic Mountain Shrub Mix	1,221	0	0	1,221
	Pinon-Juniper	2,693	0	0	2,693
	PJ-Mtn Shrub Mix	2,701	0	0	2,701
	PJ-Sagebrush Mix	4,520	0	0	4,520
	Ponderosa Pine	87	0	0	87

Northwest Colorado	Selected Vegetation Class	Occupied	Vacant/ Unknown	Potential	Total
	Rock	12	0	0	12
	Sagebrush Community	73,295	0	0	73,295
	Sagebrush/Grass Mix	193,021	0	0	193,021
	Sagebrush/Greasewood	10,466	0	0	10,466
	Sagebrush/Mesic Mtn Shrub Mix	53	0	0	53
	Salt Desert Shrub Community	58,422	0	0	58,422
	Saltbush Community	124,477	0	0	124,477
	Serviceberry/Shrub Mix	10	0	0	10
	Shrub Riparian	1,014	0	0	1,014
	Shrub/Brush Rangeland	2,990	0	0	2,990
	Soil	25,171	0	0	25,171
	Sparse Juniper/Shrub/Rock Mix	12,299	0	0	12,299
	Sparse PJ/Shrub/Rock Mix	3,531	0	0	3,531
	Spruce/Fir/Lodgepole/Aspen Mix	0	0	0	0
	Water	827	0	0	827
	Willow	328	0	0	328
	(blank)	3,718	0	0	3,718
Zone 2 Total					**0**
Zone 3a	Aspen	0	0	0	0
	Aspen/Mesic Mountain Shrub Mix	334	0	0	334
	Bitterbrush Community	5,684	0	0	5,684
	Grass Dominated	6,424	0	0	6,424
	Grass/Forb Mix	122	0	0	122
	Greasewood	5,675	0	0	5,675
	Herbaceous Riparian	212	0	0	212
	Irrigated Ag	1,920	0	0	1,920
	Riparian	0	0	0	0
	Sagebrush Community	49,825	0	0	49,825
	Sagebrush/Grass Mix	120,934	0	0	120,934
	Sagebrush/Greasewood	3,906	0	0	3,906
	Sagebrush/Mesic Mtn Shrub Mix	1	0	0	1
	Salt Desert Shrub Community	4,756	0	0	4,756
	Saltbush Community	21,576	0	0	21,576
Zone 3a Total		**221,370**	**0**	**0**	**221,370**
Zone 3b	Aspen	58	0	0	58
	Aspen/Mesic Mountain Shrub Mix	140	0	0	140
	Bitterbrush Community	1,940	0	0	1,940
	Disturbed Rangeland	614	0	0	614
	Dryland Ag	5,531	0	0	5,531
	Foothill and Mountain Grasses	55	0	0	55
	Gambel Oak	1	0	0	1
	Grass Dominated	4,405	0	0	4,405

Northwest Colorado	Selected Vegetation Class	Occupied	Vacant/ Unknown	Potential	Total
	Grass/Forb Mix	2,371	0	0	2,371
	Greasewood	759	0	0	759
	Herbaceous Riparian	370	0	0	370
	Irrigated Ag	4,135	0	0	4,135
	Mesic Mountain Shrub Mix	139	0	0	139
	Riparian	144	0	0	144
	Rock	2,023	0	0	2,023
	Sagebrush Community	131,387	0	0	131,387
	Sagebrush/Grass Mix	84,933	0	0	84,933
	Sagebrush/Greasewood	827	0	0	827
	Sagebrush/Mesic Mtn Shrub Mix	1,286	0	0	1,286
	Sedge	7	0	0	7
	Shrub Riparian	421	0	0	421
	Shrub/Brush Rangeland	1,280	0	0	1,280
	Shrub/Grass/Forb Mix	792	0	0	792
Zone 3b Total		**243,615**	**0**	**0**	**243,615**
Zone 3c	Bitterbrush Community	2,750	0	0	2,750
	Dryland Ag	18,914	0	0	18,914
	Grass Dominated	12,515	0	0	12,515
	Grass/Forb Mix	33,463	0	0	33,463
	Greasewood	2,557	0	0	2,557
	Herbaceous Riparian	1,124	0	0	1,124
	Irrigated Ag	6,710	0	0	6,710
	Mesic Mountain Shrub Mix	4,631	0	0	4,631
	Sagebrush Community	61,682	0	0	61,682
	Sagebrush/Grass Mix	127,741	0	0	127,741
	Sagebrush/Greasewood	2,917	0	0	2,917
	Sagebrush/Mesic Mtn Shrub Mix	1,405	0	0	1,405
	Salt Desert Shrub Community	1,103	0	0	1,103
	Saltbush Community	6,083	0	0	6,083
	Sedge	22	0	0	22
	Shrub/Grass/Forb Mix	252	0	0	252
Zone 3c Total		**283,871**	**0**	**0**	**283,871**
Zone 4a	Disturbed Rangeland	24	0	0	24
	Foothill and Mountain Grasses	315	0	0	315
	Grass Dominated	2,258	0	316	2,574
	Herbaceous Riparian	100	0	0	100
	Irrigated Ag	1,990	0	116	2,106
	Mesic Mountain Shrub Mix	3,637	0	946	4,583
	Riparian	55	0	0	55
	Sagebrush Community	13,787	0	1,654	15,441
	Sagebrush/Grass Mix	19,457	0	740	20,197

Northwest Colorado	Selected Vegetation Class	Occupied	Vacant/ Unknown	Potential	Total
	Sagebrush/Mesic Mtn Shrub Mix	22,868	0	2,642	25,510
	Shrub/Brush Rangeland	163	0	0	163
Zone 4a Total		**64,653**	**0**	**6,413**	**71,066**
Zone 4b	Dryland Ag	24,627	1,229	1,846	27,703
	Grass Dominated	18,631	2,425	1,342	22,398
	Grass/Forb Mix	42,442	1,098	2,655	46,194
	Herbaceous Riparian	538	21	47	606
	Irrigated Ag	4,171	1,798	123	6,092
	Mesic Mountain Shrub Mix	8,823	1,413	995	11,231
	Sagebrush Community	37,233	1,574	2,128	40,934
	Sagebrush/Grass Mix	46,086	3,189	1,887	51,162
	Sagebrush/Mesic Mtn Shrub Mix	25,315	4,004	3,912	33,231
	Sedge	476	115	23	614
	Shrub/Grass/Forb Mix	542	10	9	560
Zone 4b Total		**208,884**	**16,877**	**14,966**	**240,727**
Zone 5	Barren Land	22	8	0	30
	Bitterbrush Community	7,117	0	46	7,163
	Disturbed Rangeland	1,384	0	639	2,022
	Grass Dominated	20,934	344	4,104	25,382
	Grass/Forb Mix	7,520	198	593	8,311
	Greasewood	9,163	0	208	9,371
	Herbaceous Riparian	1,780	2	84	1,866
	Irrigated Ag	9,588	6	4,506	14,100
	Juniper/Sagebrush Mix	16,275	0	1,301	17,576
	Mesic Mountain Shrub Mix	29,069	1,026	817	30,912
	Riparian	0	0	69	70
	Sagebrush Community	83,115	1,114	19,231	103,460
	Sagebrush/Grass Mix	144,800	646	7,482	152,928
	Sagebrush/Greasewood	5,112	0	652	5,764
	Sagebrush/Mesic Mtn Shrub Mix	6,032	2,325	5,678	14,036
	Salt Desert Shrub Community	934	0	1	936
	Saltbush Community	8,468	0	48	8,515
	Sedge	80	3	0	84
	Shrub Riparian	2,111	91	1,324	3,527
	Shrub/Grass/Forb Mix	114	4	0	118
Zone 5 Total		**353,618**	**5,768**	**46,782**	**406,168**
Zone 6	Disturbed Rangeland	1,276	2,187	1	3,464
	Foothill and Mountain Grasses	6,049	1,660	35	7,744
	Grass Dominated	18,078	6,813	92	24,984
	Herbaceous Riparian	975	64	0	1,039
	Irrigated Ag	1,796	10	0	1,807

Northwest Colorado	Selected Vegetation Class	Occupied	Vacant/ Unknown	Potential	Total
	Mesic Mountain Shrub Mix	13,471	0	4	13,475
	Sagebrush Community	66,180	3,466	2,601	72,247
	Sagebrush/Grass Mix	71,488	6,564	1,355	79,407
	Sagebrush/Greasewood	8,265	713	122	9,100
	Sagebrush/Mesic Mtn Shrub Mix	13,171	0	1	13,171
	Sagebrush/Rabbitbrush Mix	266	0	0	266
	Saltbush Community	18,847	3,610	63	22,520
	Serviceberry/Shrub Mix	1,362	0	0	1,362
	Shrub Riparian	1,784	68	27	1,879
	Xeric Mountain Shrub Mix	483	0	0	483
Zone 6 Total		**223,491**	**25,156**	**4,301**	**252,947**
Zone 7	Bitterbrush Community	10	0	0	10
	Bitterbrush/Grass Mix	30	0	0	30
	Grass Dominated	12	0	0	12
	Greasewood	3	0	0	3
	Herbaceous Riparian	1	0	0	1
	Irrigated Ag	0	0	0	0
	Sagebrush Community	3,602	0	0	3,602
	Sagebrush/Grass Mix	7,551	0	0	7,551
	Sagebrush/Greasewood	41	0	0	41
	Saltbush Community	1	0	0	1
Zone 7 Total		**11,250**		**0**	**11,250**

Table J-20. Parachute – Piceance - Roan: selected vegetation class data used for habitat model analysis and population target development.

Selected Vegetation Class	Occupied	Vacant/Unknown	Potential	Grand Total
Disturbed Rangeland	2,323	440	3,009	5,772
Dryland Ag	0	0	6	6
Foothill and Mountain Grasses	70	7	0	78
Gambel Oak	6,079	640	1,176	7,894
Grass Dominated	4,694	883	3,518	9,095
Grass/Forb Mix	9,785	1,501	5,527	16,813
Herbaceous Riparian	52	0	444	497
Irrigated Ag	330	658	8,192	9,180
Juniper/Mtn Shrub Mix	0	0	5	5
Juniper/Sagebrush Mix	0	2,547	8,103	10,650
Mesic Mountain Shrub Mix	24,932	2,153	387	27,472
PJ-Mtn Shrub Mix	15,305	5,367	19,477	40,149
PJ-Oak Mix	1,660	25	1,825	3,510
PJ-Sagebrush Mix	3,779	10,317	24,908	39,004
Rabbitbrush/Grass Mix	34	390	379	804
Riparian	77	0	29	106
Sagebrush Community	17,050	2,405	48,249	67,704
Sagebrush/Gambel Oak Mix	0	0	30	30
Sagebrush/Grass Mix	51,418	38,954	31,928	122,299
Sagebrush/Greasewood	198	1,541	775	2,515
Sagebrush/Mesic Mtn Shrub Mix	54,702	3,076	10,793	68,571
Sagebrush/Rabbitbrush Mix	416	1,070	947	2,432
Sedge	0	3	138	141
Serviceberry/Shrub Mix	38,344	2,186	3,174	43,703
Shrub Riparian	6	0	1,554	1,560
Shrub/Brush Rangeland	0	3	212	215
Shrub/Grass/Forb Mix	268	312	1,184	1,765
Snakeweed/Shrub Mix	0	0	1	1
Snowberry	4	0	0	4
Snowberry/Shrub Mix	26,955	2,532	38	29,525
Sparse Juniper/Shrub/Rock Mix	1,018	2,858	4,525	8,401
Sparse PJ/Shrub/Rock Mix	3,042	5,039	6,872	14,953
Subalpine Grass/Forb Mix	1	0	0	1
Willow	0	1	96	97
Xeric Mountain Shrub Mix	268	1	0	268
TOTAL	**262,811**	**84,909**	**187,498**	**535,218**

APPENDIX K

POPULATION VIABILITY ANALYSIS REPORT (Miller et al. 2006)

Brian Maxfield

Population Viability Analysis for the Greater Sage-grouse (*Centrocercus urophasianus*) in Colorado

PRELIMINARY REPORT

Report prepared by:
Philip S. Miller
IUCN / SSC Conservation Breeding Specialist Group

In collaboration with

Members of the
Colorado Greater Sage-grouse
Conservation Plan Steering Committee

Preliminary Population Viability Analysis for the Greater Sage-grouse (*Centrocercus urophasianus*) in Colorado

Philip Miller, Conservation Breeding Specialist Group
and
Colorado Greater Sage-grouse Conservation Plan Steering Committee Members

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Population Viability Analysis for the Greater Sage-grouse (*Centrocercus urophasianus*) in Colorado

Philip Miller, Conservation Breeding Specialist Group
and
Colorado Greater Sage-grouse Conservation Plan Steering Committee Members

Introduction

Dependent exclusively on sagebrush ecosystems that define the ecology of much of western North America, the greater sage-grouse (*Centrocercus urophasianus*) was once distributed across twelve states of the western United States and three provinces of Canada. Greater sage-grouse currently occupy 700,000 km^2, or 56%, of their potential pre-settlement range, which once covered approximately 1,200,000 km^2 (Connelly et al. 2004). The species is now lost from Nebraska and Alberta, and other peripheral populations are at increasing risk of extirpation. As a result of these declines, petitions have been filed to list the species under the United States Endangered Species Act.

In Colorado, greater sage-grouse occupy significant tracts of sagebrush habitat in the northwestern region of the state. Authors of the Colorado Greater Sage-grouse Conservation Plan (CCP) have identified six largely discrete regions where birds are found. In five of these areas local working groups have formed, comprised of concerned citizens, researchers, and managers dedicated to developing grouse conservation strategies at the local level. As in many other western states, there is concern over a variety of human activities – new housing development, oil and natural gas exploration, livestock grazing, surface mining, and hunting – that may unintentionally result in significant negative impacts to local sage-grouse populations. These impacts might possibly destabilize the integrity of the sagebrush habitat or the populations themselves to an extent where the risk of local extinction is greatly increased. Therefore, it is critical that the potential impact of these activities is evaluated using sound scientific methodologies, and the results of these analyses are incorporated into the evolving statewide species conservation strategies.

Population viability analysis, or PVA, can be an extremely useful tool for investigating current and future risk of Colorado greater sage-grouse population decline or extinction. The need for and consequences of alternative management strategies can be modeled to suggest which practices may be the most effective in managing sage-grouse populations in its wild habitat. *VORTEX*, a simulation software package written for population viability analysis, was used here as a vehicle to study the interaction of a number of greater sage-grouse life history and population parameters, to explore which demographic parameters may be the most sensitive to alternative management practices, and to test the effects of selected management scenarios.

The *VORTEX* package is a simulation of the effects of a number of different natural and human-mediated forces – some, by definition, acting unpredictably from year to year – on the health and integrity of wildlife populations. *VORTEX* models population dynamics as discrete sequential events (e.g., births, deaths, sex ratios among offspring, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modeled as constants or random variables that follow specified distributions. The package simulates a population by recreating the essential series of events that describe the typical life cycles of sexually reproducing organisms.

PVA methodologies such as the *VORTEX* system are not intended to give absolute and accurate “answers” for what the future will bring for a given wildlife species or population. This limitation arises simply from two fundamental facts about the natural world: it is inherently unpredictable in its detailed behavior; and we will never fully understand its precise mechanics. Consequently, many researchers have cautioned against the exclusive use of absolute results from a PVA in order to promote specific management actions for threatened populations (e.g., Ludwig 1999; Beissinger and McCullough 2002; Reed et al. 2002; Ellner et al. 2002; Lotts et al. 2004). Instead, the true value of an analysis of this type lies in the assembly and critical analysis of the available information on the species and its ecology, and in the ability to compare the quantitative metrics of population performance that emerge from a suite of simulations, with each simulation representing a specific scenario and its inherent assumptions about the available data and a proposed method of population and/or landscape management. Interpretation of this type of output depends strongly upon our knowledge of greater sage-grouse biology in its habitat, the environmental conditions affecting the species, and possible future changes in these conditions.

The *VORTEX* system for conducting population viability analysis is a flexible and accessible tool that can be adapted to a wide variety of species types and life histories as the situation warrants. The program has been used around the world in both teaching and research applications and is a trusted method for assisting in the definition of practical wildlife management methodologies. For a more detailed explanation of *VORTEX* and its use in population viability analysis, refer to Appendix I, Lacy (2000) and Miller and Lacy (2003).

Specifically, we were interested in using this preliminary analysis to address the following questions:

- Can we build a series of simulation models with sufficient detail and precision that can accurately describe the dynamics of greater sage-grouse populations distributed across Colorado?
- What are the primary demographic factors that drive growth of greater sage-grouse populations in Colorado?
- How vulnerable are small, fragmented populations of greater sage-grouse in Colorado to extinction under current management conditions? How small must a population become to increase its risk of extinction to an unacceptable level?
- What are the predicted impacts of current and potential future levels of housing development on selected greater sage-grouse populations in Colorado?
- What are the predicted impacts of current and potential future levels of mining and other surface activities on selected greater sage-grouse populations in Colorado?
- What are the predicted impacts of current and potential future levels of hunting on selected greater sage-grouse populations in Colorado?
- What are the predicted impacts of current and potential future levels of petroleum and natural gas development on selected greater sage-grouse populations in Colorado?
- Can reproductive mitigation improve the viability of greater sage-grouse populations in Colorado in the face of other anthropogenic processes?

Baseline Input Parameters for Stochastic Population Viability Simulations

Much of the data discussed below are gleaned from Zablan et al. (2003), the radio telemetry studies on greater sage-grouse of Hausleitner (2003) and Thompson (unpublished) in Moffat County, Colorado and Peterson (1980) in North Park, Colorado.

Breeding System: The greater sage-grouse is a polygynous lek-breeding species. In *VORTEX*, a set of adult females are therefore randomly selected each year to breed with a given male. Breeding success of adult males within a give year is often dependent on the success of that male in the previous year. This was not specifically simulated in this analysis as this aspect of the breeding biology is unlikely to have a noticeable demographic impact on future population performance.

Age of First Reproduction: *VORTEX* considers the age of first reproduction as the age at which the first clutch of eggs is laid, not simply the onset of sexual maturity. Female sage-grouse can lay their first clutch at one year of age, while males are much more likely to be two years old at the time of egg-laying. Because of the very low probability of breeding success among yearling males, we elected to ignore this possibility in our models.

Age of Reproductive Senescence: In its simplest form, *VORTEX* assumes that animals can reproduce (at the normal rate) throughout their adult life. There are no real data available on senescence in sage-grouse, so we made a reasonable estimate of the maximum age possible for this species as 10 years. In reality, surpassing this age in our models is unlikely given observed mortality rates (see below).

Offspring Production: Based on the depth of our knowledge of sage-grouse life history, we have defined reproduction in these models as the production of newly-hatched chicks by a given female, roughly early May – June. Field data have been collected on the rates of nest initiation and success among both yearling and adult females. Of those that are initially unsuccessful in nesting, additional data exist on the rates of renesting success. With these data in hand, we can calculate the proportion of females that successfully reproduce in a given year through the following equation:

P(♀) = [(first nest initiation)(first nest success)] +
[(first nest initiation)(first nest NO success)(second nest initiation)(second nest success)]

Radio telemetry data from Hausleitner (2003) and Thompson (unpublished) in Moffat County allow us to derive estimates of these important parameters:

	Nest initiation	Nest success	Renest initiation	Renest success
Adults	0.93	0.50	0.16	0.75
Yearlings	0.83	0.39	0.22	0.57

Taken together, these data means that, on average, 38.7% of greater sage-grouse yearlings successfully reproduce in a given year, and 52.1% of adults are likewise successful. These results were combined in an equation used within *VORTEX* to describe the relationship between the average percentage of adult females breeding each year and their age.

Annual environmental variation in female reproductive success is modeled in *VORTEX* by specifying a standard deviation (SD) for the proportion of adult females that successfully lay a clutch of eggs within a given year. Wing receipt data from greater sage-grouse populations suggest that annual variability in reproductive success among yearling females is about 8%, while slightly lower among older birds (SD = 6%).

The maximum number of eggs per clutch has been set at 9, based on data collected by Griner (1939) in greater sage-grouse populations in eastern Utah. Given that an adult female lays a clutch of eggs, the distribution of clutch size was set as follows:

Number of eggs	%
1	1.0
2	1.0
3	1.0
4	1.0
5	5.5
6	27.3
7	35.0
8	25.0
9	3.2

This distribution yields an average clutch size of 6.75 eggs. The overall population-level sex ratio among eggs is assumed to be 50%.

Density-Dependent Reproduction: *VORTEX* can model density dependence with an equation that specifies the proportion of adult females that reproduce as a function of the total population size. In addition to including a more typical reduction in breeding in high-density populations, the user can also model an Allee effect: a decrease in the proportion of females that bread at low population density due, for example, to difficulty in finding mates that are widely dispersed across the landscape.

While a significant source of debate among species experts, there are no current field data to support density dependence in reproduction in greater sage-grouse populations. Consequently, this option was not included in the models presented here.

Male Breeding Pool: In many species, some adult males may be socially restricted from breeding despite being physiologically capable. This can be modeled in *VORTEX* by specifying a portion of the total pool of adult males that may be considered “available” for breeding each year. Observational data suggests that as few as 10% of the adult males are actually participating in the displays on leks within a given population segment, and this value was used in our baseline population analysis. Other researchers think this value may be much higher, approaching as high as 33%.

Mortality: *VORTEX* defines mortality as the annual rate of age-specific death from year x to $x + 1$; in the language of life-table analysis, this is equivalent to $q(x)$. Juvenile rates were composed of data estimated from hatching to 1 September (Northwestern Colorado: Thompson, unpublished), then 1 September to 30 March (Idaho: Beck et al., in press). Yearling and adult rates are largely based on data collected in North Park by Zablan et al. (2003), with additional data provided by Hausleitner (2003).

Age Class	% Mortality (SD)	
	Females	Males
0 – 1	75.7 (5.0)	74.5 (5.0)
1 – 2	24.0 (4.0)	36.5 (3.0)
2 - +	42.0 (4.0)	63.0 (1.0)

Inbreeding Depression: *VORTEX* includes the ability to model the detrimental effects of inbreeding, most directly through reduced survival of offspring through their first year. Because of the complete absence of information on the effects of inbreeding on the demography of greater sage-grouse, the group concluded that this option should not be included in our models.

Initial Population Size: A total of six discrete populations of greater sage-grouse were considered in this analysis. These populations are listed below, with their estimated numbers based on observed spring breeding counts of males on leks and a presumed 2:1 female:male ratio.

Population	**Breeding Males***	**Total Population**
Piceance / Parachute / Roan	186	1,104
Meeker / White River	28	153
North Park	1,234	6,731
Middle Park	290	1,581
Northern Eagle / Southern Routt Counties	104	567
Eagle	11	60
Routt	93	507
Northwestern Colorado	2,387	13,023
Zone 1	153	834
Zone 2	28	153
Zone 3A	534	2,913
Zone 3B	625	3,408
Zone 3C	139	759
Zone 4A	217	1,185
Zone 4B	76	414
Zone 5	294	1,605
Zone 6	304	1,659
Zone 7	17	93

* Average value, 2001 - 2005

** Total N = (0.55)(Breeding males) + 2(0.55)(Breeding males)

Note that the Northern Eagle / Southern Routt Counties and Northwestern Colorado regions are actually composed of metapopulations – that is, aggregates of subpopulations that are linked together through differential rates of dispersal. See below for a detailed discussion of additional metapopulation parameters.

VORTEX distributes the specified initial population among age-sex classes according to a stable age distribution that is characteristic of the mortality and reproductive schedules described previously.

Carrying Capacity: The carrying capacity, K, for a given habitat patch defines an upper limit for the population size, above which additional mortality is imposed randomly across all age classes in order to return the population to the value set for K.

The estimation of a carrying capacity is a very difficult process. The approach taken in this analysis involved identifying the most reasonable estimated high male lek count in a given region and, by applying the same transformation used to calculate current population size, determining total local carrying capacity. These results are given in the table below.

