IV. ANALYSIS

The "Analysis" section is a collection of "tools" that may be used to help address some of the issues in GrSG conservation. Some of these are modeling or GIS exercises (e.g., "Population Viability Analysis", identification of "GrSG Habitat Linkages in Colorado", "Avoiding Impacts: the Refuge Concept: Preventing Impacts - Identifying Core Areas" regarding energy and mineral development), while others present a literature review and summary of the current knowledge of certain potential approaches to addressing issues (e.g., "Population Augmentation", "Off-site Mitigation of Impacts" for energy and mineral development). In this section we also develop population targets ("Colorado GrSG Population Management Zones").

A. Population Viability Analysis

Concepts and Principles

Population viability analysis (PVA) is a risk analysis tool that has been used for about 20 years by conservationists and biologists to predict the relative probability of extinction for a wildlife population under various management scenarios, in order to aid in decision-making for population management (Shaffer 1991, Boyce 1993, McCarthy et al. 2001, Reed et al. 2002). In most cases, PVA uses available population information to develop a model (a simplified representation of a real system) that simulates how the population functions (Shaffer 1991, Boyce 1993). The model can then be used to project various future scenarios and predict resulting outcomes for the population. The model may incorporate many factors that affect the status of a population, such as environmental stochasticity (e.g., normal variation in weather and available food supply), demographic stochasticity (e.g., normal variation in breeding success and survival), catastrophes (e.g., drought, disease), genetic stochasticity (e.g., inbreeding, genetic drift), and interaction among these factors (Gilpin and Soulé 1986, Shaffer 1991). These factors enter the life of an individual as events that occur with particular probabilities, rather than with absolute certainty, at any given time (see Appendix K, "Population Viability Analysis Report").

An individual with extensive knowledge of a population may have an idea, or "hypothesis" about how the population behaves, but this information is difficult to share with others and cannot be assessed objectively or quantitatively. Computer simulations are regularly used in PVA to allow for complex models that are explicitly stated and can be tested (Shaffer 1991, Appendix K, "Population Viability Analysis Report").

PVA is particularly effective in making "relative" predictions, such as how a population or species may be affected by various alternative management strategies, or the relative risk to different populations, allowing managers to prioritize conservation efforts among the populations (Beissinger and Westphal 1998, Boyce 2001, Ellner et al. 2002, McCarthy et al. 2003). Another strength of PVA is the complexity that it can accommodate; multiple factors and their interactions can be integrated into the process of evaluating a population's relative extinction risk (Shaffer 1991, McCarthy et al. 2003). In addition, sensitivity analysis can identify the parameters in the model (e.g., adult survival rate) that have the largest impacts on the modeled population (Reed et al. 2002). PVA results can be used to identify future research needs by exposing the parameters for which data are weakest or lacking (Reed et al. 2002), which is particularly important if sensitivity analysis shows those parameters are key to the population's persistence.

One of the criticisms of PVA is that the increasing availability of user-friendly PVA software allows some users to generate population persistence predictions without a full understanding of assumptions and limitations in the model, and while ignoring weaknesses in data supporting the model (Beissinger and Westphal 1998, Boyce 2001, Reed et al. 2002). "Absolute" predictions, such as a precise probability of population extinction, are not realistic, but relative predictions are more reliable (Beissinger and Westphal 1998, Ellner et al. 2002, McCarthy et al. 2003). Because a PVA uses a model, it will not present a complete picture of the system of interest, but an approximation of it, and results must be used with this in mind (Reed et al. 2002, McCarthy et al. 2003). PVA will likely be based in part on inadequate data (Beissinger and Westphal 1998, Boyce 2001), especially because data for populations at risk may be limited (Shaffer 1991, Boyce 1993) and the populations may be difficult to study. However, if the limitations are recognized, a PVA can offer an opportunity to direct future research towards (1) obtaining more reliable data; (2) developing more precise estimates of population parameters; (3) modifying the model to improve its performance; and (4) framing testable hypotheses about how the population/system functions (Boyce 1993, Beissinger and Westphal 1998, Reed et al. 1998, McCarthy et al. 2003). McCarthy et al. (2003:987) concluded that, "The process of parameter estimation, model construction, prediction, and assessment should be viewed as a cycle rather than a one-way street."