Population	Max. Breeding Males*	Total K
Piceance / Parachute / Roan	285	1554
Meeker / White River	--	300
North Park	1521	8296
Middle Park	327	1784
Northern Eagle / Southern Routt Counties	307	1673
Eagle	79	429
Routt	228	1244
Northwestern Colorado	2,387	18,170
Zone 1	268	1462
Zone 2	129	704
Zone 3A	570	3109
Zone 3B	667	3638
Zone 3C	153	835
Zone 4A	486	2651
Zone 4B	--	414
Zone 5	565	3082
Zone 6	400	2182
Zone 7	--	93

Metapopulation Parameters: For the Northern Eagle / Southern Routt Counties and Northwestern Colorado populations, additional data on dispersal was required. Field observations indicate that dispersing birds are predominantly composed of yearlings; as a result, we limited dispersal to only those birds aged 1 year. Moreover, while a small percentage of dispersing birds are observed to be male, the model assumes that only females disperse.

Largely in order to achieve a higher degree of model realism with respect to overall metapopulation dynamics, we derived a conditional function that limited the amount of dispersal into populations that were already approaching a given habitat's carrying capacity. Specifically, we prohibited dispersal into a given population when the recipient population was at least 80% saturated; in other words, under conditions when $N \geq 0.8K$.

Rates of dispersal – defined in *VORTEX* as the probability (expressed as a percentage) of an individual moving from one population to another, are given in the table below. Note that the rates between any two populations are not constrained to be symmetric, based on the available data. Source populations are listed as rows, while columns designate recipient populations.

Zone	1	2	3A	3B	3C	4A	4B	5	6	7
1	87	10	0	0	0	0	0	0	1	2
2	3	77	6	5	0	0	0	5	3	1
3A	1	2	69	10	10	0	0	5	3	0
3B	0	3	10	62	10	10	0	5	0	0
3C	0	1	15	15	60	0	4	5	0	0
4A	0	0	0	15	5	75	5	0	0	0
4B	0	0	0	0	3	3	93	1	0	0
5	0	3	5	5	5	0	3	74	5	0
6	1	3	3	0	0	0	0	3	87	3
7	1	1	0	0	0	0	0	0	1	97

Iterations and Years of Projection: All population projections (scenarios) were simulated 500 times. Each projection extends to 50 years, with demographic information obtained at annual intervals. All simulations were conducted using *VORTEX* version 9.60 (March 2006).

Table 1 below summarizes the baseline input dataset upon which all subsequent *VORTEX* models are based.

Table 1. Demographic input parameters for the baseline *VORTEX* Colorado greater sage-grouse models. See accompanying text for more information.

Model Input Parameter	Baseline Value
Breeding System	Polygynous
Age of first reproduction (♀ / ♂)	1 / 2
Maximum age of reproduction	10
Annual % adult females reproducing	38.7 (Yrl) / 52.1% (Ad)
Density dependent reproduction?	No
Maximum clutch size	9
Mean clutch size†	6.75
Overall offspring sex ratio	0.5
Adult males in breeding pool	10%
% annual mortality, ♀ / ♂ (SD)	
0 – 1	75.7 / 74.5 (5.0)
1 – 2	24.0 / 36.5 (3.0)
2 – +	42.0 / 63.0 (4.0 / 1.0)
Initial population size / carrying capacity	
Piceance / Parachute / Roan	1,104 / 1,554
Meeker / White River	153 / 300
North Park	6,731 / 8,296
Middle Park	1,581 / 1,784
Northern Eagle / Southern Routt Counties	567 / 1,673
Eagle	60 / 429
Routt	507 / 1,244
Northwestern Colorado	13,023 / 18,170
Zone 1	834 / 1,462
Zone 2	153 / 704
Zone 3A	2,913 / 3,109
Zone 3B	3,408 / 3,638
Zone 3C	759 / 835
Zone 4A	1,185 / 2,651
Zone 4B	414 / 414
Zone 5	1,605 / 3,082
Zone 6	1,659 / 2,182
Zone 7	93 / 93

† Exact probability distribution of individual clutch size specified in input file.

Definitions of Simulation Modeling Results

Results reported for selected modeling scenarios include:

$\underline{r_s}$ (SD) – The mean rate of stochastic population growth or decline (standard deviation) demonstrated by the simulated populations, averaged across years and iterations, for all simulated populations that are not extinct. This population growth rate is calculated each year of the simulation, prior to any truncation of the population size due to the population exceeding the carrying capacity.

$\underline{P(E)_{50}}$ – Probability of population extinction after 50 years, determined by the proportion of 500 iterations within that given scenario that have gone extinct within the given time frame. "Extinction" is defined in the *VORTEX* model as the lack of either sex.

$\underline{N_{50}}$ (SD) – Mean (standard deviation) population size at the end of the simulation, averaged across all simulated populations, including those that are extinct.

$\underline{GD_{50}}$ – The gene diversity or expected heterozygosity of the extant populations, expressed as a percent of the initial gene diversity of the population. Fitness of individuals usually declines proportionately with gene diversity.

Baseline Model Validation through Retrospective Population Analysis

An important component of population viability analysis involves testing our baseline simulation models against historical population census data. In this approach, we set the model's initial population size with a value based on historical data and then project the model forward to the present day, comparing the predicted trajectory with the real trajectory determined from field census counts. A reasonable fit between the observed and predicted curves gives considerable credibility to the simulation's mechanics and, therefore, instills much more confidence in the relative results from models that predict future responses of greater sage-grouse populations to human activities on the landscape.

The results of these retrospective analyses for each population are shown in Figure 1. With the exception of the Meeker / White River population, all other simulation models appear to accurately predict the true population census within a reasonable degree of uncertainty. Given this general degree of accuracy, the disparity between predicted population size and field census counts in the Meeker / White River analysis is likely not an error in the simulation model but instead probably reflects the small number of leks included in the field census, the difficulty in conducting detailed studies in the area, and the short time period over which the census was conducted. Therefore, the overall conclusion from this retrospective analysis is that our simulation model of Colorado greater sage-grouse population dynamics can be used with acceptable confidence in predicting the relative outcomes of alternative management scenarios for the species.

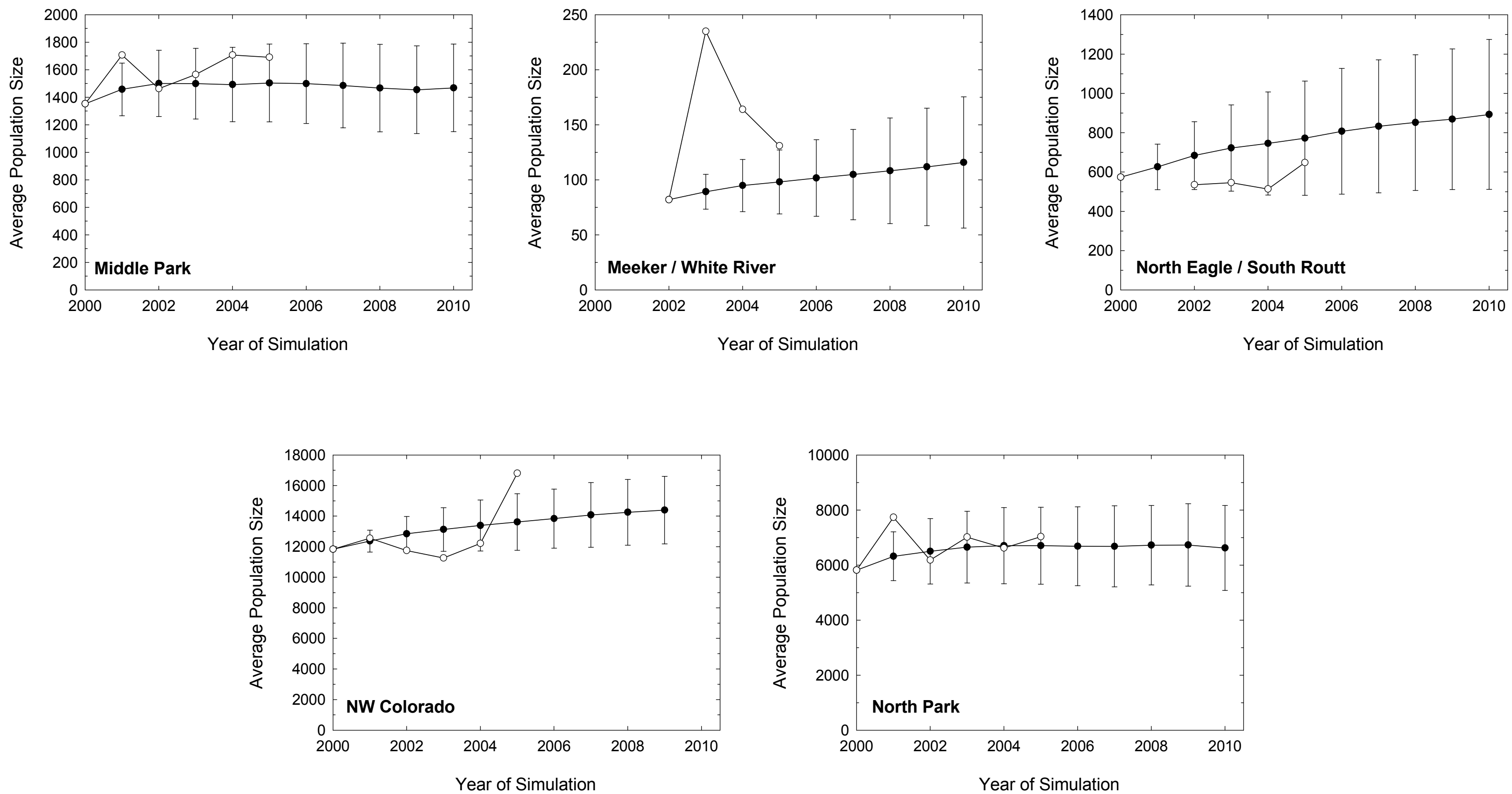


Figure 1. Retrospective projections for simulated greater sage-grouse populations in Colorado. Filled symbols indicate population sizes predicted using the PVA platform *Vortex*, while open symbols give “true” population size estimates derived from field counts. Analysis of the Piceance / Parachute / Roan population is not included here as field census data do not exist. See accompanying text for additional details on model construction and interpretation.

Baseline Model Projections

Table 2 and Figure 2 give the results of fifty-year projections for each of the six regional greater sage-grouse populations considered here. With the exception of Meeker / White River, each population displays long-term population growth values between 0.025 and 0.030, with no risk of extinction over the 50-year timeframe of the simulation. Consistent with the general theoretical expectations of small population biology, the Meeker / White River population shows a lower growth rate and a non-zero (albeit small) risk of extinction. This is a simple demonstration of the demographic instability inherent in smaller populations, as the underlying rates of mortality and reproduction are identical among all simulated populations studied here.

Table 2. Greater sage-grouse PVA: fifty-year projections of baseline models for each regional population. See text for additional information on model construction and parameterization.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Middle Park				
Baseline	0.022 (0.138)	0.000	1370 (400)	0.9531
Meeker / White River				
Baseline	0.019 (0.160)	0.016	208 (83)	0.6619
North Eagle / South Routt				
Baseline	0.031 (0.167)	0.000	988 (471)	0.8980
Piceance / Parachute / Roan				
Baseline	0.025 (0.139)	0.000	1202 (342)	0.9422
Northwest Colorado				
Baseline	0.030 (0.081)	0.000	15739 (1872)	0.9956
North Park				
Baseline	0.025 (0.135)	0.000	6582 (1794)	0.9903

Note that despite the robust levels of growth displayed for each population, the Middle Park and North Park simulated populations show a slightly negative trend in population size over the timeframe of the simulations presented here. This is a consequence of the rather "hard" demographic boundary imposed by *VORTEX* in the form of a carrying capacity, *K*. In the model's structure, if a given population is larger than the specified carrying capacity, animals within the population are removed randomly across all age-sex classes until the size is below *K*. When populations are close to this capacity, this reflective nature of carrying capacity in the model tends to drive a population away from K until a new equilibrium is reached at a level that is somewhere below the specified capacity. While the trajectories shown here may not be completely accurate in the long-term, they do suffice as informative baseline projections from which robust comparative analyses can be made in the risk analyses to follow.

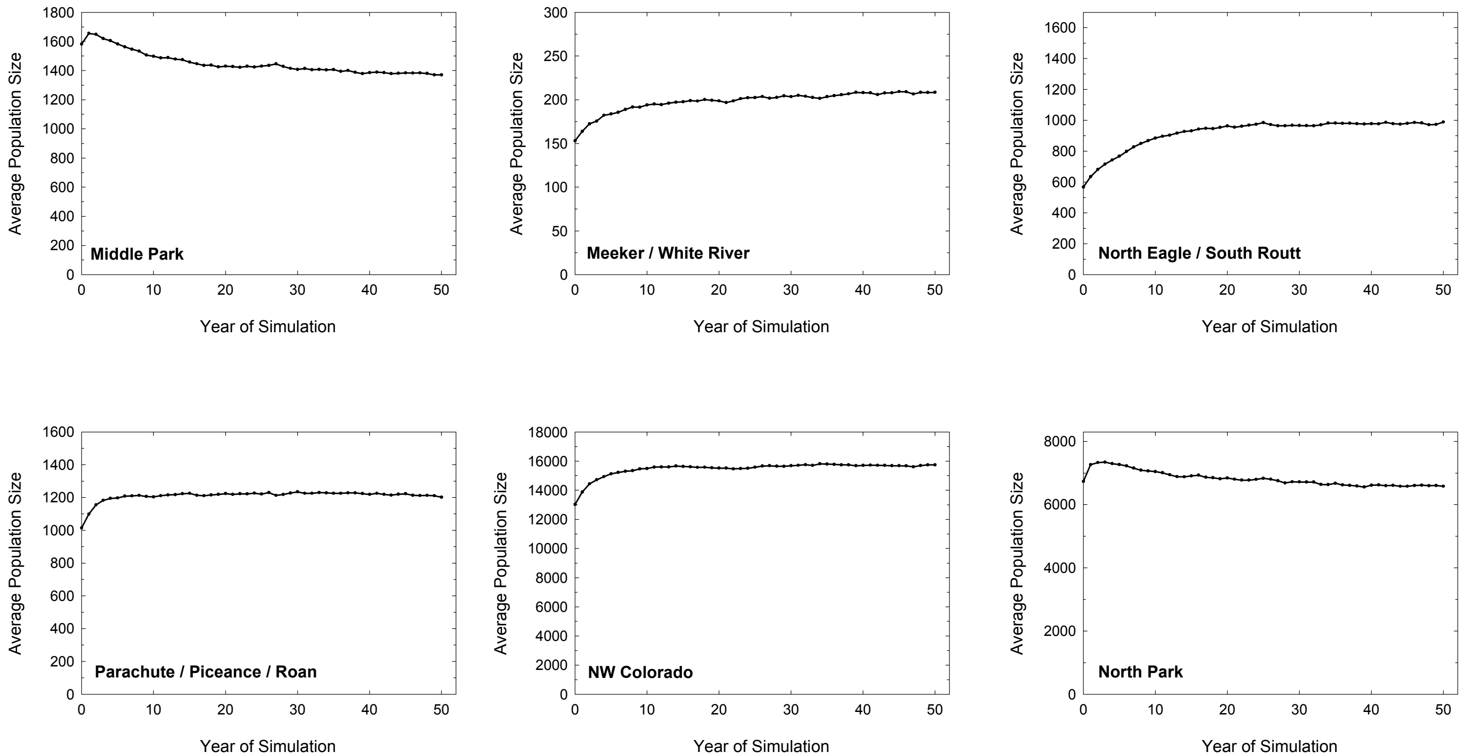


Figure 2. Fifty-year prospective projections for each of the six regional populations of greater sage-grouse in Colorado. See accompanying text for additional details on model construction and interpretation.

Demographic Sensitivity Analysis

During the development of the baseline input dataset, it quickly became apparent that a number of demographic characteristics of greater sage-grouse populations were being estimated with varying levels of uncertainty. This type of measurement uncertainty, which is distinctly different from the annual variability in demographic rates due to extrinsic environmental stochasticity and other factors, impairs our ability to generate precise predictions of population dynamics with any degree of confidence. Nevertheless, an analysis of the sensitivity of our models to this measurement uncertainty can be an invaluable aid in identifying priorities for detailed research and/or management projects targeting specific elements of the species' population biology and ecology.

To conduct this demographic sensitivity analysis, we identify a selected set of parameters from Table 1 whose estimate we see as considerably uncertain. We then develop proportional minimum and maximum values for these parameters (see Table 3).

Table 3. Uncertain input parameters and their stated ranges for use in demographic sensitivity analysis for the Colorado population of greater sage-grouse. Highlighted rows indicate those demographic parameters that show the highest sensitivity, *S*, as listed in the far right-hand column of the table. See accompanying text for more information.

	Estimate			
Model Parameter	Minimum	Baseline	Maximum	*S*
Maximum Age	9	10	11	-0.01269
% Yearling Females Reproducing	34.83	38.7	42.57	-0.11957
% Adult Females Reproducing	46.89	52.1	57.31	-0.27038
Clutch Size	6.08	6.75	7.43	-0.39531
% Female Chick Mortality	68.13	75.7	83.27	1.273304
% Male Chick Mortality	67.05	74.5	81.95	-0.00098
% Yearling Female Mortality	21.6	24.0	26.4	0.080039
% Yearling Male Mortality	32.85	36.5	40.15	0.000976
% Adult Female Mortality	37.8	42.0	46.2	0.253294
% Adult Male Mortality	56.7	63.0	69.3	0.006833

For each of these parameters we construct two simulations, with a given parameter set at its prescribed minimum or maximum value, with all other parameters remaining at their baseline value. With the ten parameters identified above, and recognizing that the aggregate set of baseline values constitute our single baseline model, the table above allows us to construct a total of 20 additional, alternative models whose performance (defined, for example, in terms of average population growth rate) can be compared to that of our starting baseline model.

For the entire suite of sensitivity analysis models, we will consider a generic population of 6,700 individuals and a carrying capacity of 13,500 individuals. This population is large enough to be relatively immune from excessive demographic uncertainty that is characteristic of small populations. Furthermore, carrying capacity is large enough to allow for significant population growth and to observe proper demographic dynamics.

The proportional sensitivity of a given simulation model, S, is given by

$$S = [(\lambda_{Min} - \lambda_{Max}) / (0.2^* \lambda_{Base})]$$

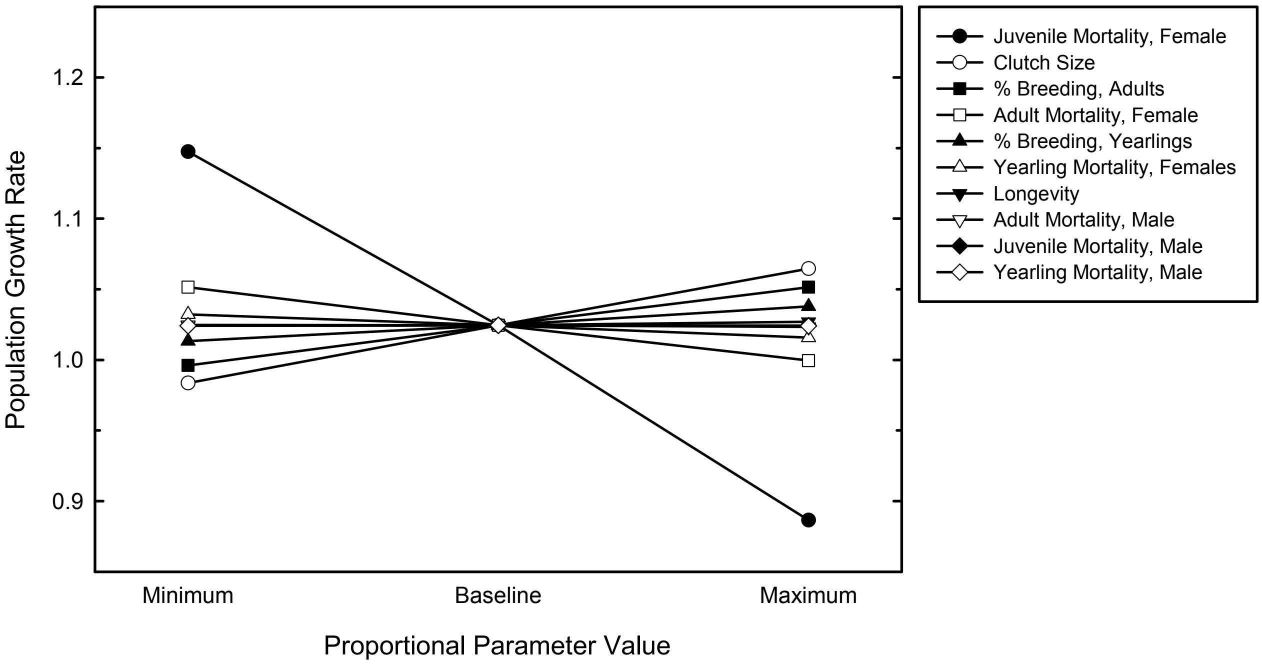
Where $\lambda = e^r$ is the annual rate of population growth calculated from the simulation and subscripts *Min*, *Max* and *Base* refer to simulations that include the minimum, maximum, and baseline values of the appropriate parameter, respectively. Using this formulation, model parameters with large S values show strong differences in λ when values are manipulated (modified from Heppell et al., 2000).

The results of the sensitivity analysis are shown in tabular form in Table 4 and graphically in Figure 3. Those lines with the steepest slope – namely, juvenile (chick) female mortality, clutch size, and adult female mortality – show the greatest degree of response in terms of population growth rate to changes in those parameters and, hence, the greatest sensitivity. These parameters can then be targeted in subsequent field activities for more detailed research and / or demographic management.

Table 4. Greater Sage-grouse PVA. Output from demographic sensitivity analysis models. See text for additional information on model construction and parameterization.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Baseline	0.024 (0.134)	0.000	10181 (3044)	0.9926
Maximum Age – Minimum	0.024 (0.135)	0.000	10230 (3218)	0.9923
Maximum Age – Maximum	0.027 (0.135)	0.000	10505 (2874)	0.9929
% Yearlings Breeding – Minimum	0.013 (0.136)	0.000	8987 (3578)	0.9914
% Yearlings Breeding – Maximum	0.037 (0.136)	0.000	11412 (2361)	0.9932
% Adult Females Breeding – Minimum	-0.004 (0.136)	0.000	5913 (3598)	0.9865
% Adult Females Breeding – Maximum	0.050 (0.135)	0.000	12077 (1837)	0.9940
Litter Size – Minimum	-0.017 (0.133)	0.000	3822 (2927)	0.9828
Litter Size – Maximum	0.063 (0.139)	0.000	112360 (1646)	0.9940
Juvenile Female Mortality – Minimum	0.138 (0.134)	0.000	13310 (564.8)	0.9933
Juvenile Female Mortality – Maximum	-0.120 (0.175)	0.226	41 (73)	0.7415
Juvenile Male Mortality – Minimum	0.024 (0.126)	0.000	10289 (3012)	0.9933
Juvenile Male Mortality – Maximum	0.024 (0.147)	0.000	10172 (3095)	0.9909
Yearling Female Mortality – Minimum	0.032 (0.136)	0.000	11132 (2625)	0.9929
Yearling Female Mortality – Maximum	0.016 (0.137)	0.000	9149 (3472)	0.9917
Yearling Male Mortality – Minimum	0.024 (0.134)	0.000	10291 (3029)	0.9928
Yearling Male Mortality – Maximum	0.024 (0.137)	0.000	10126 (3169)	0.9922
Adult Female Mortality – Minimum	0.050 (0.134)	0.000	12077 (1826)	0.9940
Adult Female Mortality – Maximum	0.000 (0.136)	0.000	6420 (3707)	0.9880
Adult Male Mortality – Minimum	0.024 (0.132)	0.000	10365 (3135)	0.9932
Adult Male Mortality – Maximum	0.023 (0.139)	0.000	10198 (3116)	0.9915

Figure 3. Demographic sensitivity analysis of a generic Colorado greater sage-grouse population. Those curves with the steepest slope indicate the model parameters with the greatest overall sensitivity. See accompanying text for additional information on model construction.



Simulating the Impacts of Human Activity on Sage-grouse Population Dynamics

Once the baseline demographic parameters are established, additional work must be devoted to determining the mechanisms through which specific human activities within greater sage-grouse habitat – namely housing development, surface mining, harvest, oil and natural gas development, and mitigation of reproductive success – may influence the bird's population dynamics in the future. Each individual activity is discussed in detail below.

Risk Analysis I: Impacts of Habitat – Centric Activities (Housing and Surface Mining) on Greater Sage-grouse Population Dynamics

Housing Development: Model Input

Regions considered: Meeker/White River; Middle Park; Northern Eagle / Southern Routt Counties

The primary assumption in our analysis is that the construction of new homes will reduce the amount of suitable sagebrush habitat available to sage-grouse. This can be modeled in *VORTEX* through a gradual reduction in habitat carrying capacity, K.

Human population projections through 2020, and associated estimates of average household size, were used to estimate the increase in new housing units across each affected region. Additional data on sagebrush habitat distribution were used to estimate the proportion of individual land parcels of different size classes that would occur within habitat considered optimal for greater sage-grouse. Using these estimates, two different levels of housing intensity were developed: Level 1, where only land parcels less than 40 acres in size were considered; and Level 2, where parcels up to 320 acres were considered to impact sagebrush habitat.

Region	% Reduction in K, 50 Years Level 1	Level 2
Meeker / White River	3.4%	23.5%
Middle Park	8.2	31.2
Northern Eagle / Southern Routt Counties		
Eagle	8.0	85.2
Routt	6.7	57.3

These reductions in carrying capacity are implemented in *VORTEX* as a linear decline in K over 50 years. For example, a Level 1 reduction in carrying capacity for Middle Park would result in a total reduction in K of 8.2%, from 1,784 to 1,638.

Surface Mining: Model Input
Regions considered: Middle Park, Northern Eagle / Southern Routt Counties, Northwestern Colorado, Piceance / Parachute / Roan

As with new housing development, the primary assumption in our analysis here is that surface mining for gravel, oil shale and similar resources will reduce the amount of suitable sagebrush habitat available to Sage-grouse. This can be modeled in *VORTEX* through a gradual reduction in habitat carrying capacity, K.

GIS analysis methods were used to identify sage-grouse habitat areas that could be targeted for surface mining activities, and linear rates of habitat carrying capacity loss were calculated over the 50-year period of the PVA model. Two levels of activity were considered, with increasing extent of disturbance to sage-grouse habitat (see table below). Low levels of activity in the Meeker / White River region were initially considered, then removed from the analysis due to their negligible impact. Detailed analysis of the Northwestern Colorado region indicates that mining activity is relevant only for zones 3C, 4B, 5, and 6.

Region	% Reduction in K, 50 Years Level 1	Level 2
Middle Park	15.0	26.0
Northern Eagle / Southern Routt Counties		
Eagle	17.0	35.0
Routt	17.0	35.0
Northwestern Colorado		
3C	6.0	10.0
4B	6.0	10.0
5	6.0	10.0
6	6.0	10.0
Piceance / Parachute / Roan	11.0	40.0

Results of Housing and Surface Mining Risk Analysis

Table 5 and Figure 4 show the combined results of the housing and surface activities analysis for the affected populations: Meeker / White River, Middle Park, Northern Eagle / Southern Routt Counties, and

Piceance / Parachute / Roan (the extent of sagebrush habitat loss was so small in the Northwestern Colorado region as to be essentially negligible). All four regions show some degree of greater sage-grouse population decline in the presence of the activities, with the lowest level seen in Meeker / White River and the greatest level of decline in Northern Eagle / Southern Routt Counties. In Middle Park, the relative contributions of housing and surface mining to population decline appear to be roughly equal as evidenced by the gradual increase in the magnitude of the decline from scenarios in which both housing and surface activities are at a low level (H1 – M1) to when both are at a high level (H2 – M2). On the other hand, in the Northern Eagle / Southern Routt Counties region the impacts of housing appear to be more severe since the high-level H2 housing scenarios show a more precipitous population decline. Interestingly, this appears to be at least partly linked to the more rapid decline seen in the much smaller Eagle subpopulation, which then contributes to the overall greater instability of the larger metapopulation. In addition, the high-level housing scenarios included a significant rate of habitat decline, with more than 85% of available greater sage-grouse habitat being lost over the time period of the simulation. This magnitude of decline, when combined with the small population sizes and their inherent demographic instability, works to put the larger metapopulation at a marked risk of extinction if conditions of habitat alteration reach predicted levels.

The extent of sagebrush habitat loss was so small in the Northwestern Colorado region as to be essentially negligible. As a result, this activity had no measurable impact on the predicted dynamics of a simulated Northwestern Colorado population. These results are not graphically depicted here.

Table 5. Greater sage-grouse PVA. Output from analysis of habitat – centric activities models. See text for additional information on model construction and parameterization.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Middle Park				
Baseline	0.022 (0.138)	0.000	1370 (400)	0.9531
Housing 1 – Mining 1	0.025 (0.139)	0.000	1122 (273)	0.9502
Housing 1 – Mining 2	0.025 (0.139)	0.000	979 (214)	0.9462
Housing 2 – Mining 1	0.023 (0.139)	0.000	802 (175)	0.9427
Housing 2 – Mining 2	0.023 (0.140)	0.000	667 (121)	0.9366
Meeker / White River				
Baseline	0.019 (0.160)	0.016	208 (83)	0.6619
Housing 2	0.021 (0.160)	0.022	198 (84)	0.6718
Northern Eagle / Southern Routt Counties				
Baseline	0.031 (0.167)	0.000	988 (471)	0.8980
Housing 1 – Mining 1	0.030 (0.168)	0.000	276 (55)	0.8156
Housing 1 – Mining 2	0.031 (0.168)	0.000	646 (261)	0.8921
Housing 2 – Mining 1	0.030 (0.172)	0.000	255 (82)	0.8217
Housing 2 – Mining 2	0.024 (0.177)	0.014	87 (19)	0.7854
Piceance / Parachute / Roan				
Baseline	0.025 (0.139)	0.000	1202 (342)	0.9422
Mining 1	0.025 (0.139)	0.000	1084 (296)	0.9404
Mining 2	0.023 (0.141)	0.000	778 (176)	0.9329

It may be important to note that the overall risks of population extinction under these habitat modification scenarios are perhaps an underestimate of the true risks. All of our modeling scenarios do not include significant levels of density dependence in either reproduction or mortality, other than the rather harsh "truncation" form of density dependence imposed when a simulated population exceeds the stated carrying capacity. The decision to exclude it from the modeling effort was based on the fact that specific data on the mode of action of density dependence is not available for greater sage-grouse. In these models, population growth continues at a relative constant average rate until K is exceeded, at which time individuals from the population are randomly removed across all age-sex classes until the population returns to a value at or slightly below K. In other words, the growth rate can remain high, even when the population is at K and the population has been reduced to relatively small numbers through the activity of something like housing development or surface mining activities. Some biologists may argue a contrary view – where the underlying intrinsic population growth declines to near 0.0 when the population reaches carrying capacity. This reduction in growth can lead to accompanying increases in demographic instability over time, especially when the population has been reduced to a small remnant as we are seeing in the Northern Eagle / Southern Routt Counties complex. Reduced average growth rates and instability in these rates can conspire to increase risk of further population decline and perhaps even extinction.

Therefore, the absence of density dependence in this system may result in an artificially high level of apparent stability and, consequently, population security. This characteristic of our simulations may perhaps be investigated in more detail and evaluated for its robustness at a later date. In the meantime, we can conclude that the reduction of available sagebrush habitat through housing development and surface mining activities can greatly reduce the size of associated greater sage-grouse populations.

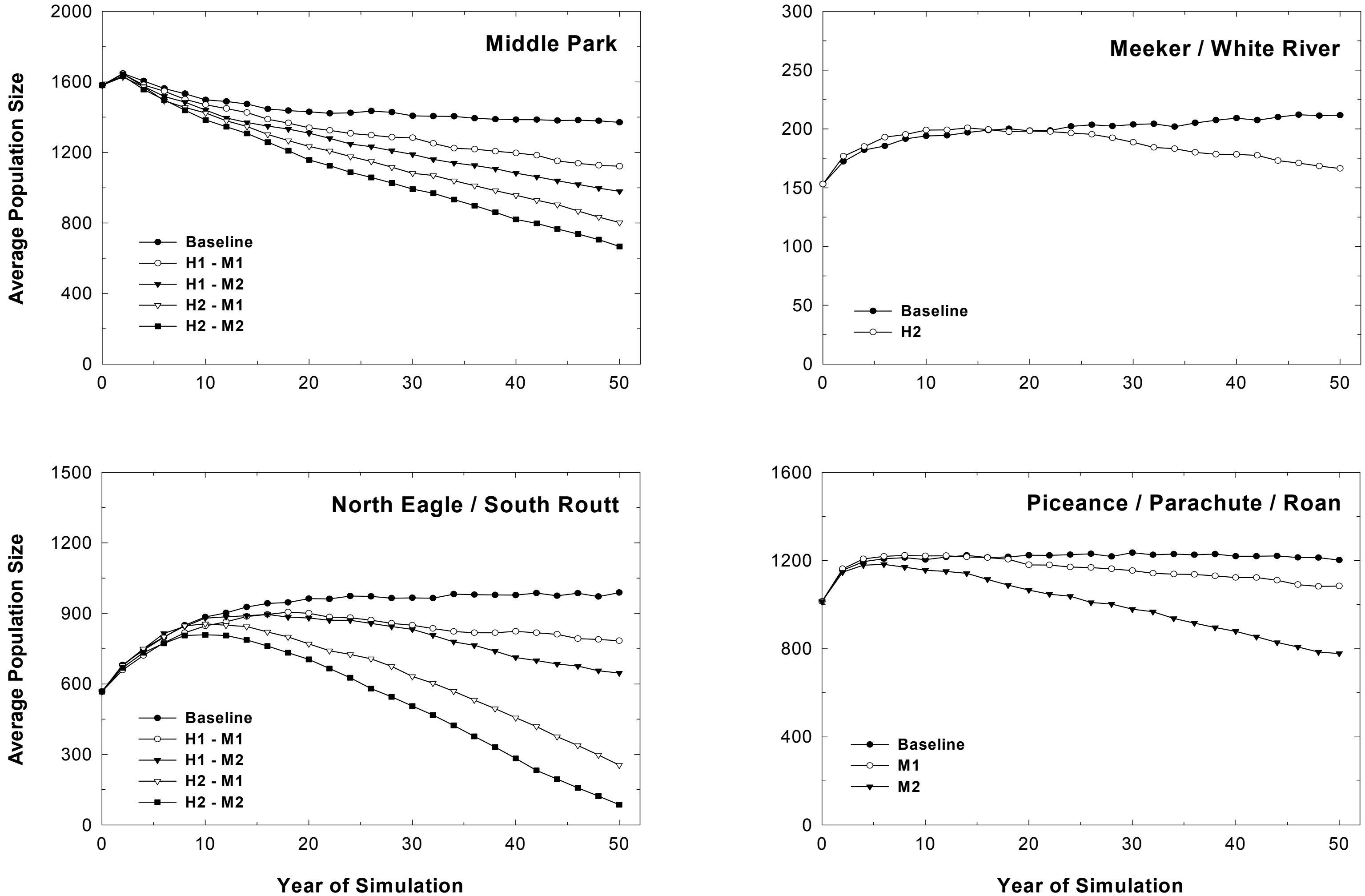


Figure 4. Average projected size of simulated greater sage-grouse populations in the presence of habitat – centric human activities (housing development = H, surface mining = M). Numerical designations "1" and "2" refer to low or high levels of development ntensity, respectively, as described in the section on model inputs. See accompanying text for additional information on model construction and results

Risk Analysis II: Impacts of Local Harvest/ Hunting on Greater Sage-grouse Population Dynamics

Harvest: Model Input

Region considered: North Park

The primary assumption in an analysis of harvest is that such a process will directly impact the mortality rates of affected age-sex classes. Detailed data on harvest composition (based on wing receipts) are available from Jackson County (North Park) dating back to 1970. These data were used in conjunction with high male lek count data in the same area to derive an estimate of the percentage of the total sage-grouse population that was harvested by hunters during the time period 2000 – 2004. From 2000 to 2003, the average harvest was approximately 3.3% of the estimated total population, while in 2004 the harvest increased dramatically to nearly 15% of the population. Moreover, additional analysis indicates that the average composition of the harvest from 1974 to 1998 does not appear to deviate significantly from the age-sex structure of the wild population. In other words, there appears to be little evidence to suggest a noticeable bias in the age or sex of the birds that are harvested.

Based on these historic data, the potential impacts of long-term additional hunting-based mortality was investigated by adding 1%, 2%, 4%, or 8% mortality to all age-sex classes of greater sage-grouse during each year of the simulation. Note that an often vigorous debate exists on the mechanism of hunting mortality in game species such as greater sage-grouse. For many species, hunting mortality is typically thought to be *compensatory*; in other words, hunting is a method for removing individuals from a population that would otherwise die from other natural causes, so that the actual hunting mortality does not impose an additional burden on the population. For other species, hunting may largely act in an *additive* fashion, thereby increasing the overall mortality rate of affected cohorts above that observed in an unaffected population. As is the case with most natural phenomenon, the “truth” for greater sage-grouse likely falls between these two extremes. The hunting models described here do not by definition ascribe to a specific level of compensation and/or additivity, but instead merely serve as a tool to stimulate discussion of hypotheses and associated assumptions.

Results of Harvest Risk Analysis

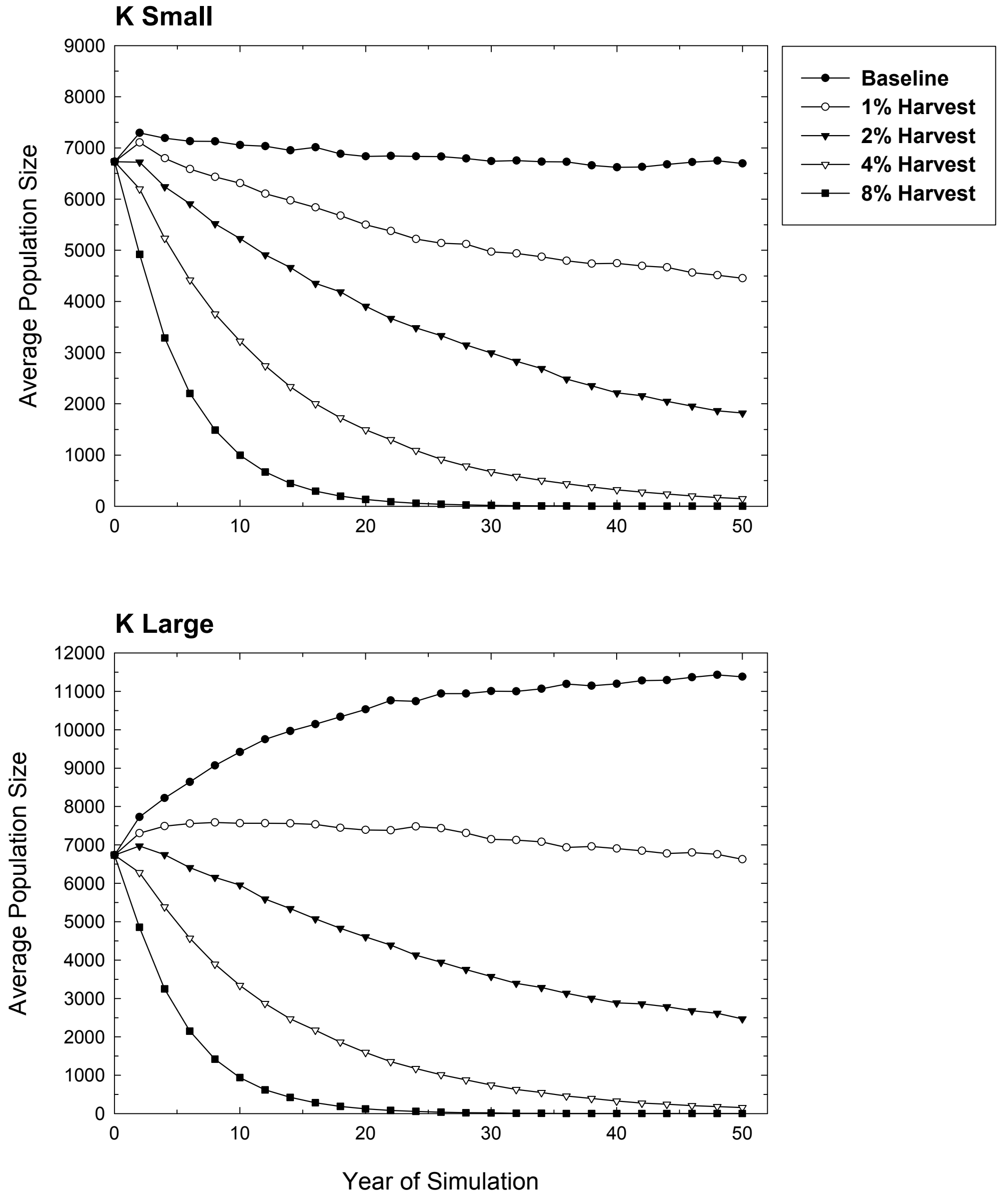
Table 6 and Figure 5 present the results of our harvest analysis on a simulated North Park population of greater sage-grouse. Note that even the imposition of an additional 1% increase in mortality across all age-sex classes can lead to a qualitative change in the growth character of our simulated population – from one that increases at approximately 2.5% per year to one that declines at 0.1 to 0.2% per year.

Table 6. Greater sage-grouse PVA. Output from North Park harvest models. See text for additional information on model construction and parameterization.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
K Small				
Baseline	0.026 (0.136)	0.000	6697 (1634)	0.9903
1% Harvest	-0.001 (0.139)	0.000	4454 (2253)	0.9855
2% Harvest	-0.030 (0.143)	0.000	1820 (1482)	0.9700
4% Harvest	-0.089 (0.163)	0.030	147 (242)	00.8253
8% Harvest	-0.225 (0.233)	0.996	1 (1)	0.1814
K Large				
Baseline	0.024 (0.135)	0.000	11379 (3272)	0.9929
1% Harvest	-0.002 (0.139)	0.000	6624 (4140)	0.9876
2% Harvest	-0.029 (0.144)	0.000	2467 (2649)	0.9718
4% Harvest	-0.089 (0.164)	0.032	156 (208	0.8286
8% Harvest	-0.224 (0.236)	0.994	1 (1)	0.5887

It is clear from these analyses that even a seemingly small increase in mortality – if applied equally to all age-sex classes at the same time – can have dramatic effects on the growth potential and long-term viability of affected populations.

Figure 5. Average projected size of simulated North Park greater sage-grouse populations under different levels of harvest. Harvest is defined here as the identified percentage increase in annual mortality rates across all age classes of both sexes. The top panel shows population projections in the presence of a restrictive carrying capacity, set as 8300 individuals, while the bottom panel shows the same projections when that restrictive carrying capacity is lifted, thereby allowing essentially unrestricted population growth throughout the duration of the simulation. See accompanying text for more information on model construction and results.



It may be argued that the marked declines in population size seen in all harvest scenarios is at least partially caused by the restrictions imposed by the addition of a carrying capacity in our North Park population models. This carrying capacity, estimated to be about 8300 individuals, might be low enough to drive populations to decline as they encounter the restriction to grow beyond the ceiling. To further investigate this hypothesis, a second set of models was developed that effectively removed this restrictive ceiling by increasing carrying capacity K from 8300 to 15,000 individuals. As seen in the bottom panel of

Figure 4, the removal of this restriction allowed the baseline (unharvested) population to nearly double in size over the 50 years of the simulation. However, the harvested populations showed a nearly identical trajectory in the presence of added mortality: significant decrease in growth potential and, in the most extreme cases, rapid population decline to extinction. Therefore, the imposition of a carrying capacity does not seem to be a major factor in predicting how a simulated greater sage-grouse population will respond to additional hunting-based mortality.

A very important assumption in these analyses is that our simulated harvest represents, effectively, 100% additive mortality on top on natural mortality acting on the population. In other words, we are assuming that all those birds that are removed from the population through harvest would have otherwise survived during the year, and many of them would have reproduced. We are therefore simulating the most extreme harvest scenario, in contrast to one where there is some level of compensatory mortality that would serve to reduce the overall magnitude of added mortality on the population. There is considerable controversy on the degree of compensatory v. additive mortality in game species such as greater sage-grouse (see Johnson and Braun 1999 for a review of this topic); while the controversy rages, the analyses presented here provide more general cautionary insights into the sensitivity of sage-grouse populations to slight increases in mortality rates – particular of juvenile and adult females.

Risk Analysis III: Impacts of Oil and Natural Gas Development on Greater Sage-grouse Population Dynamics

Oil and Natural Gas: Initial Model Input

Regions considered: North Park, Northwestern Colorado, Piceance / Parachute / Roan

Scientific evaluation of the effects of oil and gas development on greater sage-grouse in Colorado does not currently exist. Until such research can be completed, we must rely on recent studies from Holloran (2005) and Lyon and Anderson (2003) conducted in Wyoming.

Essentially, Holloran identified two levels of demographic impact on sage-grouse populations in Wyoming, as a function of the density of wells within a 3-km (2-mile) distance from a lek. Holloran (2005) found that male lek attendance was affected by increasing oil and gas development: leks with 5-15 wells within 3km (2 miles) were lightly impacted, while those with >15 wells within 3km were heavily impacted. Since the PVA model assumes that only 10% of males breed, male activity reduction is not likely to strongly influence model performance. However, Holloran also found that annual survival of adult nesting females declined 20.4% (73.4% pretreatment to 53.0% post treatment) in development areas. He also found a 6.4% decline in annual survival (91.8% pretreatment to 85.4% post-treatment) for nesting yearling females. In addition, Lyon and Anderson (2003) found that female nest initiation rates declined in disturbed areas from 89% to 65%, a 24% decline.

In an attempt to estimate oil and gas impacts on greater sage-grouse, we increased adult female mortality by 20%, increased yearling female mortality by 6.4%, and decreased nest initiation by 24% where oil and gas development reaches Holloran's heavy impact criteria (>15 wells within 3km). Holloran used leks where well density was >5 as treatment leks. Leks with less than that level of development were used as controls, where impacts were assumed to be minimal. For our analysis, we raised this control level from 5 to 8 wells/lek. Considering only current infrastructure, North Park is already at 8 wells/lek. As North Park populations remain stable, we believe this upward adjustment in the bottom impact threshold is warranted and supported by current trend data in North Park. Impacts at levels of development between the control and 15 wells/lek were considered to be less than those above 15 wells/lek, though intermediate levels of demographic impacts to female sage-grouse were not reported by Holloran (2005) or Lyon and Anderson (2003). For development densities between our control level of 8 wells/lek and the high impact threshold of 15 wells/lek, we imposed a gradual increase in demographic impact, applying an annual increment of additional mortality and decreased nest initiation each year until the high threshold was reached. The heavy impact parameters were applied each year once the heavy impact threshold was crossed.

To cover a range of possible scenarios, we evaluated three levels of future development (1000, 5000, 20,000 additional wells) in addition to currently active wells. The first two scenarios (1000, 5000) were used for the North Park population (we eliminated 20,000 because forecasts indicate that even 5,000 was a very high estimate for this area), while all three were used for Northwestern Colorado and Piceance / Parachute / Roan. The future development scenarios for each population are intended to represent reasonable low, medium and high levels of potential development over the 50-year life of the PVA model. They do not represent published estimates of development but are selected only to provide a picture of what impacts might be at each level of development. We attempt to keep the scenarios plausible however, by comparing with estimates of foreseeable development for the three areas developed by BLM and others, especially in Northwestern Colorado and Piceance / Parachute / Roan. The medium and high levels in North Park substantially exceed current estimates (~100 wells in the next 20 years). We assumed that existing and new wells would operate through the full life of the model. Holloran (2005) found that existing facilities continued to impact populations after construction, so both existing and potential new wells were combined in each portion of this analysis.

To evaluate development intensity, we randomly plotted wells for each development scenario and then counted the number of wells (current and future) within each 3-km (2-mi) lek buffer. These counts were then averaged across each population or zone. Current active wells were plotted in a GIS within each of the three target populations. Well placement for the various scenarios was then added to the existing well layer. New wells were randomly placed within greater sage-grouse overall range in each population area in the North Park and Piceance / Parachute / Roan populations. In the Northwestern Colorado population, half of the wells were randomly placed in Zones 2 and 3b, both areas with substantial current oil and gas activity. The remaining wells were randomly placed in the remaining Zones, except Zone 7.

For the purposes of this PVA, we assumed that the density of new wells will increase linearly over time. We also assumed that sage-grouse demographic responses will also react linearly over time between the thresholds > 8 wells per lek and >15 wells/lek as described in the table above. The model assumes that impacts of development increase linearly from no impact below the control threshold (8 wells/lek) to the high impact measures once the high threshold is reached (15 wells/lek). That is, no impact is assessed from 0 to 8 wells, annually increasing impacts (heavy impact rates/number of years between control and high threshold) from 9 to 15 wells, and heavy impacts above 15 wells. Therefore, sage-grouse demographic rates will change linearly over time as well until the critical well density threshold is reached (15 wells/lek). Once the heavy impact development level is reached, heavy impact demographic parameters will continue to be applied throughout the remaining course of the 50-year simulation.