Current Model

Thus, as with many analytical tools, PVA can be very useful in the decision-making process for managing species at risk, but only if used properly (Boyce 1993, Beissinger and Westphal 1998, Ellner et al. 2002, McCarthy et al. 2003). We contracted with the Conservation Breeding Specialist Group (CBSG) to develop a PVA for GrSG. Dr. Philip Miller of CBSG used a simulation software program called *VORTEX* (Miller and Lacy 2003) to address a series of questions regarding GrSG in Colorado. The full report of this work is given in Appendix K. This section represents a summary of the key points regarding the analysis.

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

- Can we build simulation models with sufficient detail and precision that can accurately describe the dynamics of GrSG populations in Colorado?
- What are the primary demographic factors that drive growth of GrSG populations in Colorado?
- How vulnerable are small, fragmented populations of GrSG 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 GrSG populations in Colorado?

- What are the predicted impacts of current and potential future levels of mining and other surface activities on selected GrSG populations in Colorado?
- What are the predicted impacts of current and potential future levels of hunting on selected GrSG populations in Colorado?
- What are the predicted impacts of current and potential future levels of petroleum and natural gas development on selected GrSG populations in Colorado?
- Can mitigation to improve the productivity also improve the viability of GrSG populations in Colorado in the face of other anthropogenic processes?

VORTEX is a Monte Carlo model that simulates the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wild populations. It is an individual-based model that follows the fate of each animal in a theoretical population as the individual encounters various life and environmental events during a given year. These events occur with a user-specified probability, and the model will run for a user-specified number of consecutive years. By following the entire population, it is possible to estimate relative population extinction risk and loss of genetic diversity in a specified time period.

Baseline Parameters and Simulations

Demographic parameters used in the GrSG PVA included type of breeding system, age at first reproduction, several measures of reproductive success, sex ratio, mortality rates, and environmental carrying capacity. For the NESR and NWCO populations we also estimated GrSG dispersal, in order to model metapopulations. For each parameter, we used available data, primarily from Moffat County (NWCO population area: Hausleitner 2003; Zablan et al. 2003; and T. R. Thompson, unpublished data), and North Park (Peterson 1980). We chose a time interval of 50 years for population projections because we felt uncertainty at 100 years was too great to allow reasonable predictions.

Parameters that we did not incorporate in the PVA included effects of disease, inbreeding depression, and density-dependent reproduction. We have no data to determine which or how demographic rates will be affected by these factors. West Nile virus is a potential threat to GrSG (see "Disease and Parasites" issue section, pg. 103). However, our lack of knowledge about the disease precludes us from being able to make reasonable predictions at this time. West Nile virus should be included in future analyses as we learn more about the epidemiology of the virus. Inbreeding depression can potentially influence population parameters in small populations (see "Genetics: Small Populations", issue section, pg. 134); however, we currently have no data to evaluate whether inbreeding is a significant factor or whether there is a population size threshold at which inbreeding becomes significant (i.e., which GrSG populations might be at risk because of inbreeding).

We have no information that allows us to conclude GrSG demography is density-dependent, or to even estimate what effect population density might have on GrSG population dynamics. The model assumes that GrSG behavior (e.g., lek attendance) does not change during the model progression (even during dramatic declines), that other factors (e.g., nesting habitat) are unaffected, and that the population is ready for population growth even after significant impacts to the population.

We used the GrSG PVA to evaluate the relative risk of extinction for each population under the current conditions (i.e., the risk of extinction if nothing changes). Therefore, we concluded that a valid GrSG PVA should not include these potential factors until we have some reliable data that can be used to estimate how specific demographic parameters are influenced by the various factors.

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 projected the model forward to the present day, comparing the predicted trajectory with a trajectory estimated from population indices (see population estimation summary under "Conclusions", pg. 55). 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 Fig. 31. With the exception of the MWR population, all other simulation models appear to accurately predict the true population census within a reasonable degree of uncertainty. Given this degree of accuracy, the disparity between predicted population size and estimated population size (based on lek counts) in the MWR analysis is likely not an error in the simulation model but instead probably reflects the small number of leks included in the field counts, 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 GrSG population dynamics can be used with acceptable confidence in predicting the relative outcomes of alternative management scenarios for the species.