A representative set of "trajectories" for the three demographic rates affected is shown in Figure 5 below, considering only adult female mortality in the Piceance / Parachute / Roan region.

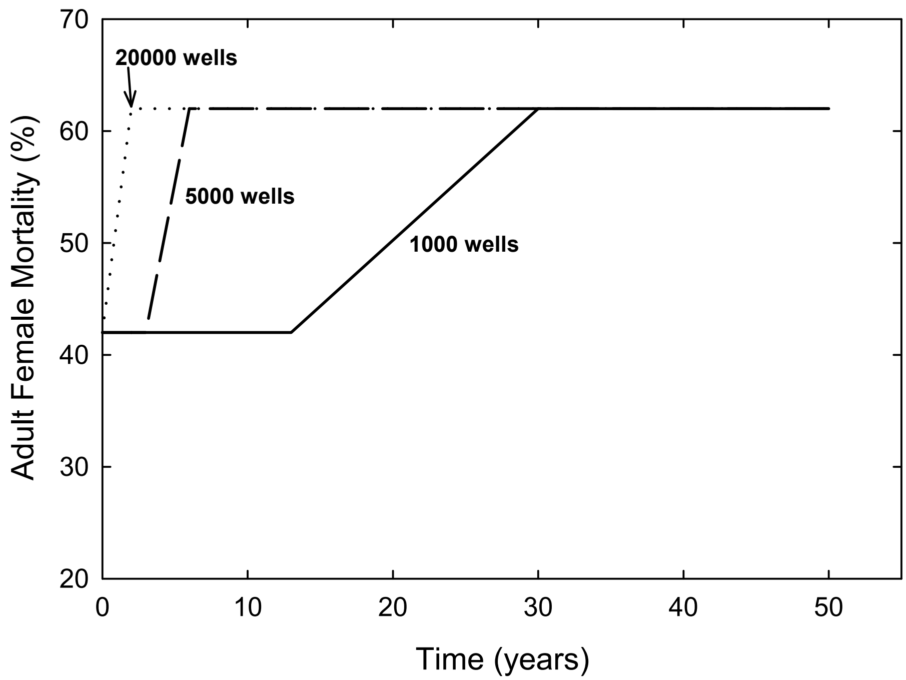


Figure 6. Simulated increase in adult female mortality of Greater sage-grouse in the Piceance / Parachute / Roan region under alternative scenarios of oil and natural gas well development in the region. As the total number of proposed wells increases, the time required to reach the "critical" threshold density of 15 wells / lek decreases, leading to a more rapid rise in mortality as wells are constructed. See text for additional information.

The year at which each threshold is reached under each development scenario was derived from the GIS well plots for each population and Northwestern Colorado zone. These threshold points are presented in Table 7. The body of the table indicates the number of years required to reach the appropriate threshold for each population and development scenario.

Table 7. Time thresholds for impacts from oil and natural gas well development on greater sage-grouse population demographics. The first value gives the number of years before an impact begins, while the second value indicates the number of years before maximum impact is reached. "—" indicates that the appropriate impact threshold is not reached within the 50-year span of the PVA model. See text for additional information on model parameterization.

	Proposed Well Density		
Region	1000	5000	20,000
North Park	1 / 20	1 / 4	
Piceance / Parachute / Roan	13 / 30	3 / 6	1 / 2
Northwestern		25 / 50	6 / 13
1	— / —	30 / —	8 / 20
2	— / —	15 / 30	4 / 8
3A	— / —	40 / —	10 / 20
3B	5 / 30	10 / 30	3 / 8
3C	— / —	20 / 50	5 / 13
4A	— / —	40 / —	10 / 20
4B	— / —	45 / —	11 / 20
5	— / —	40 / —	10 / 20
6	— / —	40 / —	10 / 20
7			

Oil and Natural Gas: Initial Risk Analysis Results

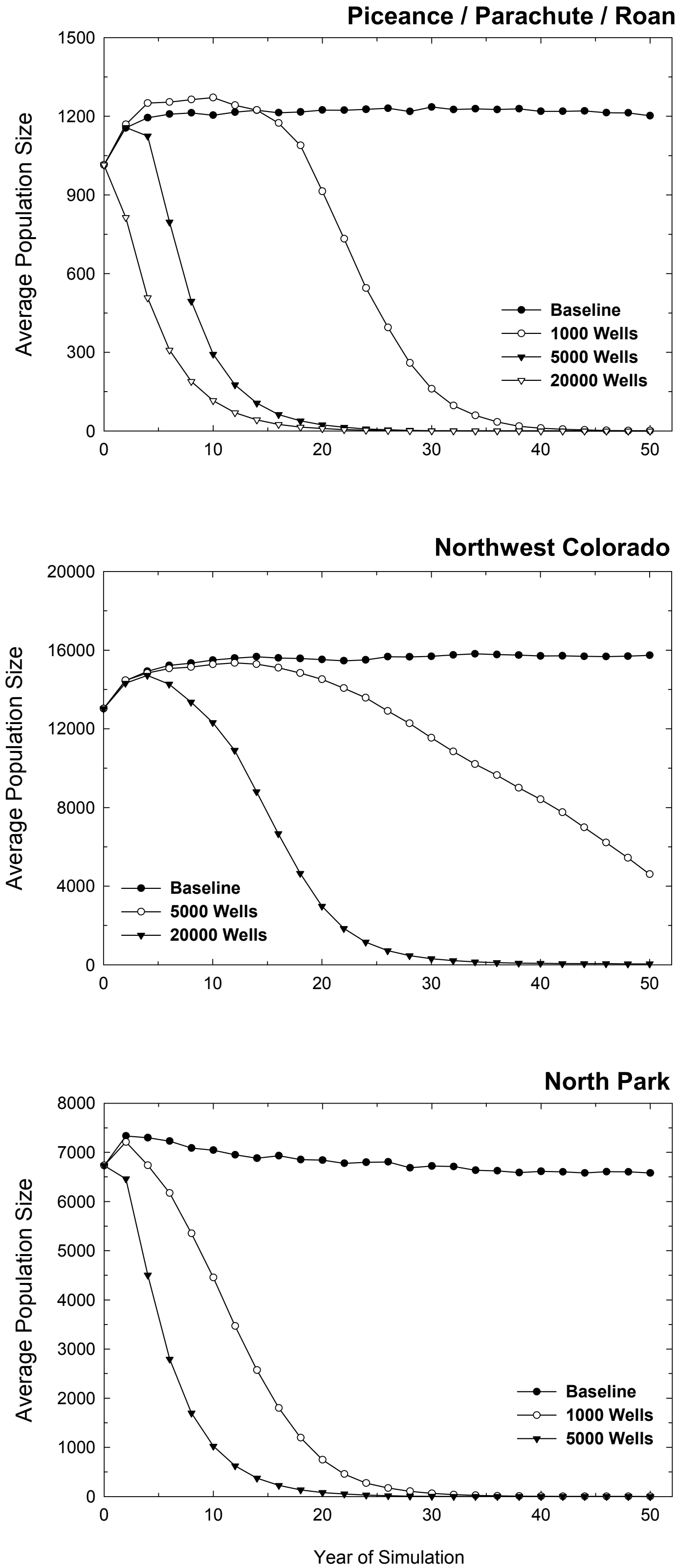
The results of our analysis of oil and natural gas development, and its impact on local populations of greater sage-grouse, are depicted in Table 8 and Figure 7. In all three regions where such development is either currently underway or to begin soon, our simulations suggest that the impact may be severe on the future viability of nearby greater sage-grouse populations. The onset of development leads to strongly negative population growth, rapid population decline and, in all cases but one (lower levels of development in Northwestern Colorado), nearly certain extinction of local grouse populations within 50 years.

This rather dramatic result is clearly the result of imposing strong demographic consequences on greater sage-grouse populations that live and breed near current or proposed oil and natural gas development areas. The data of Holloran (2005) indicate a marked reduction in survival and breeding success of greater sage-grouse in close proximity to oil and natural gas development areas; these data have been used essentially unmodified in this analysis, and clearly represent an unsustainable situation.

Table 8. Greater sage-grouse PVA. Output from initial oil and natural gas analysis models. See text for additional information on model construction and parameterization.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Piceance / Parachute / Roan				
Baseline	0.025 (0.139)	0.000	1202 (342)	0.9422
1000 Wells	-0.120 (0.245)	0.907	1 (2)	0.4616
5000 Wells	-0.220 (0.260)	1.000	—	—
20,000 Wells	-0.260 (0.257)	1.000	—	—
Northwestern Colorado				
Baseline	0.030 (0.081)	0.000	15739 (1872)	0.9956
5000 Wells	-0.011 (0.089)	0.000	4604 (1798)	0.9925
20,000 Wells	-0.011 (0.163)	0.072	48 (29)	0.5142
North Park				
Baseline	0.025 (0.135)	0.000	6582 (1794)	0.9903
1000 Wells	-0.191 (0.230)	0.988	1 (1)	0.4636
5000 Wells	-0.252 (0.238)	1.000	—	—

Figure 7. Average projected size of simulated greater sage-grouse populations in the presence of oil and natural gas development in selected regions of Colorado. See accompanying text for more information on model construction and results.



It is possible that the "raw" data presented in Holloran (2005) represent a worst-case scenario with respect to local greater sage-grouse population viability, for two primary reasons:

1. The natural gas fields Holloran studied were in the most intense development phase, where activity is at its highest and, consequently, impacts on local grouse populations may be most severe. Such development lasts a finite period of time – perhaps only 5 to 10 years – before the field transitions into a production phase where activity is reduced and subsequent impacts on local grouse populations may actually decline. The simulations presented here effectively assume that this development phase remains in effect throughout the 50-year duration of the simulation – thereby possibly over-estimating the long-term impact of the well field on sage-grouse dynamics.
2. Through environmental conditions beyond his control, Holloran actually collected data on the impacts of oil and natural gas field development on greater sage-grouse during a period of marked drought. While the detailed mechanisms of drought's impact on local grouse populations is not fully understood, it is possible that the measured effects in the presence of oil and natural gas development were compounded by the coincident drought – thereby leading to an overestimate of the true impacts of well-field development on local grouse populations.

Oil and Natural Gas: Revised Model Input

Regions considered: Northwestern, Piceance / Parachute / Roan

For several reasons we conducted a second, revised oil and natural gas development modeling exercise. First, the scenario we used in our initial analysis was oversimplified in comparison to actual well field development. That is, the amount of disturbance to sage-grouse can be expected to vary greatly over the process of oil or natural gas exploration, drilling, and production. The initial model data input were derived from the development phase, which creates the most disturbance for sage-grouse.

Second, even though the data on which we based the model input (Holloran 2005) are from the phase of development when the most disturbance to sage-grouse can be expected to occur, sage-grouse populations in the area continue to exist and are not currently demonstrating a population "crash" as depicted in our model results (Figure 7). This suggests our model oversimplifies the relationship between GrSG populations and oil and gas development.

Third, oil and gas development and greater sage-grouse co-exist in several landscapes (including North Park), so we know that not all situations are as extreme as we initially modeled.

Fourth, the initial oil and natural gas modeling exercise showed dramatic impacts from oil and natural gas development (Figure 7). The results from this modeling exercise are not very instructive regarding the relative potential impacts of oil and gas development, because all model versions showed such extreme effects. Even if the extreme impacts are to be expected at one end of the impact "continuum", valuable information regarding management of greater sage-grouse and oil and gas development may be derived from exploring other areas of the impact continuum, before the impacts are so severe.

Therefore, it was decided to revise certain elements of the risk analysis pertaining to the impacts of oil and natural gas development. We constructed a more complicated, but hopefully more realistic model that accounts for changes in the level of disturbance to sage-grouse over the process of oil and gas well field development (termed "*Progressive Well Field Development and Mitigation*" analyses). Our revised models also allow us to explore how sage-grouse might respond to differing levels of disturbance (termed

"*Alternate Disturbance Levels*" analyses), and how best to manage for sage-grouse population viability in areas where oil and/or natural gas development is likely.

These additional analyses were specifically designed to help us address the following questions:

- How would the demographic behavior of our simulated populations of GrSG respond if we modify the oil and gas development model to more accurately reflect the progression of impacts, reclamation, and mitigation at and/or near individual well pad sites, throughout the oil and natural gas development process? We assume that reclamation and mitigation provide effective demographic responses in the population.
- To what extent will the demographic behavior of our simulated populations of greater sage-grouse change if we assume a less severe direct impact to GrSG demographics through oil and gas development, even in the absence of mitigation?

We focused on the Piceance / Parachute / Roan and Northwestern Colorado regions as they effectively represented what we believe to be, on a comparative scale, high-intensity and low-intensity development scenarios, respectively.

Description of Modified Input Parameters

Progressive Well Field Development and Mitigation (Region considered: Piceance / Parachute / Roan)- As displayed graphically in Figure 6, we originally assumed that once the maximum level of demographic disturbance due to well-field development was reached, this high level of disturbance would persist throughout the duration of the simulation. This demographic profile is repeated specifically for adult female mortality in (A) of Figure 8. However, it was recognized that a shift in activity from well-field development to production, in conjunction with a concerted effort in well-field reclamation by responsible authorities, could lead to a reduction in demographic disturbance in nearby greater sage-grouse populations. This recognition was then simulated through a more complex description of those demographic variables thought to be most acutely impacted by this activity, namely, yearling and adult female breeding success (% birds successfully breeding in a given year), and yearling and adult female mortality rates.

In order to describe these more complex demographic profiles, we have derived the following parameters that describe the general trajectories of breeding success and mortality over the duration of the simulations:

- R_0 The magnitude of change in the specified demographic variable following the onset of well-field development;
- T_1 The time period over which the specified demographic variable changes following the onset of well-field development;
- D The duration of time that the demographic disturbance is at a maximum, i.e., when well-field development is most intense;
- T_2 The time period over which the specified demographic variable changes (rebounds) following the shift in activity from well-field development to well-field production;
- R_1 The magnitude of change (rebound) in the specified demographic variable following the shift in activity from well-field development to well-field production.

In all initial simulations, we assume that well-field development results in an increase in demographic disturbance directly in accordance with the data from Holloran (2005). This is portrayed in Figure 8 by an increase in adult female mortality from the pre-development rate of 42% to the maximum rate of 62% – just as we assumed in our initial analyses. Therefore, R_0 = 20%. In all Piceance / Parachute / Roan simulations, we have estimated that a total of 16,000 wells (2,000 pads, 8 wells/pad) will be developed over the next decade. Moreover, we now assume that the beginning of demographic disturbance occurs when the well-pad density reaches 1 pad/km^2 within a 2-mile radius of an active lek, and reaches its maximum when the density reaches 2 pads/km^2 within the same radius. This translates into upper and lower disturbance triggers of 24 and 50 wells/lek, respectively. These new triggers are rather different from the thresholds identified in earlier PVA work (8 and 15 wells/lek), but are considered to be considerably more realistic and defensible.

Based on this assessment, we assume that the onset of demographic disturbance from this development begins at year 4 and reaches its maximum level at year 8; therefore, T_1 is set at 4 years. Duration D is plausibly set at either 5 or 10 years in order to explore the sensitivity of our models to variation in this variable. Return time T_2 is either set to the initial period T_1 or, more pessimistically, set to $2T_1$ to simulate a more difficult and longer effort required to mitigate well-field development in the shift to production. The demographic recovery/rebound (R_1) was set equal to R_0, or was considered incomplete (due, for example, to difficulties in returning the well-field landscape to a more undisturbed setting), in which case we set $R_1 = 0.5R_0$.

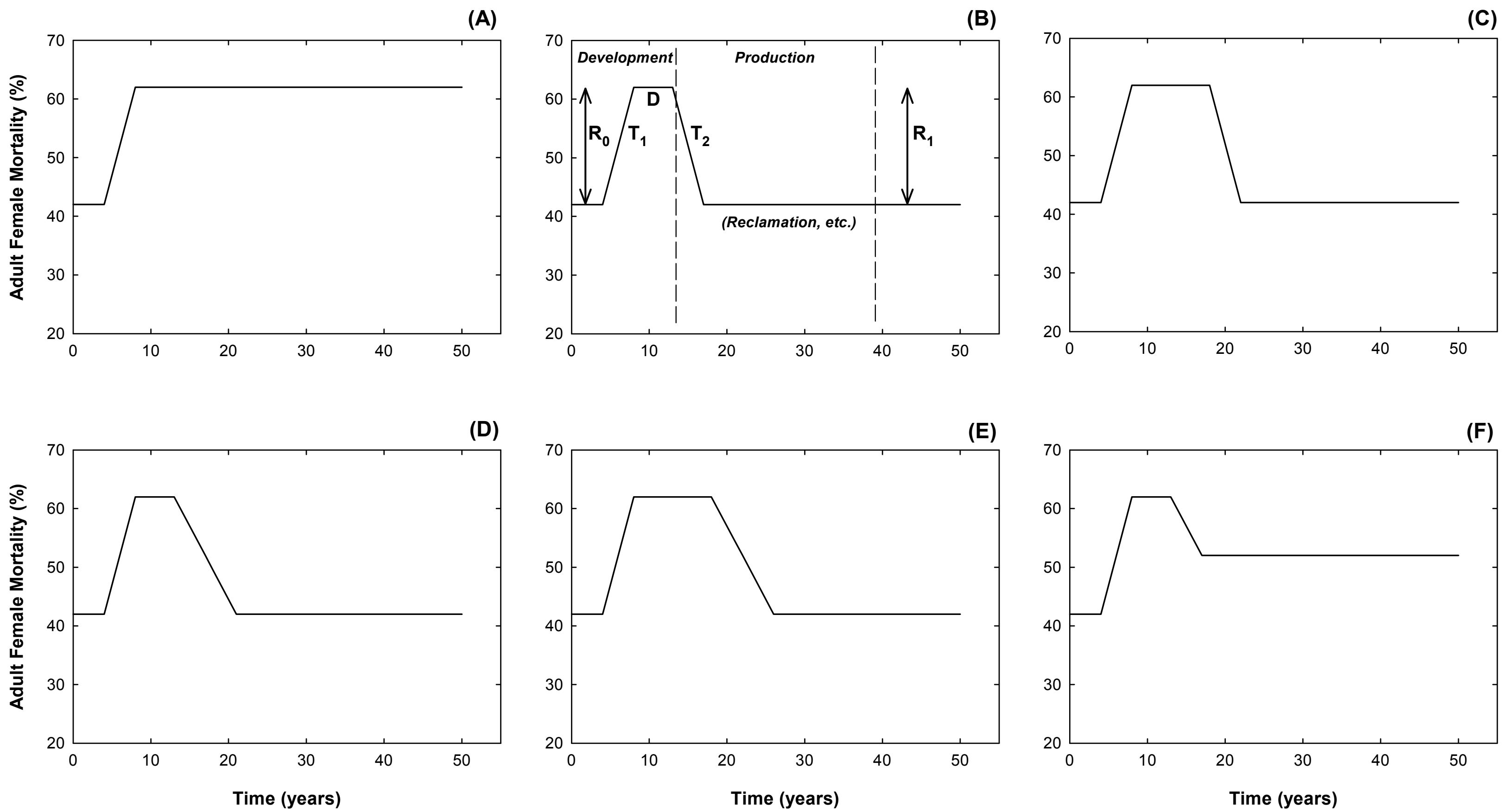


Figure 8. Revised oil and natural gas development risk analysis: generalized adult female greater sage-grouse mortality profiles associated with different timing and mitigation scenarios in *Progressive Well Field Development and Mitigation* analyses in the Piceance / Parachute / Roan region of Colorado. In (A), mitigation is absent and the maximum impacts of well development persist through the duration of the simulation. In (B), well development leads to a mortality increase to the maximum impact over time period T_1 (4 years), over which time the well density increases from 24 to 50 wells/2-mile radius of an active lek. The maximum impact persists for duration D (5 years), after which time the shift to well production and associated landscape reclamation lead to a reduction in impact over time period T_2 (4 years). Finally, the mortality rate declines by magnitude R_1, in this case equivalent to the original magnitude R_0, representing the onset of well development. (C) $T_1 = T_2 = 4$ years; $D = 10$ years. (D) $T_1 = 4$ years, $D = 5$ years, $T_2 = 8$ yeas. (E) $T_1 = 4$ years, $D = 10$ years, $T_2 = 8$ years. (B) through (E) are repeated as in (F), with only partial demographic recovery following reclamation as $R_1 = 0.5R_0$. See accompanying text for more details.

Upon inspection of Figure 8, we can see that (B) represents a "best-case" scenario – where duration *D* is short, return time T_2 is also short, and demographic recovery is full ($R_1 = R_0$). On the other end of the spectrum, (E) represents a "worst-case" scenario where duration and return times are long. Even more pessimistic is the corresponding scenario combining (E) and (F) – where duration and return times are long and recovery is only partial ($R_1 = 0.5R_0$). It is particularly interesting in this analysis to try to tease apart the relative contributions of these individual parameters to the demographic performance of an impacted greater sage-grouse population. In other words, if well-field mitigation and reclamation is to occur, what would be most beneficial to the long-term viability of associated sage-grouse populations – minimizing duration *D*, minimizing return time T_2, or maximizing the extent of demographic recovery R_1? Through a process akin to demographic sensitivity analysis, we can begin to shed some light on these questions in the context of designing optimal management strategies that strive for environmental responsibility and economic necessity.

Alternate Disturbance Levels (Regions considered: Northwestern Colorado and Piceance / Parachute / Roan) - To explore how sage-grouse might respond to varying levels of disturbance during development (and recognizing that the initial analysis was based on data from the most intensive disturbance period of well field development), a replicate set of models was constructed for Piceance / Parachute / Roan in which the impacts of oil and natural gas development were reduced by 50% relative to the original models constructed directly from Holloran's observations (Figure 9). Specifically, we increased adult female mortality by 10%, increased yearling female mortality by 3.2%, and decreased nest initiation by 12% when oil and gas development reaches the critical threshold of 50 wells/lek.

Oil and natural gas development in the Northwestern Colorado metapopulation is expected to be less intense than that currently expected in the Piceance / Parachute / Roan region. Specifically, we assume that 50% of the total level of development will occur in Zones 2 and 3B, lower levels occurring in Zones 3A and 3C, and the remainder taking place in the remaining Zones with the exception of Zone 7 where no activity is assumed to take place. Therefore, we included energy development only in Zones 2, 3A, 3B and 3C. Using the same quantitative triggers as used in PPR, we estimate that the lower well-density threshold will be reached in 26 years for Zones 2 and 3B, and in 44 years for Zones 3A and 3C (Figure 10). Maximum thresholds are reached at 50 years (end of the simulation) for Zones 2 and 3B, while the maximum is not reached within this time period for Zones 3A and 3C. Under this assumption, and given the 50-year time period for simulation in this analysis, we do not have the opportunity to investigate well-field mitigation as we did in the Piceance / Parachute / Roan analysis. Nevertheless, the Northwestern Colorado scenarios will provide a valuable contrast to the PPR analyses with respect to the impacts of differing levels of development on populations of considerably different sizes.

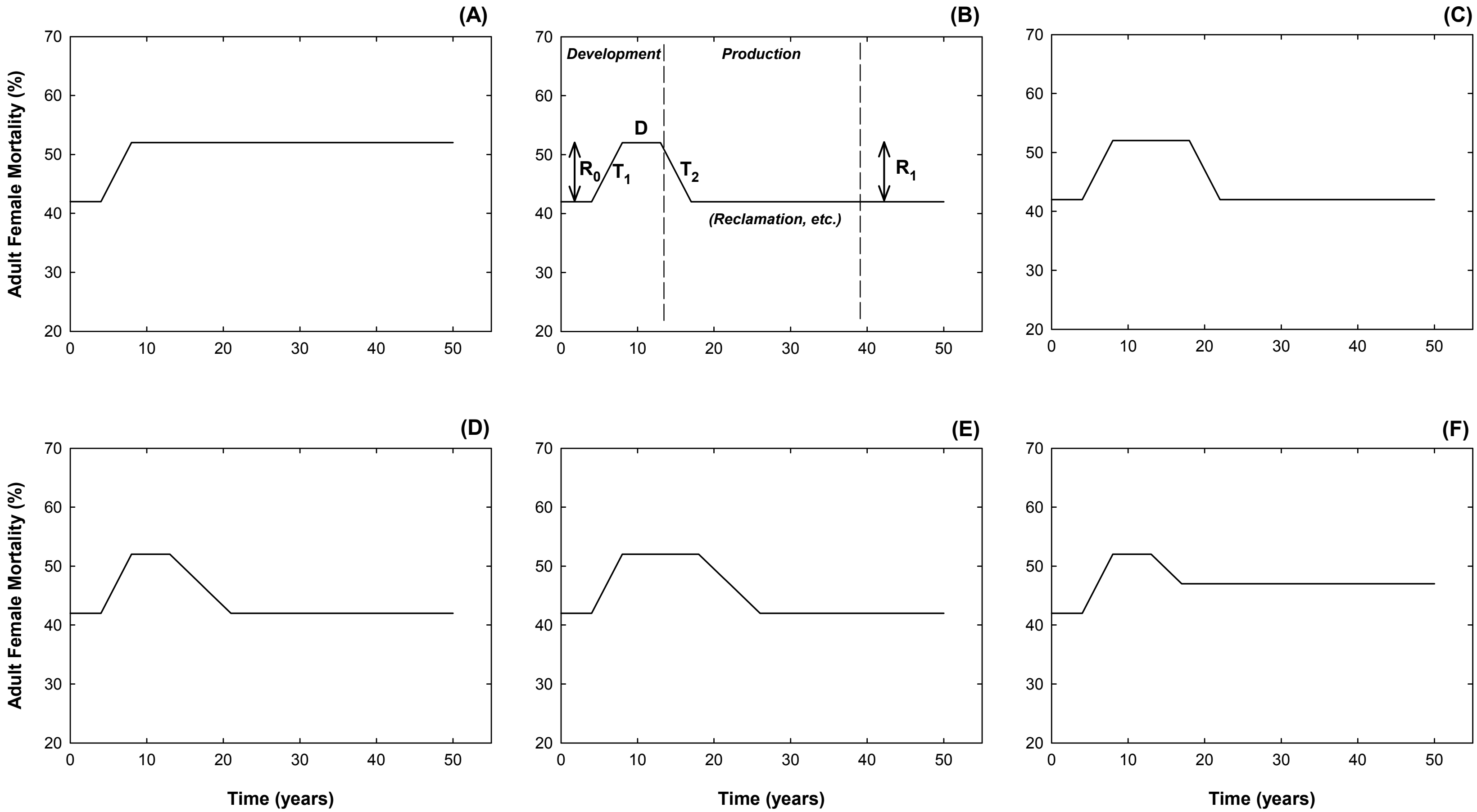


Figure 9. Revised oil and natural gas development risk analysis: *Alternate Disturbance Levels* applied to generalized adult greater sage-grouse female mortality profiles from *Progressive Well Field Development and Mitigation* analyses in the Piceance / Parachute / Roan region of Colorado. In contrast to the graphs given in Figure 8, base demographic impacts in the *Alternate Disturbance Levels* analysis are assumed to be 50% lower than those directly observed by Holloran (2005). In (A), mitigation is absent so the maximum impacts of well development persist through the duration of the simulation. In (B), well development leads to a mortality increase to the maximum impact over time period T_1 (4 years), over which time the well density increases from 24 to 50 wells/2-mile radius of an active lek. The maximum impact persists for duration D (5 years), after which time the shift to well production and associated landscape reclamation lead to a reduction in impact over time period T_2 (4 years). Finally, the mortality rate declines by magnitude R_1, in this case equivalent to the original magnitude R_0, representing the onset of well development. (C) $T_1 = T_2 = 4$ years; $D = 10$ years. (D) $T_1 = 4$ years, $D = 5$ years, $T_2 = 8$ yeas. (E) $T_1 = 4$ years, $D = 10$ years, $T_2 = 8$ years. (B) through (E) are repeated as in (F), with only partial demographic recovery following reclamation as $R_1 = 0.5R_0$. See accompanying text for more details.

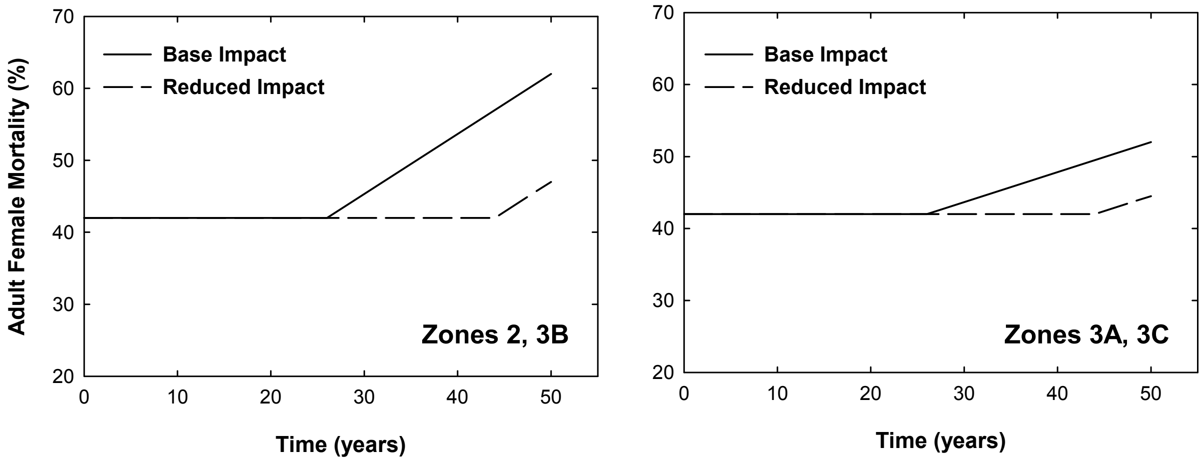


Figure 10. Revised oil and natural gas development risk analysis: *Alternate Disturbance Levels* applied to generalized adult greater sage-grouse female mortality profiles in selected subpopulations of the Northwestern Colorado region. Base demographic impacts are assumed to be directly taken from those observed by Holloran (2005), while in the *Alternate Disturbance Levels*, impacts are 50% less ("reduced impact") than those reported in Holloran (2005). Note that the maximum demographic disturbance levels seen in the Piceance / Parachute / Roan region are not reached before the end of the 50-year simulation for any Northwestern Colorado area, thereby making a detailed analysis of well-field mitigation impractical. See accompanying text for more details.

Oil and Natural Gas: Revised Risk Analysis Results

Progressive Well Field Development and Mitigation (Region considered: Piceance / Parachute / Roan)- The results of our basic well-field development and mitigation analysis are presented in Table 9 and Figures 11 and 12. As was seen in the initial analyses for this region, the simplified treatment of well-field development and production leads to an extremely rapid rate of population decline and extinction within 30 years of the onset of well-field construction (Figure 11, (A) line). When mitigation and reclamation are included in the simulations, and in particular under the assumption of full demographic recovery through this activity, extinction risks can decline significantly and growth rates (particularly in the time period following the onset of mitigation and reclamation) can become much more robust. For example, under the most optimistic conditions of well-field mitigation and reclamation (D and T_2 low, with full demographic recovery) population growth rates may remain highly negative for the first 15 to 20 years but can rebound to average more than 2.5% for the remaining 30 to 35 years of the simulation (Figure 11, (B) line).

Figures 11 and 12 can help us separate the relative contributions of each phase of well-field evolution and mitigation activities to the viability of impacted greater sage-grouse populations. The top panel of Figure 11 indicates that the largest extent of population recovery as determined by average population size occurs when duration D (the duration of the most intense disturbance) is low (B and D lines). This effect is seen even more dramatically when we use extinction probability as a measure of population performance (Figure 12). The greatest level of impact is demonstrated when the extent of demographic recovery, R_1, is incomplete (Table 9, $R_1 = 0.5R_0$). Under these conditions, growth rates remain highly negative and extinction probabilities remain very high, even if other aspects of well-field mitigation are pursued aggressively.

Table 9. Greater sage-grouse PVA.: output from the analysis of well-field development and mitigation options in Piceance / Parachute / Roan region. See Figure 8 and text for additional information on model construction and parameterization.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Full Recovery ($R_1 = R_0$)				
No mitigation	-0.205 (0.266)	1.000	—	—
D Low; T_2 Low	-0.033 (0.195)	0.058	374 (385)	0.6956
D High; T_2 Low	-0.081 (0.243)	0.366	112 (196)	0.5485
D Low; T_2 High	-0.049 (0.211)	0.132	233 (304)	0.6181
D High; T_2 High	-0.107 (0.256)	0.542	59 (137)	0.4951
Partial Recovery ($R_1 = 0.5R_0$)				
No mitigation	-0.205 (0.266)	1.000	—	—
D Low; T_2 Low	-0.139 (0.248)	0.838	4 (11)	0.4023
D High; T_2 Low	-0.164 (0.260)	0.924	1 (7)	0.3571
D Low; T_2 High	-0.145 (0.252)	0.852	4 (12)	0.4607
D High; T_2 High	-0.172 (0.263)	0.948	1 (4)	0.3835

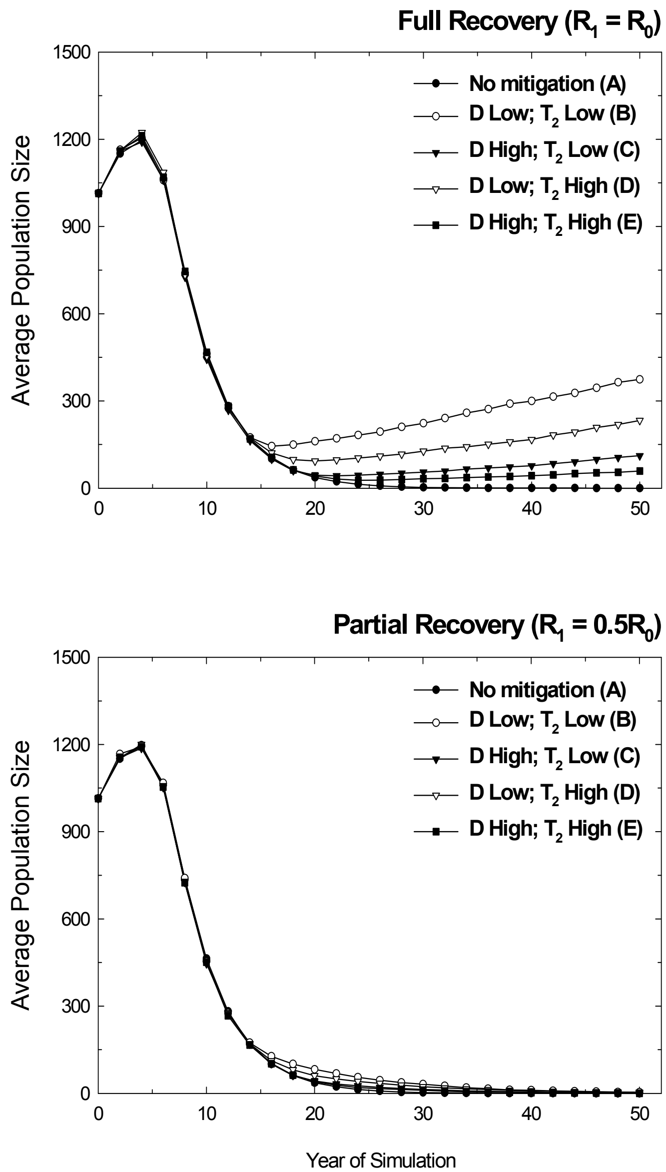


Figure 11. Average projected size of simulated greater sage-grouse populations in the Piceance / Parachute / Roan region, in the presence of varying scenarios of oil and natural gas well-field development and mitigation. Total well development includes the construction of 16,000 wells spread over 2,000 well pads. Labels (B) – (E) refer to profiles identified in Figure 8. See Figure 8 and text (“*Progressive Well Field Development and Mitigation”)* for accompanying information on model construction and parameterization.

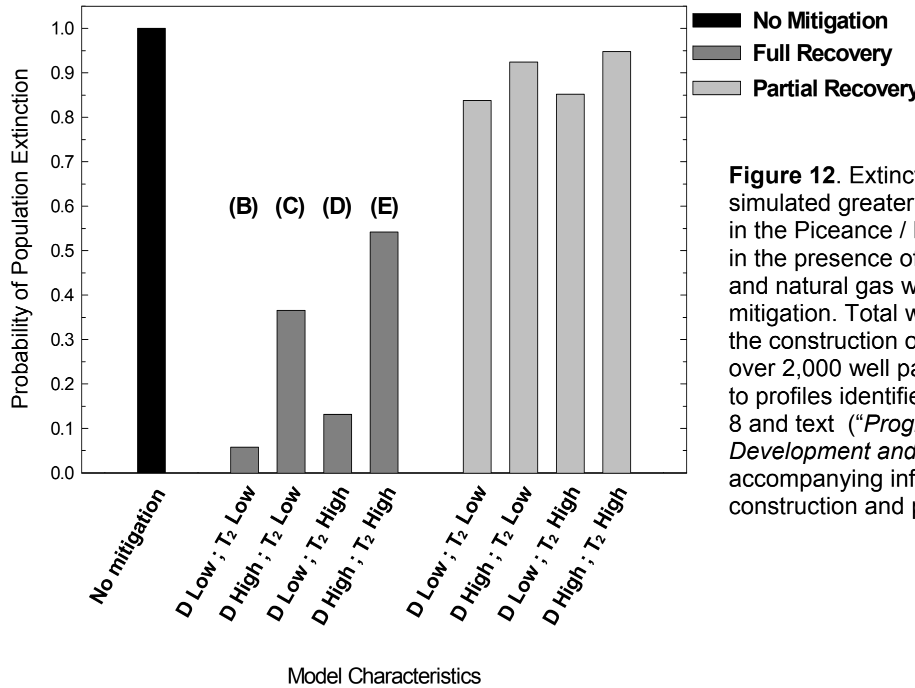


Figure 12. Extinction probabilities for simulated greater sage-grouse populations in the Piceance / Parachute / Roan region, in the presence of varying scenarios of oil and natural gas well-field development and mitigation. Total well development includes the construction of 16,000 wells spread over 2,000 well pads. Labels (B) – (E) refer to profiles identified in Figure 8. See Figure 8 and text (*"Progressive Well Field Development and Mitigation")* for accompanying information on model construction and parameterization.

Given this information, we may conclude that with respect to maintaining viability of greater sage-grouse populations in the presence of oil and natural gas extraction, the impacts of well-field development and production are most effectively mitigated by, in order of decreasing efficacy,

- Maximizing the extent of sage-grouse demographic recovery to near levels observed before the onset of well-field development ($R_1 = R_0$);
- Minimizing the time period of maximum demographic impact (D);
- Minimizing the time period over which demography recovery is achieved (T_s).

The relative feasibility of these activities on the ground is outside the expertise of this author. Nevertheless, it is hoped that this analysis can stimulate discussion among those parties both involved in the undertaking and concerned with the consequences of these activities so that effective protection of nearby greater sage-grouse populations can be achieved.

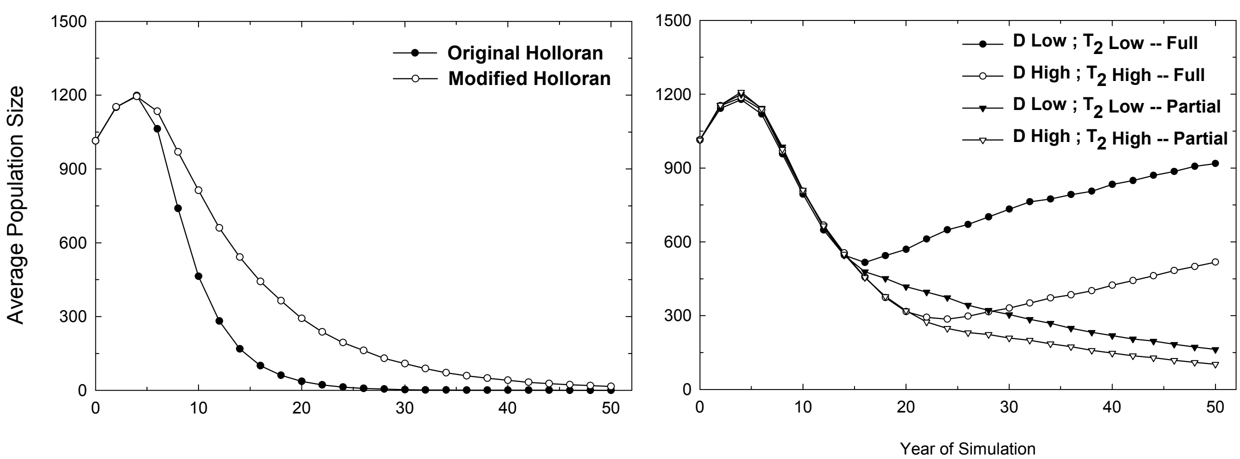
Alternate Disturbance Levels – Even when the demographic impacts are reduced by 50% from Holloran's (2005) original estimates, the simulated Piceance / Parachute / Roan population is heavily impacted by oil and natural gas development and production (Table 10 [first 2 rows of data], Figure 13 [left panel]). The initial population decline is less severe under the assumption of reduced demographic disturbance, and the population growth rate shows significant improvement over the original simulations, but the underlying growth rate remains highly negative and the ultimate outcome of the simulations are very similar.

Table 10. Greater sage-grouse PVA: output using revised assumptions of the impact of oil and natural gas

development. Data are the outcome of different well-field development and mitigation scenarios in Piceance / Parachute / Roan region (*Progressive Well Field Development and Mitigation*), where the base impacts of well-field development are reduced by 50% (*Alternate Disturbance Levels*) from the initial analyses that used the direct observations of Holloran (2005). See Figure 9 and text for additional information on model construction and parameterization.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Original impact (Holloran 2005)	-0.205 (0.139)	1.000	—	—
Modified impact (50% of original)	-0.102 (0.208)	0.478	15 (25)	0.5766
Mitigation Options (using modified impact from above)				
D Low; T_2 Low – Full Recovery	-0.001 (0.151)	0.000	918 (479)	0.8808
D High; T_2 High – Full Recovery	-0.020 (0.163)	0.006	517 (426)	0.7918
D Low; T_2 Low – Partial Recovery	-0.049 (0.167)	0.042	162 (188)	0.7525
D High; T_2 High – Partial Recovery	-0.058 (0.175)	0.080	102 (124)	0.6999

Figure 13. Average projected size of simulated greater sage-grouse populations in the Piceance / Parachute Roan region under revised assumptions of the impact of oil and natural gas development. The left panel illustrates *Alternate Disturbance Levels*: the original estimated impact compared with the modified impact (50% of the original). The right panel illustrates alternative scenarios of well-field development and mitigation, using the modified base impact level from the left panel. See Figures 8 and 9 and text for accompanying information on model construction and parameterization.



When oil and natural gas development occurs in selected Zones of the Northwestern Colorado region, overall greater sage-grouse metapopulation viability is high over the time period of the simulations presented here (Table 11, Figure 14). The consequences of the delayed onset of demographic disturbance following oil and natural gas development is clear in Figure 14, as is the lower overall impact of development under the *Alternate Disturbance Levels* analysis. As expected, the consequences of oil and natural gas activity begin to show themselves around year 30 of the simulation, in accordance with the onset of demographic disturbance in Zones 2 and 3B at year 26. While the disturbance does not lead to a measurable risk of metapopulation extinction in the 50-year timeframe of the simulations presented here, population size does indeed decline markedly in the latter portions of the simulation. Oil and natural gas development activity, it is clear, is predicted to have an impact in this region, with the possibility that the overall greater sage-grouse regional population may decline to levels below those currently estimated.

Table 11. Greater sage-grouse PVA: output using revised assumptions of the impact of oil and natural gas development. Data are the outcome of different well-field development and mitigation scenarios in the Northwestern Colorado region (*Progressive Well Field Development and Mitigation*), where the base impacts of well-field development are reduced by 50% (*Alternate Disturbance Levels*) from the initial analyses that used the direct observations of Holloran (2005). See Figure 9 and text for additional information on model construction and parameterization. Population size and extinction probability are given for the entire metapopulation. See text for additional information on model construction.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Original impact (Holloran 2005)				
No well development	0.030 (0.081)	0.000	15824 (1824)	0.9956
10,000 wells	0.016 (0.083)	0.000	10809 (2526)	0.9951
Modified impact (50% of original)				
No well development	0.030 (0.081)	0.000	15824 (1824)	0.9956
10,000 wells	0.022 (0.082)	0.000	13484 (2384)	0.9954

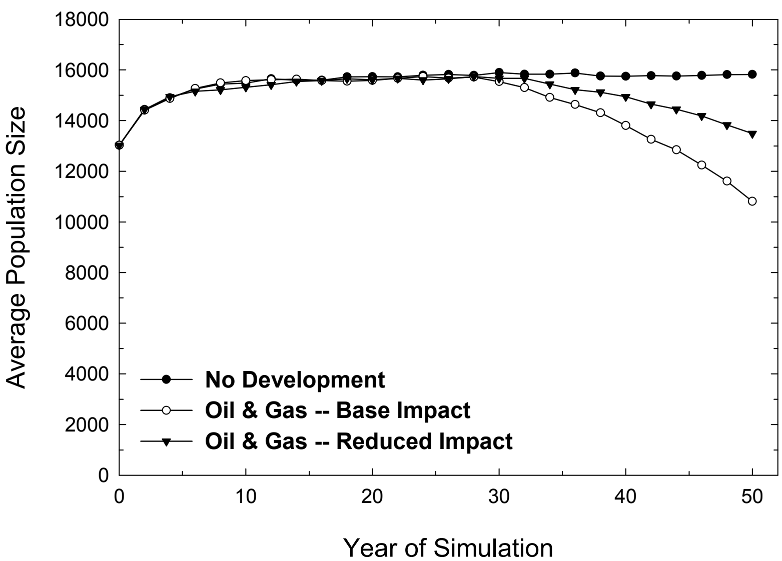


Figure 14. Average projected size of simulated greater sage-grouse populations in the Northwestern Colorado region, under revised assumptions of the base impact of oil and natural gas development. *Alternate Disturbance Levels* analysis is illustrated: the original estimated impact (base) compared with the reduced impact (50% of the original). See text for additional information on model construction.

The PVA analyses presented here may be seen as preliminary, particularly because they are based on data collected from Wyoming under a single development phase (Holloran 2005), and may be subject to refinement at a later date. Nevertheless it is important to recognize that in our models oil and natural gas development are expected to impact two important demographic parameters: adult female breeding success and mortality. Those two parameters are precisely the demographic parameters that appear to be primary drivers of population growth as determined in the sensitivity analysis of the PVA. Therefore, while the exact degree of impact is unknown at the present time, it remains quite likely that this type of activity, with its direct impacts on sage-grouse demographic rates, can have a much more severe impact on the stability and future viability of local sage-grouse populations than those activities such as housing development, which we believe act solely to reduce the quantity and/or quality of available sagebrush habitat.

Risk Analysis IV: An Assessment of Increasing Reproductive Success Through Reproductive Mitigation as a Greater Sage-grouse Management Tool

Reproductive Success Mitigation: Model Input
Regions considered: All

In addition to the anthropogenic activities in Risk Analyses I - III, our PVA model considers the impact that increasing reproductive success could have on improving greater sage-grouse population demographics. Mitigation activities that might increase sage-grouse reproductive success can include improving habitat quality and/or availability, population augmentation, or predator mitigation. It is important to consider that “predator mitigation” does not by necessity mean “predator control” in the typical sense. Mitigation can also be at least partially achieved through, for example, habitat modifications that make predation on nesting sage-grouse less likely.

The choice was made to simulate reproductive mitigation through improving reproductive success, since past research (e.g., Duebbert and Kantrud 1974; Garretson and Rohwer 2001) has demonstrated that such activity can be highly beneficial during the breeding season for waterfowl species. Unfortunately, analogous data do not exist for greater sage-grouse, and studies on European species have targeted adult survival.

In light of the data cited above, we elected to simulate three different levels of reproductive mitigation by increasing the percentage of breeding-age greater sage-grouse that successfully reproduce in a given year by 5%, 10%, or 15%. These values were added to the baseline measures for both yearlings and adults. For example, the baseline value of 38.7% of yearling females breeding was increased to 43.7%, 48.7%, and 53.7%. Reproductive mitigation was simulated in the large majority of models that included one or more human activities in order to evaluate its utility as a management action that could possibly ameliorate the negative impact of other activities on the landscape.