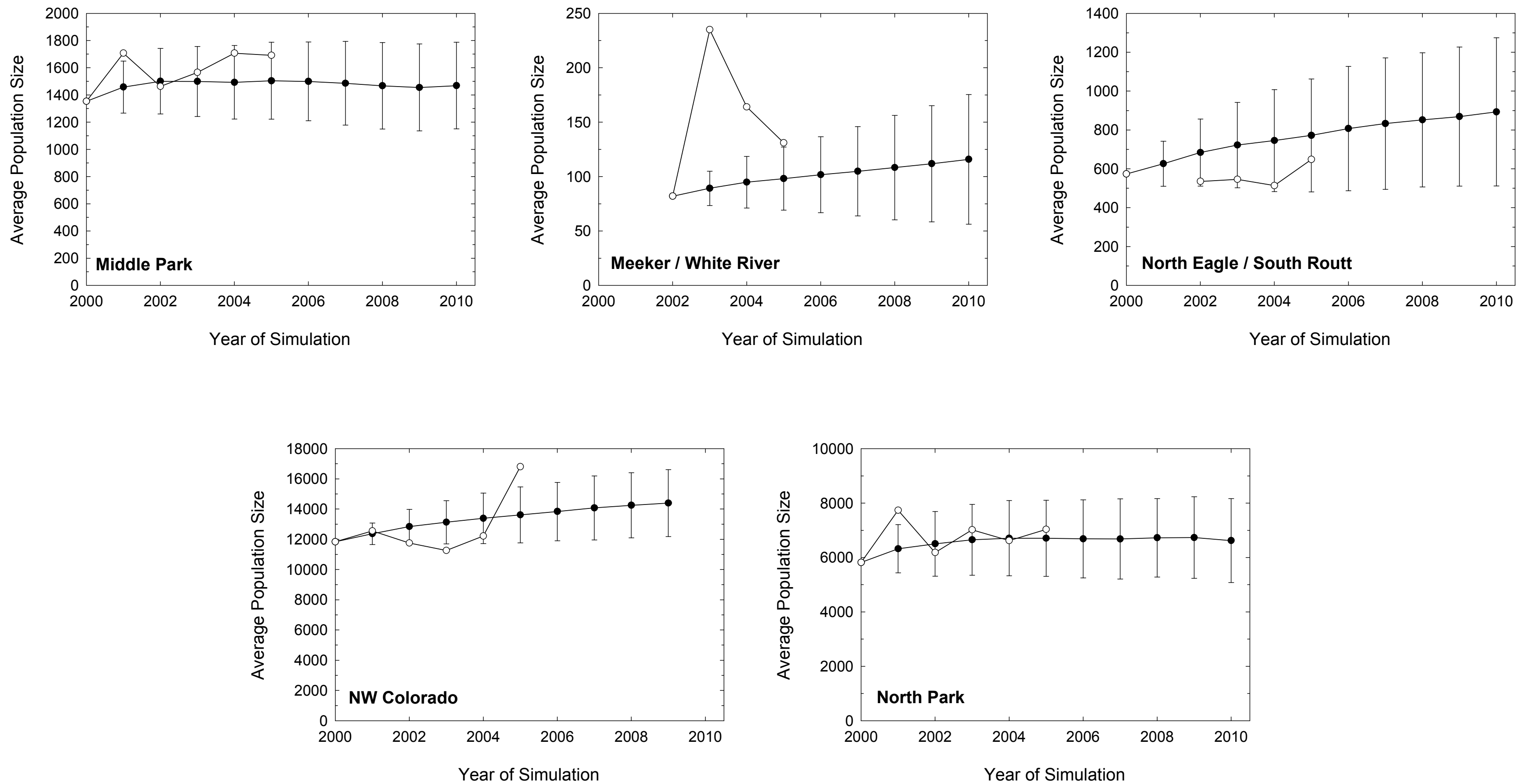


Fig. 31. Retrospective projections for simulated GrSG populations in Colorado. Filled symbols indicate population sizes predicted using the PVA platform *VORTEX*, while open symbols give "true" population size estimates derived from field counts. Analysis of the PPR population is not included here because adequate lek count data do not exist. See Appendix K for additional details on model construction and interpretation.