Reproductive Mitigation Results: (1) Housing and Surface Mining; (2) Harvest (3) Initial Oil and Natural Gas Development Model

The results of our reproductive mitigation models for housing, surface mining, and the initial oil and natural gas development analysis are shown in Table 12 and Figure 15. The efficacy of reproductive mitigation as a management tool for greater sage-grouse depends on the primary type of human activity that takes place within sage-grouse habitat, and on the underlying growth dynamics of the grouse populations. For example, in Middle Park where housing and surface activities are of primary concern and the current population is already thought to be close to its habitat carrying capacity, reproductive mitigation appears to have relatively little overall impact. This is because, as we have learned before, housing development and surface mining activities act to reduce carrying capacities, while leaving the underlying greater sage-grouse population demography unchanged (in the absence of density-dependent phenomena). The increase in reproductive success through various mitigation activities only serves to hasten the approach of the simulated population to carrying capacity, after which time the population’s trajectory is constrained by the gradual decrease in available habitat.

In contrast, consider the case of Meeker / White River where the population has an opportunity to grow to a carrying capacity that is currently rather large compared to today's population size. In this instance, an increase in reproductive success through mitigation activities can have a dramatic effect on the growth potential of the simulated greater sage-grouse population. Over the first 20 years of the simulation, the population can increase in size by as much as about 50% compared to the baseline trajectory, in the absence of housing development and reproductive mitigation. At later stages of the simulation, the model's growth potential is ultimately constrained by the gradual reduction in habitat carrying capacity – but reproductive mitigation models still show final population sizes that are at least as large as the baseline model. Under these conditions, reproductive mitigation can have a considerable impact potential.

The effects of reproductive mitigation can be much more pronounced under moderate levels of harvest mortality, as demonstrated in North Park in Table 12 and Figure 15. When reproductive mitigation is strong, the population can grow to a level that is larger than that predicted in the baseline model where harvest is absent. Even under low levels of reproductive mitigation, the final size of the harvested population is nearly three times that of a population where reproductive mitigation is absent. Of course, under conditions of higher harvest mortality, the benefits gained from reproductive mitigation are not as pronounced. The practice of reproductive mitigation, however, is shown here to have significant potential to improve the viability of greater sage-grouse populations in the presence of certain types of detrimental human activities on the landscape.

When reproductive mitigation is assessed in the context of our initial assumptions around the impacts of oil and natural gas development, the situation remains much less optimistic. As exemplified by the Piceance / Parachute / Roan example given in Table 12 and Figure 15 the increase in reproductive success achieved through mitigation does not sufficiently compensate for the significant declines in survival and breeding success that result from oil and natural gas development. Overall population sizes may be considerably higher in the early stages of the simulation, particularly under assumed conditions of strong reproductive mitigation, but the general trend in population trend remains strongly negative, with high extinction risks by the end of the 50-year simulation.

Table 12. Greater sage-grouse PVA: output from analysis of reproductive mitigation models. "H2" and "M2" refer to high levels of habitat loss through housing and surface mining activities, respectively, in Middle Park and Meeker / White River. "20,000 Wells" refers to a given level of oil and natural gas activity in the Piceance / Parachute / Roan region (in the initial oil an gas risk analysis), and "2%" in North Park refers to specific level of harvest mortality through hunting. Reproductive mitigation is simulated through a 5%, 10% or 15% increase in the number of yearling and adult females that breed in a given year. See text for additional information on model construction and results.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Middle Park				
Baseline	0.022 (0.138)	0.000	1370 (400)	0.9351
Housing 2 – Mining 2	0.023 (0.140)	0.000	667 (121)	0.9366
Housing 1 – Mining 2 +5%	0.064 (0.140)	0.000	725 (71)	0.9410
Housing 2 – Mining 1 +10%	0.103 (0.140)	0.000	741 (50)	0.9408
Housing 2 – Mining 2 +15%	0.140 (0.142)	0.000	752 (38)	0.9374
Meeker / White River				
Baseline	0.019 (0.160)	0.016	208 (83)	0.6619
Housing 2	0.020 (0.162)	0.010	165 (62)	0.6347
Housing 2 +5%	0.061 (0.153)	0.000	208 (32)	0.6937
Housing 2 +10%	0.099 (0.154)	0.000	219 (22)	0.7024
Housing 2 +15%	0.139 (0.153)	0.000	224 (16)	0.7007
North Park				
Baseline	0.026 (0.136)	0.000	6697 (1634)	0.9903
2%	-0.030 (0.143)	0.000	1820 (1482)	0.9700
2% +5%	0.010 (0.145)	0.000	5379 (2208)	0.9870
2% +10%	0.048 (0.145)	0.000	7237 (1306)	0.9903
2% +15%	0.084 (0.148)	0.000	7829 (825)	0.9907
Piceance / Parachute / Roan				
Base line	0.025 (0.139)	0.000	1202 (342)	0.9422
20,000 Wells	-0.260 (0.257)	1.000	—	—
20,000 Wells +5%	-0.204 (0.251)	0.998	1 (2)	0.5559
20,000 Wells +10%	-0.152 (0.243)	0.916	1 (5)	0.3953
20,000 Wells +15%	-0.107 (0.216)	0.530	17 (44)	0.5612

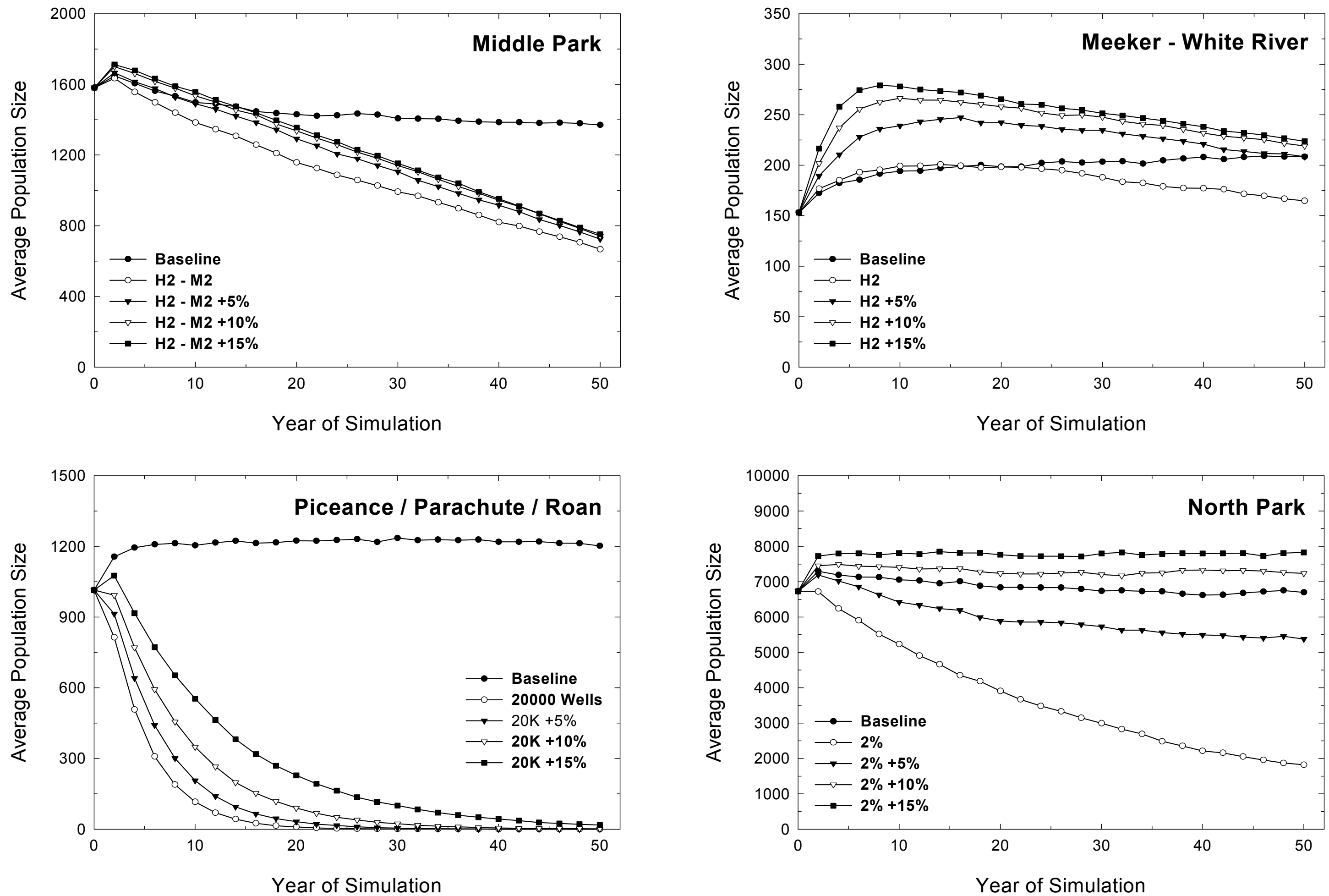


Figure 15. Average projected size of simulated greater sage-grouse populations in the presence of region-specific human activities and with varying levels of reproductive mitigation. “H2” and “M2” refer to high levels of habitat loss through housing and surface mining activities, respectively, in Middle Park and Meeker / White River. “20000 Wells” refers to a given level of oil and natural gas activity in the Piceance / Parachute / Roan region, and “2%” in North Park refers to specific level of harvest mortality through hunting. Reproductive mitigation is simulated through a 5%, 10% or 15% increase in the number of yearling and adult females that breed in a given year. See accompanying text for additional information on model construction and results

Reproductive Success Mitigation
Revised O&G; Regions considered:

In addition to investigating well-field mitigation and reclamation, another set of models was developed for both Piceance / Parachute / Roan and Northwestern Colorado that included increasing reproductive success as a complementary tool for greater sage-grouse management. As in earlier models, female breeding success was increased in selected models by 5%, 10%, or 15% in accordance with an assumed level of intensity of any of a number of alternative management activities such as improvements in habitat quality / availability, population augmentation, and predator mitigation.

Reproductive Mitigation: Results for Revised Oil and Natural Gas Development Model

Piceance / Parachute / Roan

Progressive Well Field Development and Mitigation - The combined effects of well-field mitigation / reclamation and additional reproductive mitigation activities are shown in Table 13 and Figure 16. If full demographic recovery is possible with aggressive well-field mitigation, significant increases in growth rate can be achieved with as little as a 5% increase in greater sage-grouse reproductive success through additional mitigation (Figure 16A). If well-field mitigation is less aggressive, larger increases in reproductive success through additional mitigation are required to offset the impacts of well-field disturbance. At the other end of the well-field mitigation spectrum, where only partial demographic recovery is possible, high levels of increased reproductive success are required to offset well-field disturbance (Figure 16C, D).

Figure 16 shows very explicitly the interactions among the various mitigation activities. When well-field development is extended (*D* increases), the size of the population decreases further and remains at a lower level for a longer period of time. These two processes act to greatly increase the risk of population extinction in the absence of additional mitigation. The additional mitigation activities greatly diminish these risks. Once again, the impact of only partial demographic recovery is clearly demonstrated, as well as the need for aggressive reproductive mitigation in the face of incomplete well-field mitigation.

Table 13. Greater sage-grouse PVA: output from combined analysis of *Progressive Well Field Development and Mitigation* and reproductive mitigation activities in Piceance / Parachute / Roan region. See Figure 8 and text for additional model information.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Full Recovery ($R_1 = R_0$)				
D Low; T_2 Low				
+0% Reprod. success	-0.033 (0.195)	0.058	374 (385)	0.6956
+5%	0.018 (0.170)	0.000	1242 (398)	0.8674
+10%	0.059 (0.167)	0.000	1484 (146)	0.9222
+15%	0.096 (0.165)	0.000	1526 (77)	0.9422
D High; T_2 High				
+0% Reprod. success	-0.107 (0.256)	0.542	59 (137)	0.4951
+5%	-0.030 (0.211)	0.106	480 (484)	0.6582
+10%	0.020 (0.186)	0.006	1238 (444)	0.8168
+15%	0.065 (0.176)	0.000	1514 (108)	0.9087
Partial Recovery ($R_1 = 0.5R_0$)				
D Low; T_2 Low				
+0% Reprod. success	-0.139 (0.248)	0.838	4 (11)	0.4023
+5%	-0.078 (0.205)	0.270	47 (67)	0.6240
+10%	-0.026 (0.167)	0.018	358 (351)	0.8061
+15%	0.019 (0.158)	0.000	1091 (433)	0.9118
D High; T_2 High				
+0% Reprod. success	-0.172 (0.263)	0.948	1 (4)	0.3835
+5%	-0.113 (0.239)	0.590	13 (28)	0.4872
+10%	-0.050 (0.195)	0.122	154 (208)	0.6602
+15%	0.001 (0.165)	0.004	769 (483)	0.8502

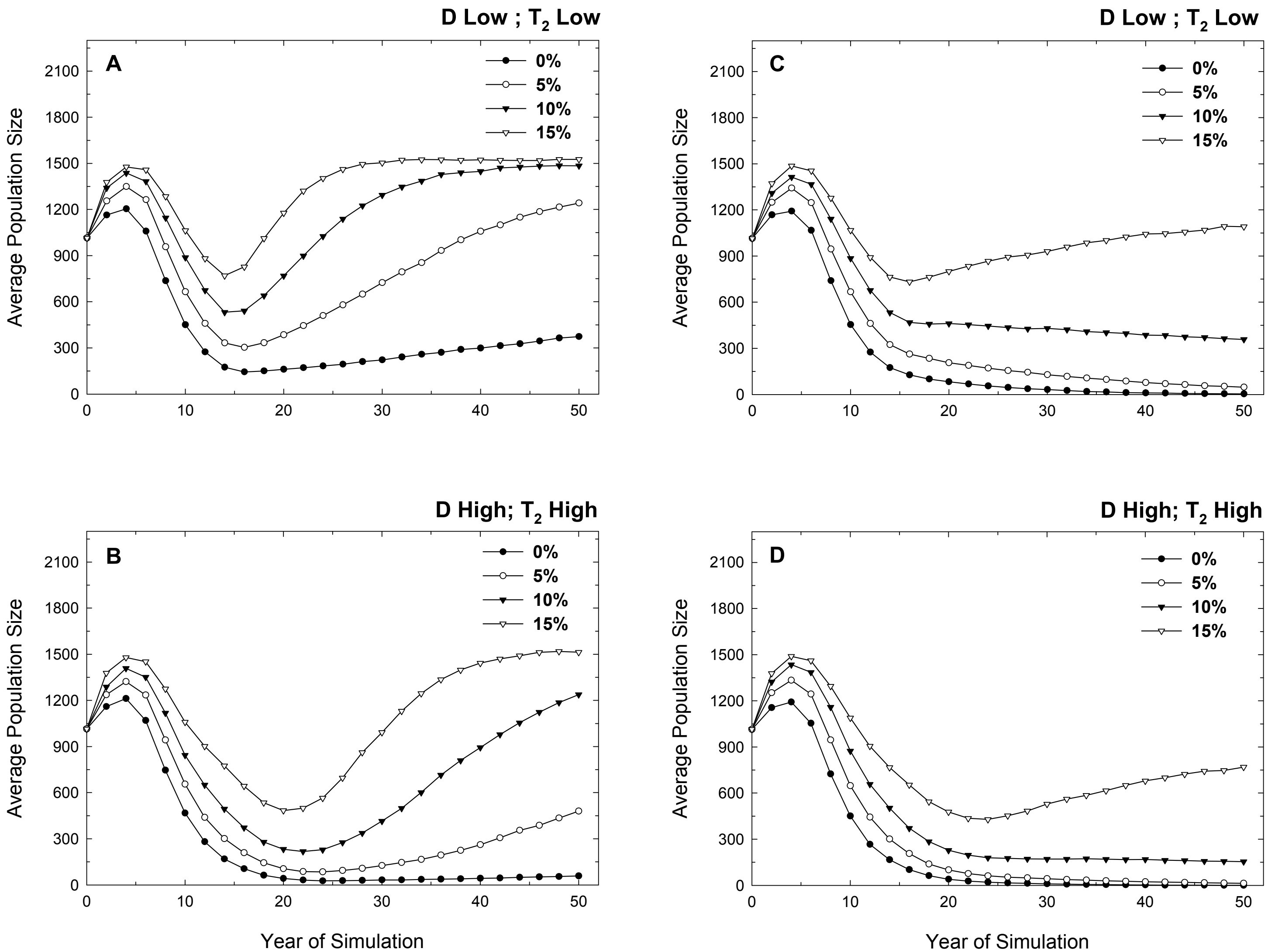


Figure 16. Average projected size of simulated greater sage-grouse populations in the Piceance / Parachute / Roan region in the presence of *Progressive Well Field Development and Mitigation* and additional levels of reproductive mitigation. Reproductive mitigation is simulated through a 5%, 10% or 15% increase in the number of yearling and adult females that breed in a given year. Left-side panels A and B include full demographic recovery following well-field development, while right-side panels C and D include only partial recovery. See Figure 8 and text for accompanying information on model construction and parameterization.

Alternate Disturbance Levels – If we assume the base impacts to be set at the reduced level (50% of initial analysis, which was based on Holloran 2005), the benefits of well-field mitigation are enhanced by reproductive mitigation (Table 14; Figure 17, right panel; compare with trajectories in Figure10). If full demographic recovery is possible through well-field mitigation and reclamation, just a 5% increase in reproductive success through mitigation activities can dramatically increase the growth rate to as high as 0.042, in contrast to a negative growth rate in the absence of reproductive mitigation (Figure 17). Even if demographic recovery is only partial, low levels of reproductive mitigation are sufficient to offset the impacts of well-field development. As expected, this enhancement through mitigation is much more effective when the underlying base impact of oil and natural gas development is assumed to be lower than that estimated initially by Holloran (2005).

Table 14. Greater sage-grouse PVA: output from combined analysis of *Progressive Well Field Development and Mitigation* and additional reproductive mitigation in Piceance / Parachute / Roan region, along with *Alternate Disturbance Levels* of oil and natural gas development. See Figure 9 and text for additional information on model construction

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Full Recovery ($R_1 = R_0$)				
D Low; T_2 Low				
+0% Reprod. success	-0.001 (0.151)	0.000	918 (479)	0.8808
+5%	0.042 (0.147)	0.000	1413 (210)	0.9383
+10%	0.081 (0.048)	0.000	1500 (116)	0.9488
+15%	0.119 (0.148)	0.000	1519 (91)	0.9504
D High; T_2 High				
+0% Reprod. success	-0.020 (0.163)	0.006	517 (426)	0.7918
+5%	0.024 (0.153)	0.000	1302 (341)	0.9108
+10%	0.065 (0.150)	0.000	1486 (142)	0.9446
+15%	0.104 (0.150)	0.000	1524 (90)	0.9490
Partial Recovery ($R_1 = 0.5R_0$)				
D Low; T_2 Low				
+0% Reprod. success	-0.049 (0.167)	0.042	162 (188)	0.7525
+5%	-0.001 (0.147)	0.000	806 (462)	0.8994
+10%	0.043 (0.145)	0.000	1333 (274)	0.9451
+15%	0.081 (0.145)	0.000	1467 (160)	0.9501
D High; T_2 High				
+0% Reprod. success	-0.058 (0.175)	0.080	102 (124)	0.6999
+5%	-0.011 (0.153)	0.002	613 (433)	0.8680
+10%	0.033 (0.147)	0.000	1292 (323)	0.9357
+15%	0.073 (0.146)	0.000	1467 (152)	0.9487

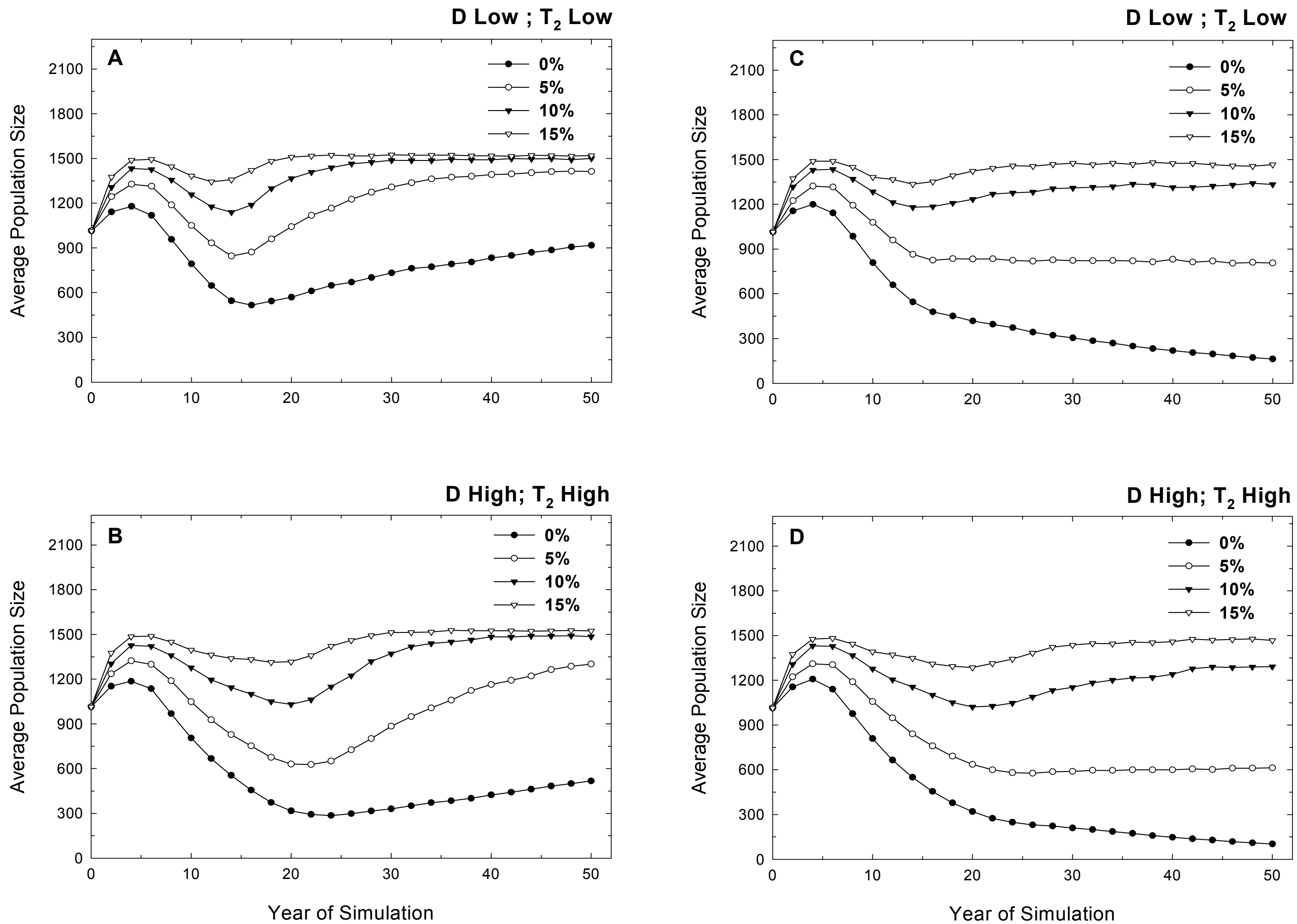


Figure 17. Average projected size of simulated greater sage-grouse populations in the Piceance / Parachute Roan region in the presence of *Progressive Well Field Development and Mitigation* and additional reproductive mitigation, along with *Alternate Disturbance Levels* of oil and natural gas development. Reproductive mitigation is simulated through a 5%, 10% or 15% increase in the number of yearling and adult females that breed in a given year. Left-side panels A and B include full demographic recovery following well-field development, while right-side panels C and D include only partial recovery. See Figure 9 and text for accompanying information on model construction and parameterization.

Northwestern Colorado

An increase in greater sage-grouse reproductive success through mitigation activities may be an option to offset the consequences of demographic disturbances brought on by oil and natural gas development in the region. The predicted consequences of this activity are presented in Table 15 and Figure 18. As in the case of the Piceance / Parachute / Roan analyses, even modest increases in reproductive success through mitigation activities can lead to significant increases in metapopulation growth rate and final population size, even if the base impact of oil and natural gas development as defined by Holloran (2005) is in place (top panel, Figure 18). A small set of additional models was constructed that were meant to investigate the efficacy of an increase in greater sage-grouse reproductive success over a restricted geographic area – namely, only those Zones where the bulk of regional oil and natural gas development activity is predicted to occur (Zones 2, 3A, 3B, and 3C). In general, a 10% increase in reproductive success across the restricted area is as effective in increasing population size as a 5% increase in reproductive success applied to the entire region. The relative merits of each of these tactics would be necessary in order to more logically determine the most beneficial course of action in planning a reproductive mitigation plan, should one be deemed valuable.

Table 15. Greater sage-grouse PVA: output from combined analysis of *Progressive Well Field "Development and Mitigation* and additional reproductive mitigation in the Northwestern Colorado region, under *Alternate Disturbance Levels* of oil and natural gas development. Population size and extinction probability are given for the entire metapopulation. "Restricted" reproductive mitigation refers to increases in reproductive success in greater sage-grouse through mitigation activities in only those Zones that see comparatively high levels of oil and natural gas development activity (specifically, Zones 2, 3A, 3B, and 3C), as opposed to the same levels of increased success realized in all Zones comprising the Northwestern Colorado region. See text for additional information on model construction.

Scenario	r_s (SD)	PE_{50}	N_{50} (SD)	GD_{50}
Base Holloran impact				
No well development	0.030 (0.081)	0.000	15824 (1824)	0.9956
10,000 wells	0.016 (0.083)	0.000	10809 (2526)	0.9951
+5% reprod. success	0.056 (0.084)	0.000	14631 (1694)	0.9956
+10%	0.096 (0.085)	0.000	16285 (1096)	0.9956
+5% restricted reprod. success	0.035 (0.085)	0.000	13112 (2213)	0.9955
+10%	0.055 (0.085)	0.000	14630 (1922)	0.9956
Reduced Holloran impact				
No well development	0.030 (0.081)	0.000	15824 (1824)	0.9956
10,000 wells	0.022 (0.082)	0.000	13484 (2384)	0.9954
+5% reprod. success	0.064 (0.082)	0.000	16217 (1300)	0.9958
+10%	0.103 (0.083)	0.000	17136 (827)	0.9959
+5% restricted reprod. success	0.042 (0.083)	0.000	15278 (1813)	0.9957
+10%	0.062 (0.083)	0.000	16179 (1329)	0.9957

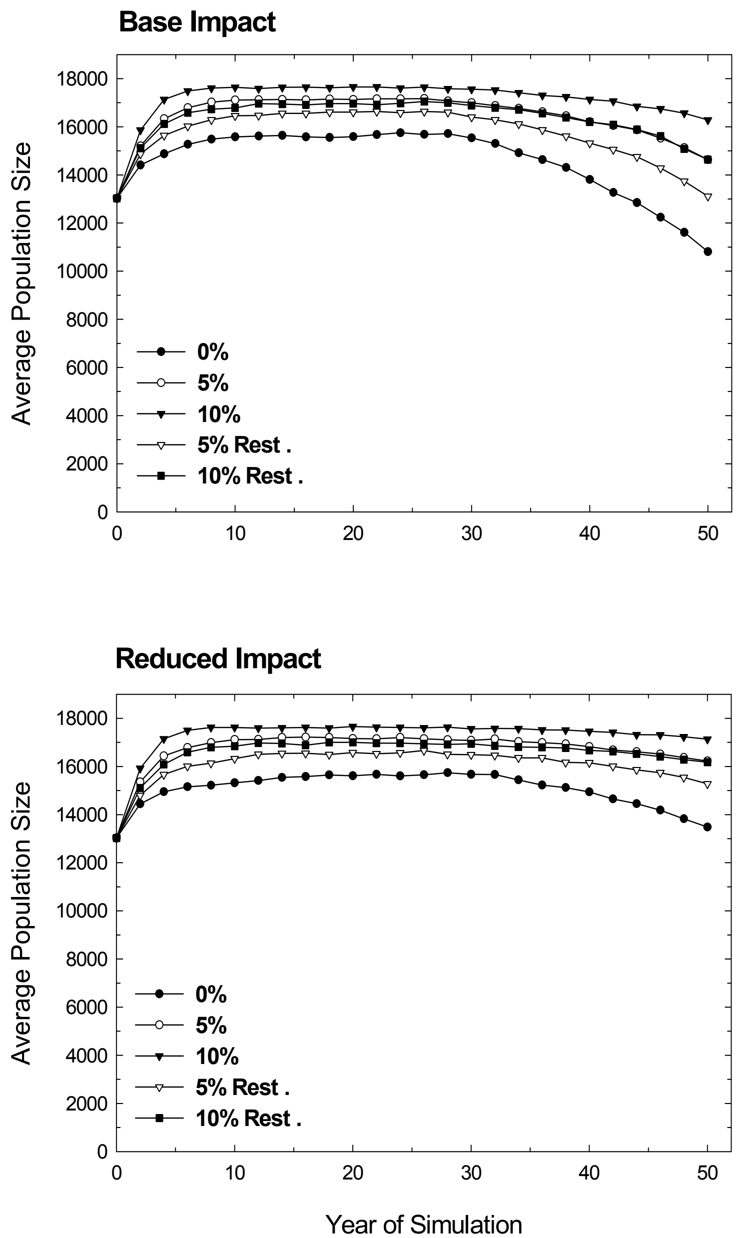


Figure 18. Average projected size of simulated greater sage-grouse populations in the Northwestern Colorado region, under reproductive mitigation *Alternate Disturbance Levels* of oil and natural gas development. "Rest." mitigation refers to increases in reproductive success through mitigation activities in only those Zones that see comparatively high levels of oil and natural gas development activity (specifically, Zones 2, 3A, 3B, and 3C), as opposed to the same levels of increased success realized in all Zones comprising the Northwestern Colorado region. See text for additional information on model construction.

Future Directions for Additional Analysis

Density dependence in demographic rates
The inclusion of density dependence in survival and/or reproduction in greater sage-grouse could possibly alter some of the qualitative results of the PVA models discussed in this document, in particular the analysis of housing development and surface mining activities where habitat loss is considerable and greater sage-grouse populations soon occupy saturated sagebrush habitats. While there is scant evidence to suggest that strong density dependence is operating to modulate demographic rates in greater sage-grouse, the controversy remains vigorous. Additional modeling, including some form of density dependent demographics, could be initiated to demonstrate its effects and stimulate more thoughtful discussion on its mode of operation and intensity.

Revised oil and natural gas scenarios
Because of the issues in model parameterization discussed herein, we feel that the oil and natural gas development models presented in this document may overestimate the long-term impact of this activity on nearby greater sage-grouse populations. Efforts are currently underway to thoroughly assess these models for their realism and to modify them accordingly so that we can come up with a more rigorous analysis of the impact of this activity on the landscape.

Impacts of disease
West Nile virus (WNV) is clearly a disease of great concern to grouse biologists in North America, but the data needed to rigorously evaluate its potential impact is lacking. *VORTEX* can, by itself, simulate fairly complex disease dynamics and their impacts on wildlife population demography. However, we have chosen to delete this option from our current analyses. The Conservation Breeding Specialist Group has also developed *OUTBREAK*, a much more sophisticated simulation model of wildlife disease epidemiology, that can be of tremendous value in studying disease processes in threatened wildlife populations. Future greater sage-grouse modeling efforts could be devoted to a deeper evaluation of WNV and its possible affects.

Conclusions

We may conclude our analysis of greater sage-grouse population viability by returning to the original set of questions that provided the foundation for our study.

- *Can we build a series of simulation models with sufficient detail and precision that can accurately describe the dynamics of greater sage-grouse populations distributed across Colorado?*

  Our retrospective demographic analysis indicates that we are indeed capable of building such models. It is extremely important to remember, however, that reliance on the absolute outcome predicted by any one modeling scenario must always be interpreted with extreme caution due to the inherent uncertainty in model input parameterization. A comparative analysis between models, in which a single factor (or at most two factors) is studied while all other input parameters are held constant, provides a much more robust environment in which alternative management scenarios can be evaluated for their effectiveness in increasing the viability of the target species.

- *What are the primary demographic factors that drive growth of greater sage-grouse populations in Colorado?*

  Our demographic sensitivity analysis indicates that models of greater sage-grouse population dynamics are most sensitive to variability in female juvenile (chick) survival, the proportion of females that successfully reproduce per year, and clutch size per successful female.

- *How vulnerable are small, fragmented populations of greater sage-grouse in Colorado to extinction under current management conditions? How small must a population become to increase its risk of extinction to an unacceptable level?*

  A formal analysis of this question is not yet part of this larger modeling effort; consequently, this question has yet to be fully determined. The analyses presented here, however, provide some preliminary insight into this issue. For example, the rather small Meeker / White River population has an intrinsically higher risk of population decline and extinction even under conditions of equivalent underlying demographic rates used as model input. The higher levels of instability we see are directly tied to the smaller size of this population and the resulting higher levels of annual random variation in survival and reproductive rates. Overall, the relatively low levels of environmental variability included in these PVA models leads to a comparatively higher level of population stability and, by extension, a lower probability of population extinction.

- *What are the predicted impacts of current and potential future levels of housing development on selected greater sage-grouse populations in Colorado?*

  This activity, manifest largely through reductions in available sagebrush habitat, appears to have comparatively minor impact on the long-term demographic viability of greater sage-grouse populations in Colorado as long as underlying population demographic rates remain robust. However, the reduced population sizes that result from the gradual erosion of available habitat cannot be ignored and, in combination with other anthropogenic factors, could lead to longer-term increases in risk of population decline.

- *What are the predicted impacts of current and potential future levels of mining and other surface activities on selected greater sage-grouse populations in Colorado?*

  This activity, manifest largely through reductions in available sagebrush habitat, appears to have comparatively minor impact on the long-term demographic viability of greater sage-grouse populations in Colorado as long as underlying population demographic rates remain robust. However, the reduced population sizes that result from the gradual erosion of available habitat cannot be ignored and, in combination with other anthropogenic factors, could lead to longer-term increases in risk of population decline.

- *What are the predicted impacts of current and potential future levels of hunting on selected greater sage-grouse populations in Colorado?*

  Through field-based evaluations of population status, current levels of greater sage-grouse harvest in North Park appear sustainable. However, our analyses presented here provide evidence to suggest that even relatively low levels of additional harvest mortality – if sustained for long periods of time (i.e., one to two decades) can lead to marked increases in the risk of significant population decline. A more complete understanding of the demographic consequences of harvest, such as the degree of compensation that acts in a harvested greater sage-grouse population, is recommended before specific adjustments to harvest quotas are made.

- *What are the predicted impacts of current and potential future levels of petroleum and* *natural gas development on selected greater sage-grouse populations in Colorado?*

Oil and natural gas development, manifest through direct impacts on demographic performance of individual birds, may have major and severe consequences for greater sage-grouse populations in Colorado. This conclusion is based on models that use data from research studies on greater sage-grouse in nearby habitats. Consequently, it is important to thoroughly and critically review this available literature and to determine the applicability of these biological studies to Colorado's greater sage-grouse populations.

- *Can reproductive mitigation improve the viability of greater sage-grouse populations in Colorado in the face of other anthropogenic processes?*

  Improving reproductive success through alternative mitigation activities could possibly lead to significant increases in greater sage-grouse demographic performance. However, these benefits can only be realized under certain conditions, particularly where specific human activities appear to directly affect population demographic rates to a relatively small degree. In other cases, the observed benefits do not appear to offset the declines in performance brought about by human activities on the landscape.

As before, we conclude our revised analysis by returning to those original questions that guided the development of the scenarios described herein.

- *How would the demographic behavior of our simulated populations of greater sage-grouse respond if we modify the model to more accurately reflect the progression of impacts, reclamation, and mitigation at and/or near individual well pad sites, throughout the oil and natural gas development process?*

  Our analysis of projected oil and natural gas development activity in the Piceance / Parachute / Roan region suggests that well-field mitigation can potentially be effective in reducing the demographic disturbance to greater sage-grouse populations occupying nearby sagebrush habitats. These mitigation measures must be conducted aggressively, however, in order for disturbance to be minimized. Most importantly, mortality and reproductive rates must rebound to as close to their original rates as practical as the field shifts to a production phase and reclamation of the surrounding habitats is undertaken. Secondarily, the duration of maximum well-field related disturbance must be minimized.

  The degree to which additional mitigation measures – such as increased reproductive success through various mitigation activities – must be undertaken is closely related to the intensity of well-field mitigation. Under conditions of aggressive well-field mitigation, lower levels of reproductive mitigation may be required to further increase the long-term viability of nearby sage-grouse populations.

- *To what extent will the demographic behavior of our simulated populations of greater sage-grouse change if we assume a less severe direct impact of oil and natural gas development, even in the absence of mitigation?*

  Our analyses indicate that even if the impacts on greater sage-grouse demography are reduced in magnitude by 50%, the extent of demographic disturbance of oil and natural gas development is sufficient to cause significant population decline soon after development begins. However, this lower overall demographic impact means that given levels of both well-field mitigation and increases in reproductive success through mitigation can have much greater benefit to the long-term viability of impacted grouse populations. Consequently, a more thorough understanding of the detailed demographic impacts of oil and natural gas development in Colorado is critical to the formulation of a specific well-field mitigation strategy.

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Appendix I: Population Viability Analysis and Simulation Modeling

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Introduction

Thousands of species and populations of animals and plants around the world are threatened with extinction within the coming decades. For the vast majority of these groups of organisms, this threat is the direct result of human activity. The particular types of activity, and the ways in which they impact wildlife populations, are often complex in both cause and consequence; as a result, the techniques we must use to analyze their effects often seem to be complex as well. But scientists in the field of conservation biology have developed extremely useful tools for this purpose that have dramatically improved our ability to conserve the planet's biodiversity.

Conservation biologists involved in recovery planning for a given threatened species usually try to develop a detailed understanding of the processes that put the species at risk, and will then identify the most effective methods to reduce that risk through active management of the species itself and/or the habitat in which it lives. In order to design such a program, we must engage in some sort of predictive process: we must gather information on the detailed characteristics of proposed alternative management strategies and somehow predict how the threatened species will respond in the future. A strategy that is predicted to reduce the risk by the greatest amount – and typically does so with the least amount of financial and/or sociological burden – is chosen as a central feature of the recovery plan.

But how does one predict the future? Is it realistically possible to perform such a feat in our fast-paced world of incredibly rapid and often unpredictable technological, cultural, and biological growth? How are such predictions best used in wildlife conservation? The answers to these questions emerge from an understanding of what has been called "the flagship industry" of conservation biology: Population Viability Analysis, or PVA. And most methods for conducting PVA are merely extensions of tools we all use in our everyday lives.

The Basics of PVA

To appreciate the science and application of PVA to wildlife conservation, we first must learn a little bit about population biology. Biologists will usually describe the performance of a population by describing its demography, or simply the numerical depiction of the rates of birth and death in a group of animals or plants from one year to the next. Simply speaking, if the birth rate exceeds the death rate, a population is expected to increase in size over time. If the reverse is true, our population will decline. The overall rate of population growth is therefore a rather good descriptor of its relative security: positive population growth suggests some level of demographic health, while negative growth indicates that some external process is interfering with the normal population function and pushing it into an unstable state.

This relatively simple picture is, however, made a lot more complicated by an inescapable fact: wildlife population demographic rates fluctuate unpredictably over time. So if we observe that 50% of our total population of adult females produces offspring in a given year, it is almost certain that more or less than 50% of our adult females will reproduce in the following year. And the same can be said for most all other demographic rates: survival of offspring and adults, the numbers of offspring born, and the offspring sex ratio will almost always change from one year to the next in a way that usually defies precise prediction. These variable rates then conspire to make a population's growth rate also change unpredictably from year to year. When wildlife populations are very large – if we consider seemingly endless herds of wildebeest on the savannahs of Africa, for example – this random annual fluctuation in population growth is of little to no consequence for the future health and stability of the population. However, theoretical and practical study of population biology has taught us that populations that are already small in size, often defined in terms of tens to a few hundred individuals, are affected by these fluctuations to a much greater extent – and the long-term impact of these fluctuations is always negative. Therefore, a wildlife population that has been reduced in numbers will become even smaller through this fundamental principle of wildlife biology. Furthermore, our understanding of this process provides an important backdrop to considerations of the impact of human activities that may, on the surface, appear relatively benign to larger and more stable wildlife populations. This self-reinforcing feedback loop, first coined the "extinction vortex" in the mid-1980's, is the cornerstone principle underlying our understanding of the dynamics of wildlife population extinction.

Once wildlife biologists have gone out into the field and collected data on a population's demography and used these data to calculate its current rate of growth (and how this rate may change over time), we now have at our disposal an extremely valuable source of information that can be used to predict the *future* rates of population growth or decline under conditions that may not be so favorable to the wildlife population of interest. For example, consider a population of primates living in a section of largely undisturbed Amazon rain forest that is now opened up to development by logging interests. If this development is to go ahead as planned, what will be the impact of this activity on the animals themselves, and the trees on which they depend for food and shelter? And what kinds of alternative development strategies might reduce the risk of primate population decline and extinction? To try to answer this question, we need two additional sets of information: 1) a comprehensive description of the proposed forest development plan (how will it occur, where will it be most intense, for what period of time, etc.) and 2) a detailed understanding of how the proposed activity will impact the primate population's demography (which animals will be most affected, how strongly will they be affected, will animals die outright more frequently or simply fail to reproduce as often, etc.). With this information in hand, we have a vital component in place to begin our PVA.

Next, we need a predictive tool – a sort of crystal ball, if you will, that helps us look into the future. After intensive study over nearly three decades, conservation biologists have settled on the use of computer simulation models as their preferred PVA tool. In general, models are simply any simplified representation of a real system. We use models in all aspects of our lives; for example, road maps are in fact relatively simple (and hopefully very accurate!) 2-dimensional representations of complex 3-dimensional landscapes we use almost every day to get us where we need to go. In addition to making predictions about the future, models are very helpful for us to: (1) extract important trends from complex processes, (2) allow comparisons among different types of systems, and (3) facilitate analysis of processes acting on a system.

Recent advances in computer technology have allowed us to create very complex models of the demographic processes that define wildlife population growth. But at their core, these models attempt to replicate simple biological functions shared by most all wildlife species: individuals are born, some grow to adulthood, most of those that survive mate with individuals of the opposite sex and then give birth to one or more offspring, and they die from any of a wide variety of causes. Each species may have its own special set of circumstances – sea turtles may live to be 150 years old and lay 600 eggs in a single event, while a chimpanzee may give birth to just a single offspring every 4-5 years until the age of 45 – but the fundamental biology is the same. These essential elements of a species' biology can be incorporated into a computer program, and when combined with the basic rules for living and the general characteristics of the population's surrounding habitat, a model is created that can project the demographic behavior of our real observed population for a specified period of time into the future. What's more, these models can explicitly incorporate random fluctuations in rates of birth and death discussed earlier. As a result, the models can be much more realistic in their treatment of the forces that influence population dynamics, and in particular how human activities can interact with these intrinsic forces to put otherwise relatively stable wildlife populations at risk.

Many different software packages exist for the purposes of conducting a PVA. Perhaps the most widely-used of these packages is *VORTEX*, developed by the IUCN Conservation Breeding Specialist Group (CBSG) for use in both applied and educational environments. *VORTEX* has been used by CBSG and other conservation biologists for more than 15 years and has proved to be a very useful tool for helping make more informed decisions in the field of wildlife population management.

Strengths and Limitations of the PVA Approach

When considering the applicability of PVA to a specific issue, it is vitally important to understand those tasks to which PVA is well-suited as well as to understand what the technique is not well-designed to deliver. With this enhanced understanding will also come a more informed public that is better prepared to critically evaluate the results of a PVA and how they are applied to the practical conservation measures proposed for a given species or population.

The dynamics of population extinction are often quite complicated, with numerous processes impact the dynamics in complex and interacting ways. Moreover, we have already come to appreciate the ways in which demographic rates fluctuate unpredictably in wildlife populations, and the data needed to provide estimates of these rates and their annual variability are themselves often uncertain, i.e., subject to observational bias or simple lack of detailed study over relatively longer periods of time. As a result, the elegant mental models or the detailed mathematical equations of even the most gifted conservation biologist are inadequate for capturing the detailed nuances of interacting factors that determine the fate of a wildlife population threatened by human activity. In contrast, simulation models can include as many factors that influence population dynamics as the modeler and the end-user of the model wish to assess. Detailed interactions between processes can also be modeled, if the nature of those interactions can be specified. Probabilistic events can be easily simulated by computer programs, providing output that gives both the mean expected result and the range or distribution of possible outcomes.

PVA models have also been shown to stimulate meaningful discussion among field biologists in the subjects of species biology, methods of data collection and analysis, and the assumptions that underlie the analysis of these data in preparation for their use in model construction. By making the models and their underlying data, algorithms and assumptions explicit to all who learn from them, these discussions become a critical component in the social process of achieving a shared understanding of a threatened species' current status and the biological justification for identifying a particular management strategy as the most effective for species conservation. This additional benefit is most easily recognized when PVA is used in an interactive workshop-type setting, such as the Population and Habitat Viability Assessment (PHVA) workshop designed and implemented by CBSG.

Perhaps the greatest strength of the PVA approach to conservation decision-making is related to what many of its detractors see as its greatest weakness. Because of the inherent uncertainty now known to exist in the long-term demography of wildlife populations (particularly those that are small in size), and because of the difficulties in obtaining precise estimates of demographic rates through extended periods of time collecting data in the field, accurate predictions of the future performance of a threatened wildlife population are effectively impossible to make. Even the most respected PVA practitioner must honestly admit that an accurate prediction of the number of mountain gorillas that will roam the forests on the slopes of the eastern Africa's Virunga Volcanoes in the year 2075, or the number of polar bears that will swim the warming waters above the Arctic Circle when our great-grandchildren grow old, is beyond their reach. But this type of difficulty, recognized across diverse fields of study from climatology to gambling, is nothing new: in fact, the Nobel Prize-winning physicist Niels Bohr once said "Prediction is very difficult, especially when it's about the future." Instead of lamenting this inevitable quirk of the physical world as a fatal flaw in the practice of PVA, we must embrace it and instead use our very cloudy crystal ball for another purpose: to make **relative**, rather than **absolute**, predictions of wildlife population viability in the face of human pressure.

The process of generating relative predictions using the PVA approach is often referred to as sensitivity analysis. In this manner, we can make much more robust predictions about the relative response of a simulated wildlife population to alternate perturbations to its demography. For example, a PVA practitioner may not be able to make accurate predictions about how many individuals of a given species may persist in 50 years in the presence of intense human hunting pressure, but that practitioner can speak with considerably greater confidence about the relative merits of a male-biased hunting strategy compared to the much more severe demographic impact typically imposed by a hunting strategy that prefers females. This type of comparative approach was used very effectively in a PVA for highly threatened populations of tree kangaroos (*Dendrolagus* sp.) living in Papua New Guinea, where adult females are hunted preferentially over their male counterparts. Comparative models showing the strong impacts of such a hunting strategy were part of an important process of conservation planning that led, within a few short weeks after a participatory workshop including a number of local hunters (Bonnaccorso et al., 1998), to the signing of a long-term hunting moratorium for the most critically endangered species in the country, the tenkile or Scott's tree kangaroo (*Dendrolagus scottae*).

PVA models are necessarily incomplete. We can model only those factors which we understand and for which we can specify the parameters. Therefore, it is important to realize that the models often underestimate the threats facing the population, or the total risk these threats collectively impose on the population of interest. To address this limitation, conservation biologists must try to engage a diverse body of experts with knowledge spanning many different fields in an attempt to broaden our understanding of the consequences of interaction between humans and wildlife.

Additionally, models are used to predict the long-term effects of the processes presently acting on the population. Many aspects of the situation could change radically within the time span that is modeled. Therefore, it is important to reassess the data and model results periodically, with changes made to the conservation programs as needed (see Lacy and Miller (2002), Nyhus et al. (2002) and Westley and Miller (2003) for more details).

Finally, it is also important to understand that a PVA model by itself does not define the goals of conservation planning of a given species. Goals, in terms of population growth, probability of persistence, number of extant populations, genetic diversity, or other measures of population performance must be defined by the management authorities before the results of population modeling can be used.