Baseline Model Results

The results of the baseline projections show no risk of extinction over the 50-year timeframe of the simulation, for all populations except MWR (Table 24 and Fig. 32). Each population displays long-term population growth values between 0.025 and 0.030. Consistent with the general theoretical expectations of small population biology, the MWR 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, since the underlying rates of mortality and reproduction are identical among all simulated populations studied here.

Table 24. Greater sage-grouse PVA: 50-year projections of baseline models for each population: r_s (SD) = the mean rate of stochastic population growth or decline (standard deviation); $P(E)_{50}$ = probability of population extinction after 50 years; $\underline{N_{50}}$ (SD) = mean (standard deviation) population size at the end of the simulation; $\underline{GD_{50}}$ = the gene diversity or expected heterozygosity of the extant populations, expressed as a percent of the initial gene diversity of the population. See Appendix K for additional information on model construction and parameterization.

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

Note that despite the robust levels of growth displayed for each population, the MP and NP 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.

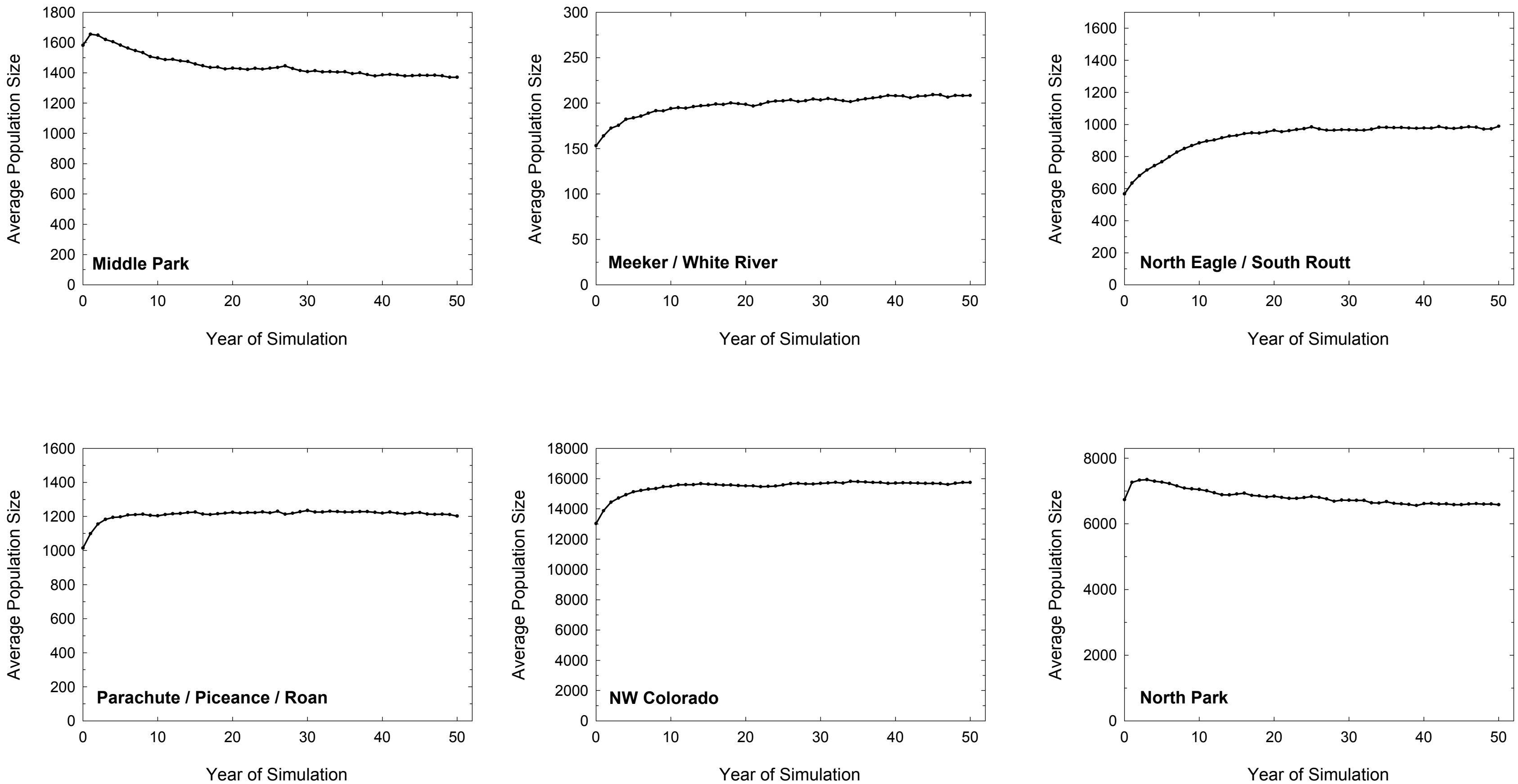


Fig. 32. Fifty-year prospective projections for the 6 GrSG populations in Colorado. See Appendix K for additional details on model construction and interpretation.

Sensitivity Analysis

During the development of the baseline input dataset, it quickly became apparent that a number of demographic characteristics of GrSG 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, can impair our ability to generate precise predictions of population dynamics with confidence. An analysis of the sensitivity of our models to this measurement uncertainty can 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 identified a set of parameters from the model whose estimate we see as considerably uncertain. We then developed proportional minimum and maximum values for these parameters, and for each parameter constructed 2 simulations, with the parameter set at its prescribed minimum or maximum value and all other parameters remaining at their baseline values. The results of these alternative models were then compared to that of our initial baseline model.

The results of the sensitivity analysis indicate that juvenile (chick) female mortality, clutch size, and adult female mortality are the parameters that, when changed, show the greatest degree of response in population growth rate (i.e., the greatest sensitivity). These parameters can then be targeted in subsequent field activities for more detailed research and/or demographic management.

Risk Analysis: Simulating the Impacts of Human Activity on GrSG Population Dynamics

Once the baseline demographic parameters were established, we examined the mechanisms through which specific human activities within GrSG habitat may influence the species' population dynamics in the future. Specifically, we investigated the potential impacts of housing development, surface mining, harvest, oil and natural gas development, and mitigation of reproductive success.