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APPENDIX L

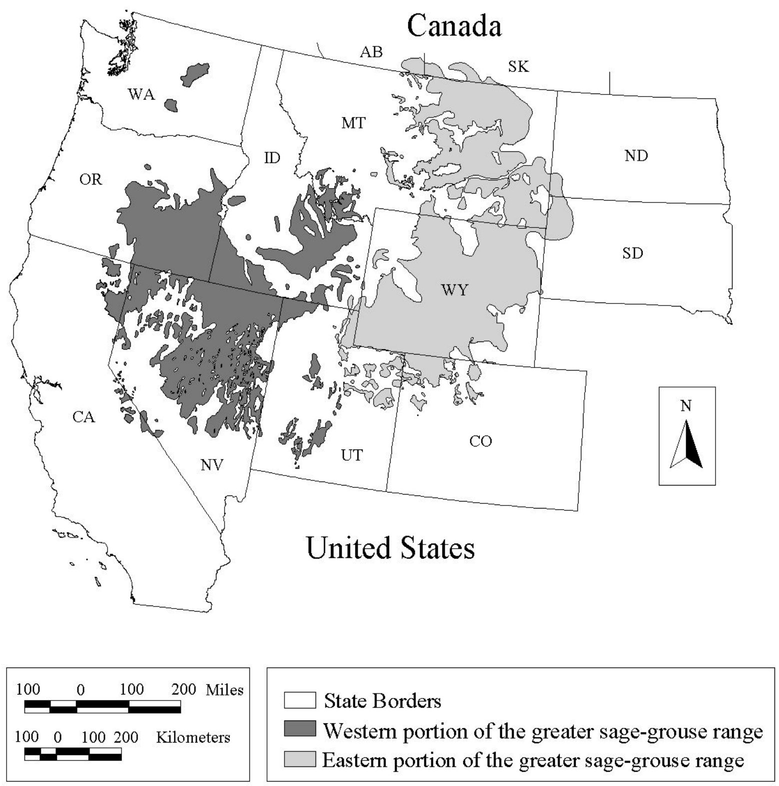
THREATS RANKING FOR GrSG

Relative ranking of threat factors for the Greater sage-grouse (Deibert 2005)

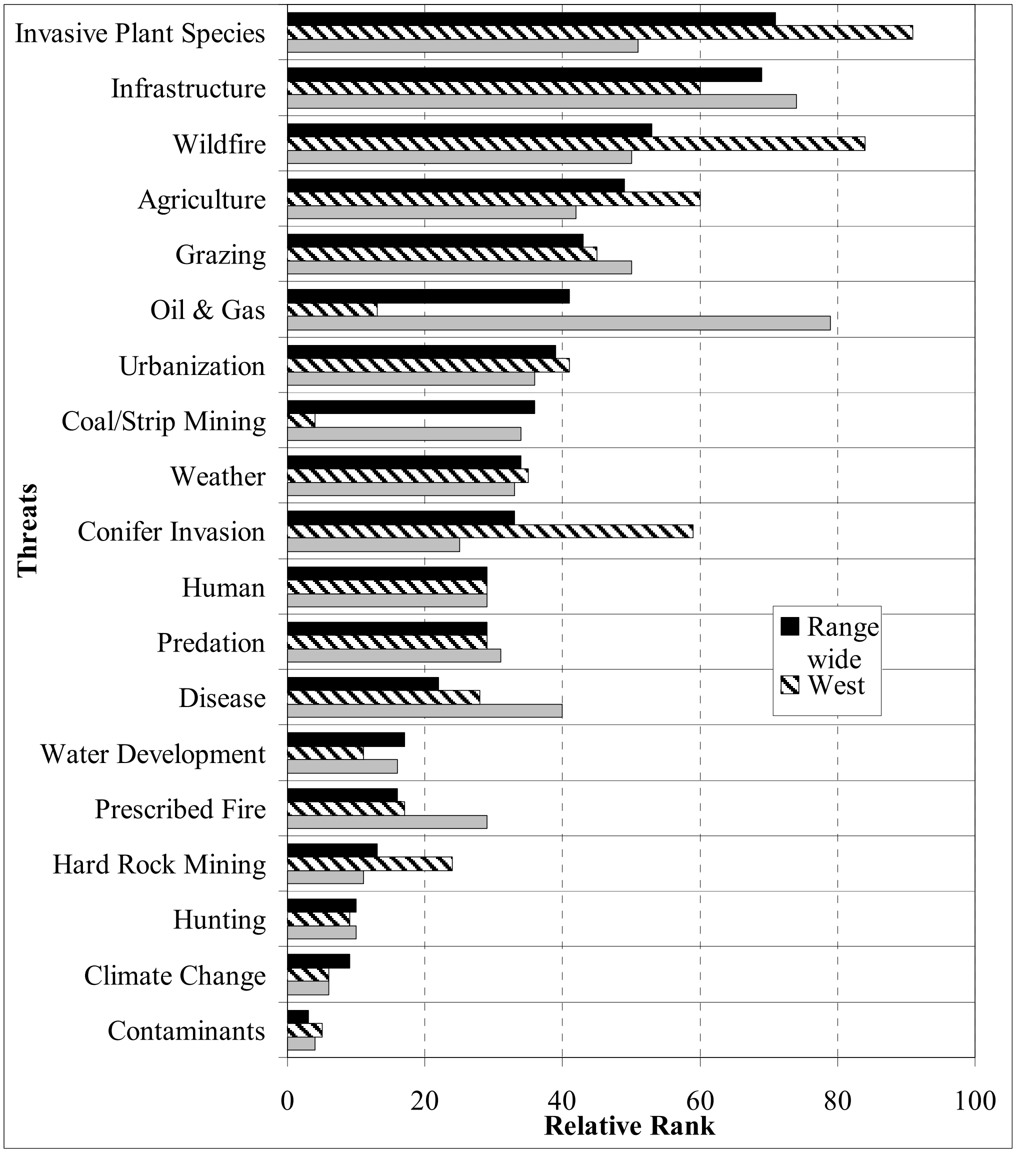
On January 12, 2005, the U.S. Fish and Wildlife Service (Service) published a not warranted decision for the greater sage-grouse, meaning that the bird will not be listed as a threatened or endangered species under the Endangered Species Act of 1973, as amended at this time. This decision culminated from review of the scientific literature, unpublished data and other information from other Federal agencies, States, private industry and individuals, and information on all Federal, State, or local conservation efforts currently underway or planned for either the greater sage-grouse or its habitats. The available information was extensive and covered all aspects of the species biology, sagebrush ecosystems, and potential threats to both. Despite the volume of information, substantial gaps and uncertainty remain in the scientific community's knowledge of all the factors that may affect sage-grouse populations across such a wide geographical range encompassing major ecological differences in sagebrush habitats. Further, scientific knowledge of how the species may respond to those factors over time is incomplete. For these reasons, the Service requested input from a panel of scientific experts outside the agency to assist in making a reasonable projection of the species' potential extinction risk. The panel consisted of experts in sage-grouse biology and ecology, sagebrush community ecology, and range ecology and management. The panel's resulting estimates of extinction risks were one tool used by the Service to make their final determination.

One of the initial exercises in estimating the risk of extinction was to identify threats to the species and its habitat. An initial list of threats was generated from the synthesis of biological information the Service prepared as part of the listing analysis. This list was modified through a discussion among the panelists. To better understand the impact of these threats to the survival of the species, each expert assigned a relative rank to each threat within each of three different geographical areas. These included the eastern and western portion of the range of the greater sage-grouse and the whole range of the species (Figure 1). Dividing the range of the species into an eastern and western region for the purposes of the expert panel exercises was intentional to facilitate understanding of the importance of the various threats to the species at different geographical scales. This geographical separation was only used to assess potential risk factors to the species, and was not based on distinctions between populations of sage-grouse. The separation was used only for purpose of the panel exercise.

Figure 1. Current distribution of greater sage-grouse in North America (AB = Alberta, CA = California, CO = Colorado, ID = Idaho, MT = Montana, ND = North Dakota, NV = Nevada, OR = Oregon, SD = South Dakota, SK = Saskatchewan, UT = Utah, WA = Washington, WY = Wyoming)



The following bar chart is the result of the threat ranking described above. It is being presented here only as a tool to facilitate discussion amongst those involved in conservation planning efforts for sage-grouse and sagebrush ecosystems. While it reflects the opinion of experts in sage-grouse and sagebrush ecology, these rankings were identified at large scales. These rankings are not assumed to be applicable to every location. Therefore it is very important to use local information when planning conservation efforts.



Key: ■ = Rangewide ▧ = Western □ = Eastern

- Infrastructure includes fences, roads, powerlines, communication towers, and pipelines, developed for any purpose
- Agriculture includes activities primarily associated with farming.
- Grazing includes all activities primarily associated with grazing.
- Weather refers to short time events, including but not limited to late season snowstorms, drought, etc. Climate change refers to long-term, permanent weather changes, usually occurring over a period of 100 years of more.
- Conifer invasion primarily refers to pinyon/juniper
- Human refers to an increased human presences in sagebrush ecosystems from recreational, residential, and resource development activities .

APPENDIX M

SCIENTIFIC NAMES OF ORGANISMS MENTIONED IN THE CCP

Table M-1. Common and scientific names of birds, mammals, reptiles, and insects referred to in the CCP.

Birds	
Common Name	**Scientific Name**
American crow	*Corvus brachyrhynchos*
American kestrel	*Falco sparverius*
Attwater's prairie chicken	*Tympanuchus cupido attwateri*
black-billed magpie	*Pica pica*
Clark's nutcracker	*Nucifraga columbiana*
common raven	*Corvus corax*
Cooper's hawk	*Accipiter cooperii*
ferruginous hawk	*Buteo regalis*
golden eagle	*Aquila chrysaetos*
greater prairie chicken	*Tympanuchus cupido*
greater sage-grouse	*Centrocercus urophasianus*
great-horned owl	*Bubo virginianus*
grey partridge	*Perdix perdix*
Gunnison sage-grouse	*Centrocercus minimus*
gyrfalcon	*Falco rusticolus*
lesser prairie-chicken	*Tympanuchus pallidicinctus*
merlin	*Falco columbarius*
northern bobwhite	*Colinus virginianus*
northern goshawk	*Accipiter gentiles*
northern harrier	*Circus cyaneus*
ring-necked pheasant	*Phasianus colchicus*
red-tailed hawk	*Buteo jamaicensis*
scrub jay	*Aphelocoma californica*
sharp-tailed grouse	*Tympanuchus phasianellus*
Swainson's hawk	*Buteo swainsoni*
Mammals	
Common Name	**Scientific Name**
badger	*Taxidea taxus*
bobcat	*Felis rufus*
cheetah	*Acinonyx jubatus*
cottontail rabbit	*Sylvilagus* spp.
coyote	*Canis latrans*
elk	*Cervus elaphus*
ground squirrel	*Spermophilus* spp.
jackrabbit	*Lepus* spp.
mule deer	*Odocoileus hemionus*
pronghorn antelope	*Antilocapra americana*
raccoon	*Procyon lotor*
red fox	*Vulpes vulpes*
Richardson's ground squirrel	*Spermophilus richardsonii*
striped skunk	*Mephitis mephitis*

Table M-1. Common and scientific names of birds, mammals, reptiles, and insects referred to in the CCP.

weasel	*Mustela* spp.
Reptiles	
Common name	**Scientific Name**
gopher snake	*Pituophis catenifer*
prairie rattlesnake	*Crotalus viridis*
Insects	
Common name	**Scientific Name**
alfalfa weevil	*Hypera postica*
fruit flies	*Drosophila* spp.
Mormon cricket	*Anabrus simplex*
Russian wheat aphid	*Diuraphis noxia*

Table M-2. Common and scientific names of herbaceous and woody plants referred to in the CCP.

Herbaceous Plants	
Common Name	**Scientific Name**
alfalfa	*Medicago* spp.
annual wheatgrass	*Eremopyrum triticeum*
arrowleaf balsamroot	*Balsamorhiza sagittata*
balsamroot	*Balsamorhiza* spp.
basin wildrye	*Leymus cinereus*
black henbane	*Hyoscyamus niger*
blue grama	*Bouteloua gracilis*
bluegrass	*Poa* spp.
bulbous bluegrass	*Poa bulbosa*
bull thistle	*Cirsium vulgare*
cheatgrass	*Bromus tecorum*
Canada thistle	*Cirsium arvense*
chicory	*Chichorium intybus*
Chinese clematis	*Clematis orientalis*
coast tarweed	*Madia sativa*
common burdock	*Arctium minus*
common dandelion	*Taraxacum officinale*
common mullein	*Verbascum thapsus*
common tansy	*Tanacetum vulgare*
corn chamomile	*Anthemis arvensis*
Dalmatian toadflax	*Linaria dalmatica*
dame's rocket	*Hesperis matronalis*
diffuse knapweed	*Centaurea diffusa*
Dyer's woad	*Isatis tinctoria*
elk sedge	*Carex garberi*
field bindweed	*Convolvulus arvensis*
flax	*Linum* spp.
fleabane	*Erigeron* spp.
globemallow	*Sphaeralcea* spp.
halogeton	*Halogeton* spp.
hawksbeard	*Crepis* spp.
hoary cress	*Cardaria* spp.
hound's tongue	*Cynoglossum officinale*
Indian Paintbrush	*Castilleja* spp.
jointed goatgrass	*Aegilops cylindrical*
knapweed	*Centaurea*
leafy spurge	*Euphorbia esula*
lupine	*Lupinus* spp.
mariposa lily	*Calochortus* spp.
mayweed chamomile	*Anthemis cotula*

Table M-2. Common and scientific names of herbaceous and woody plants referred to in the CCP.

meadow knapweed	*Centauera debeauxii*
milkvetch	*Astragalus* spp.
musk thistle	*Carduus nutans*
needlegrass	*Stipa comata*
orange hawkweed	*Hieracium aurantiacum*
oxeye daisy	*Leucanthemum vulgare*
penstemon	*Penstemon* spp.
pepperweed	*Lepidium* spp.
perennial pepperweed	*Lepidium latifolium*
plumeless thistle	*Carduus* spp.
prickly lettuce	*Lactuca serriola*
purple loosestrife	*Lythrum salicaria*
Rocky Mountain bee plant	*Cleome serrulata*
rush skeletonweed	*Chondrilla juncea*
Russian knapweed	*Centaurea repens*
Russian olive	*Elaeagnus angustifolia*
salsify	*Tragopogon* spp.
scentless chamomile	*Matricaria* spp.
scotch thistle	*Onopordum acanthium*
small burnet	*Sanguisorba minor*
spotted knapweed	*Centaurea stoebe*
sweet clover	*Melilotus* spp.
whitetop	*Cardaria* spp.
wild caraway	*Carum carvi*
yellow starthistle	*Centaurea solstitialis*
yellow toadflax	*Linaria vulgaris*
Woody Plants	
(quaking) aspen	*Populus tremuloides*
Basin big sagebrush	*Artemisia tridentata tridentata*
big sagebrush	*Artemisia tridentata*
bitterbrush	*Purshia* spp.
black sagebrush	*Artemisia nova*
chokecherry	*Prunus virginiana*
curl-leaf mountain mahogany	*Cercocarpus ledifolius*
Douglas fir	*Pseudotsuga menziesii*
Engelmann spruce	*Picea engelmannii*
fringed sagebrush	*Artemesia frigida*
Gambel oak	*Quercus gambelii*
greasewood	*Sarcobatus* spp.
horsebrush	*Tetradymia* spp.
juniper	*Juniperus* spp.
(little) Utah juniper	*Juniperus osteosperma*
lodgepole pine	*Pinus contorta*
low sagebrush	*Artemisia arbuscula*

Table M-2. Common and scientific names of herbaceous and woody plants referred to in the CCP.

Mormon tea	*Ephedra viridis*
mountain big sagebrush	*Artemisia tridentata vaseyana*
mountain mahogany	*Cercocarpus* spp.
mountain snowberry	*Symphoricarpos oreophilus*
piñon pine	*Pinus edulis*
piñon- juniper	*Pinus edulis- Juniperus communis*
ponderosa pine	*Pinus ponderosa*
rabbitbrush	*Chrysothamnus* spp. and/or *Ericameria* spp.
Rocky Mountain juniper	*Juniperus scopulorum*
rubber rabbitbrush	*Ericameria nauseosa (Chrysothamnus)*
sagebrush	*Artemisia* spp.
saltbush	*Atriplex* spp.
saltcedar	*Tamarix ramosissima*
Saskatoon serviceberry	*Amelanchier alnifolia*
serviceberry	*Amelanchier* spp.
shadscale (saltbrush)	*Artiplex confertifolia*
silver sagebrush	*Artemisia cana*
small rabbitbrush	*Chrysothamnus viscidiflorus*
snakeweed and broom snakeweed	*Gutierrezia sarothrae*
snowberry	*Symphoricarpos oreophilus*
spiny hopsage	*Grayia spinosa*
squaw apple	*Peraphyllum ramosissimum*
squawbush	*Peraphyllum ramosissimum*
sticky rabbitbrush	*Chrysothamnus* spp.
tamarisk	*Tamarix* spp.
winterfat	*Krascheninnikovia lanata (Ceratoides)*
Wyoming big sagebrush	*Artemisia tridentata wyomingensis*

APPENDIX N

DEFINITIONS OF ACRONYMS USED IN THE CCP

and

DESCRIPTIONS OF "RESPONSIBLE PARTIES" LISTED IN CONSERVATION STRATEGY

Acronym or Responsible Group	Definition
AIC	Akaike Information Criteria, the maximum log-likelihood for a model
AM	Adaptive management
APD	application for permit to drill
APHIS	Animal and Plant Health Inspection Service (USDA)
ASAP	as soon as possible
BLM	Bureau of Land Management
BMPs	Best management practices
CBM	Coal bed methane
CBSG	Conservation Breeding Specialist Group
CCA	Colorado Cattlemen's Association
CCAA	Candidate Conservation Agreement with Assurances
CCI	Colorado Counties, Inc.
CCP	Colorado Greater Sage-grouse Conservation Plan (this plan)
CDA	Colorado Department of Agriculture
CDOT	Colorado Department of Transportation
CDOW	Colorado Division of Wildlife
CDPHE	Colorado Department of Health and Environment
CDWR	Colorado Division of Water Resources
CFB	Colorado Farm Bureau
CGFC	Colorado Game and Fish Commission (now the CDOW) **S**
CHIP	Cooperative Habitat Improvement Program (CDOW program)
C.I.	Confidence interval (e.g., 95% confidence interval)
Cities	City or Town Governments
CNHP	Colorado Natural Heritage Program
COA	Conditions of approval (protection or mitigating measures necessary for approval of permits and authorization)
COGCC	Colorado Oil and Gas Conservation Commission
Colorado Hawking Club	State falconry club; affiliated with the North American Falconers' Association
County Governments	Includes several aspects of county governments, such as land use planning, pest control agents, weed control, and county commissioners.
CREA	Colorado Rural Electric Association
CRP	Conservation Reserve Program (FSA Program)
CSCP	Colorado Species Conservation Partnership Program (CDOW program)
CSFS	Colorado State Forest Service
CSP	Conservation Security Program (NRCS program)
CSTG	Columbian sharp-tailed grouse
CSU Extension	Colorado State University Extension Service

Acronym or Responsible Group	Definition
CVCP	Colorado Vegetation Classification Project, a GIS data set used by CDOW
CWF	Colorado Wildlife Federation
DAU	Data Analysis Unit (a geographic area used by CDOW in big game management plans)
Developers	Housing developers
DNA	Deoxyribonucleic acid; molecule that carries the genetic information in a cell
DNR	Colorado Department of Natural Resources
DPOR	Colorado Division of Parks and Outdoor Recreation
DRMS	Colorado Division of Reclamation, Mining and Safety
EA	Environmental Assessment
EBI	Environmental Benefits Index
EIS	Environmental Impact Statement
EQIP	Environmental Quality Incentives Program (NRCS program)
ESA	Endangered Species Act
FAN	Final Abandonment Notice
FLMPA	Federal Land Management Policy Act
FO	Field office (BLM)
FRP	Federal recovery plan
FRPP	Farm and Ranchland Protection Program (NRCS program)
FSA	Farm Services Agency
FSM	Forest Service Manual
FTE	Full-time equivalent (one person working full-time)
GBCP	Gunnison Basin Conservation Plan (see GBCP 1997 in Literature Cited)
GIS	geographic information system
GOCO	Great Outdoors Colorado
GRP	Grasslands Reserve Program (NRCS program)
GrSG	greater sage-grouse
GSFO	Glenwood Springs Field Office (BLM)
GuSG	Gunnison sage-grouse
HB	House Bill
HEP	Habitat Evaluation Procedure (a USFWS program)
HPP	Habitat Partnership Program (CDOW program)
HIS	Habitat Suitability Index, a measure of habitat, used in HEP
Industry	Oil, gas, mining, or utility industries, depending on context; see also Utility Companies
KFO	Kremmling Field Office (BLM)
Land Trusts	Non-profit corporations that protect conservation resources
LIP	Landowner Incentive Program (USFWS program)
LUP	Land use plans

Acronym or Responsible Group	Definition
LWGs	Local work groups
MFRI	Mean fire return interval
MOU	Memorandum of Understanding
MP	Middle Park GrSG Population
MPCP	Middle Park Conservation Plan (see MPCP 2001 in Literature Cited)
MPSGC	Middle Park Sage-grouse Committee
mtDNA	Mitochondrial DNA
MUSY	Multiple Use – Sustained Yield Act (USFS)
MWR	Meeker – White River GrSG Population
MZ	Management Zone: an abbreviation for the management zones that exist in the NWCO GrSG population area
N/A	Not applicable
NAGP	North American Grouse Partnership
NEPA	National Environmental Policy Act
NESR	Northern Eagle – Southern Routt Counties GrSG population
NESRCP	Northern Eagle – Southern Routt Counties Conservation Plan (see NESRCP 2004 in Literature Cited)
NFMA	National Forest Management Act
NFS	National Forest System (managed by the USFS)
NGOs	Non-governmental organizations, including local land trusts, The Nature Conservancy, and other non-profit groups
NOI	Notice of intent
NOS	Notice of staking
NP	North Park GrSG population
NPCP	North Park Greater Sage-grouse Conservation Plan (See NPCP 2001 in Literature Cited)
NPHPP	North Park Habitat Partnership Committee
NPS	National Park Service
NPSGWG	North Park Sage Grouse Working Group
NRCS	Natural Resources Conservation Service
NSO	No surface occupancy (a stipulation on some oil and gas leases)
NWCO	Northwest Colorado GrSG Population
NWCOCP	Northwest Colorado Conservation Plan (see NWCOCP 2006 in Literature Cited)
NWR	National Wildlife Refuge
NWRC	National Wildlife Research Center (part of APHIS)
NWRS	National Wildlife Refuge System (USFWS)
O&G	Oil and Gas
OMP	Owl Mountain Partnership
Other Research Institutions	Non-university research institutions

Acronym or Responsible Group	Definition
PECE	Policy for Evaluation of Conservation Efforts When Making Listing Decisions (USFWS)
PEIS	Programmatic Environmental Impact Statement
PPR	Parachute – Piceance – Roan GrSG Population
PPRCP	Parachute – Piceance – Roan Conservation Plan (see PPRCP 2008)
Private Landowners	Non-public landowners/managers
PVA	Population viability analysis
RCP	Gunnison Sage-grouse Rangewide Conservation Plan
RD&D	Research, Development, and Demonstration (a type of BLM lease)
RFD	Reasonable Foreseeable Development
RMP	Resource Management Plan (used by BLM)
ROW	Right-of-way
RPA	Forest and Rangeland Renewable Resource Planning Act (USFS)
SC	Colorado Greater Sage-grouse Conservation Plan Steering Committee
SCD	Soil Conservation District(s)
SLB	Colorado State Land Board
SMP	Suggested Management Practices
SRM	Society for Range Management
SWA	State Wildlife Area
TNC	The Nature Conservancy
UCEPC	Upper Colorado Environmental Plant Center
UP	Uncompaghre Project
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
Utility companies	Includes local Rural Electric Associations, Excel Energy, and all other utility companies within the range of GrSG
Universities	Specifically, researchers and research programs at universities
WAFWA	Western Association of Fish and Wildlife Agencies
Water Conservation Districts	Non-profit organizations that coordinate funds to conserve local natural resources
WHIP	Wildlife Habitat Incentives Program (NRCS program)
WNV	West Nile Virus
WRFO	White River Field Office (BLM)
WRIS	Wildlife Resource Information System
WRP	Wetland Reserve Program (NRCS program)
WRRA	White River Resource Area (a BLM management area)