Housing Development and Surface Mining

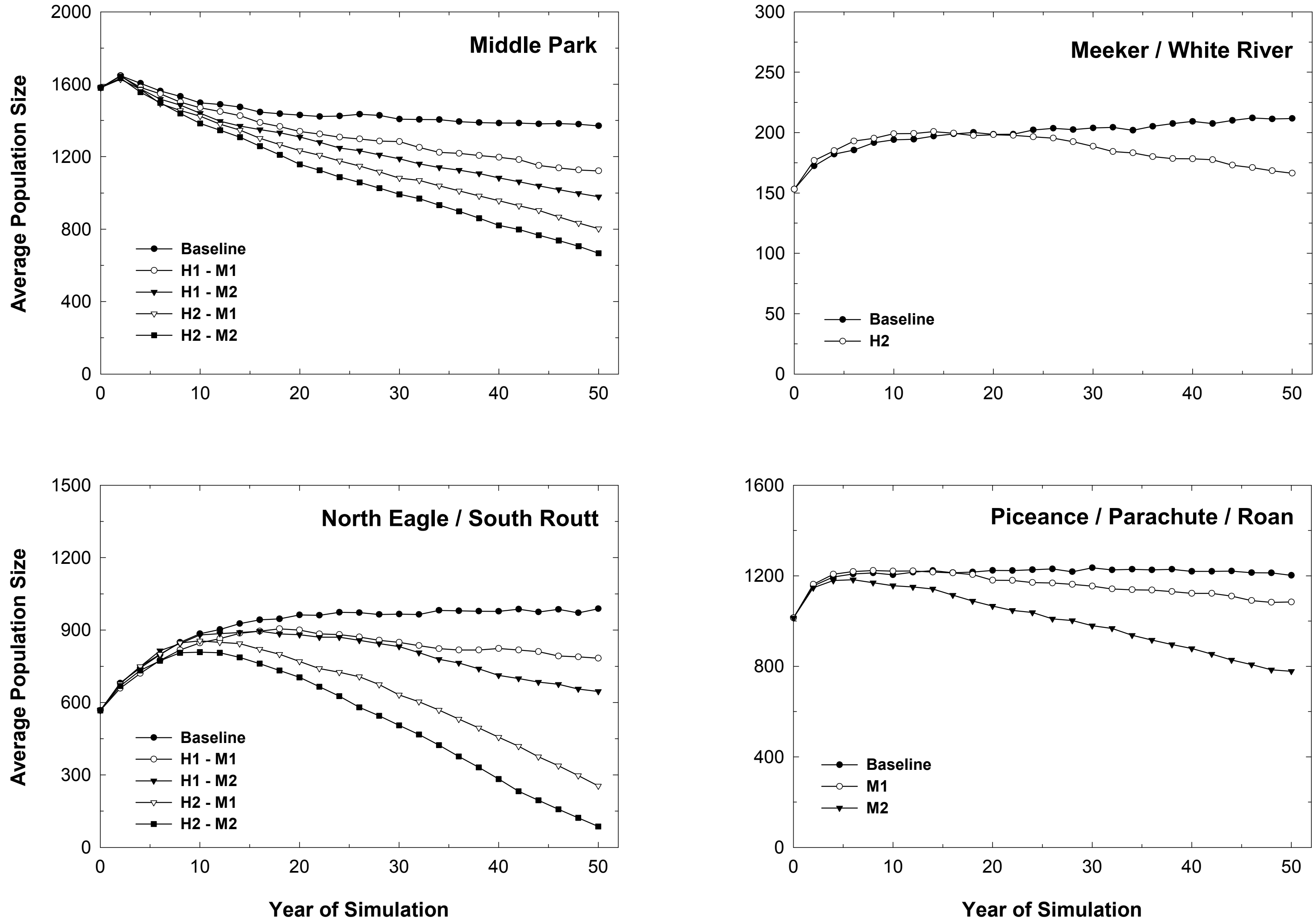
The primary assumption in our analysis of housing development and surface mining was that the construction of new homes or surface mines (e.g., gravel, oil shale; see "Energy and Mineral Development" issue section, pg. 109) will reduce the amount of suitable sagebrush habitat available to sage-grouse. This can be modeled in *VORTEX* through a gradual reduction in habitat carrying capacity, K. We identified the populations most likely to experience housing and mining impacts in the next 50 years. The populations included in the housing analysis were MWR, MP, and NESR, and for the surface mining analysis we examined MP, NESR, NWCO, and PPR.

Human population projections through 2020, associated estimates of average household size, and sagebrush habitat distribution were used to estimate the increase in new housing units within GrSG habitat (see also "Predicted Future Housing Development and GrSG Habitat Protection", pg. 268). Using these estimates, 2 different levels of housing intensity were developed.

For the surface mining analysis, GIS methods were used to identify GrSG 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. Detailed analysis for NWCO indicates that mining activity is relevant only for management zones 3C, 4B, 5, and 6.

In the combined results of housing and surface mining, all 4 population areas show some degree of GrSG population decline in the presence of the activities, with the lowest level seen in MWR and the greatest level of decline in NESR (Fig. 33; Note: the relative extent of sagebrush habitat loss for NWCO was so small that measurable population impact was negligible, and is thus not illustrated in Fig. 33). In MP, 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 NESR population 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 zone 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 GrSG habitat being lost over the time period of the simulation. This magnitude of decline, when combined with the small zone sizes and their inherent demographic instability, works to put the larger NESR metapopulation at a marked risk of extinction if conditions of habitat alteration reach predicted levels.

Fig. 33. Average projected size of simulated GrSG 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 intensity, respectively, as described in detail in Appendix K.



The overall risks of population extinction under these habitat modification scenarios may underestimate the true risk. None of the modeling scenarios includes meaningful levels of density dependence in either reproduction or mortality, other than the "truncation" 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 GrSG. 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 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 in the simulation for the NESR population. 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 GrSG populations.

Harvest

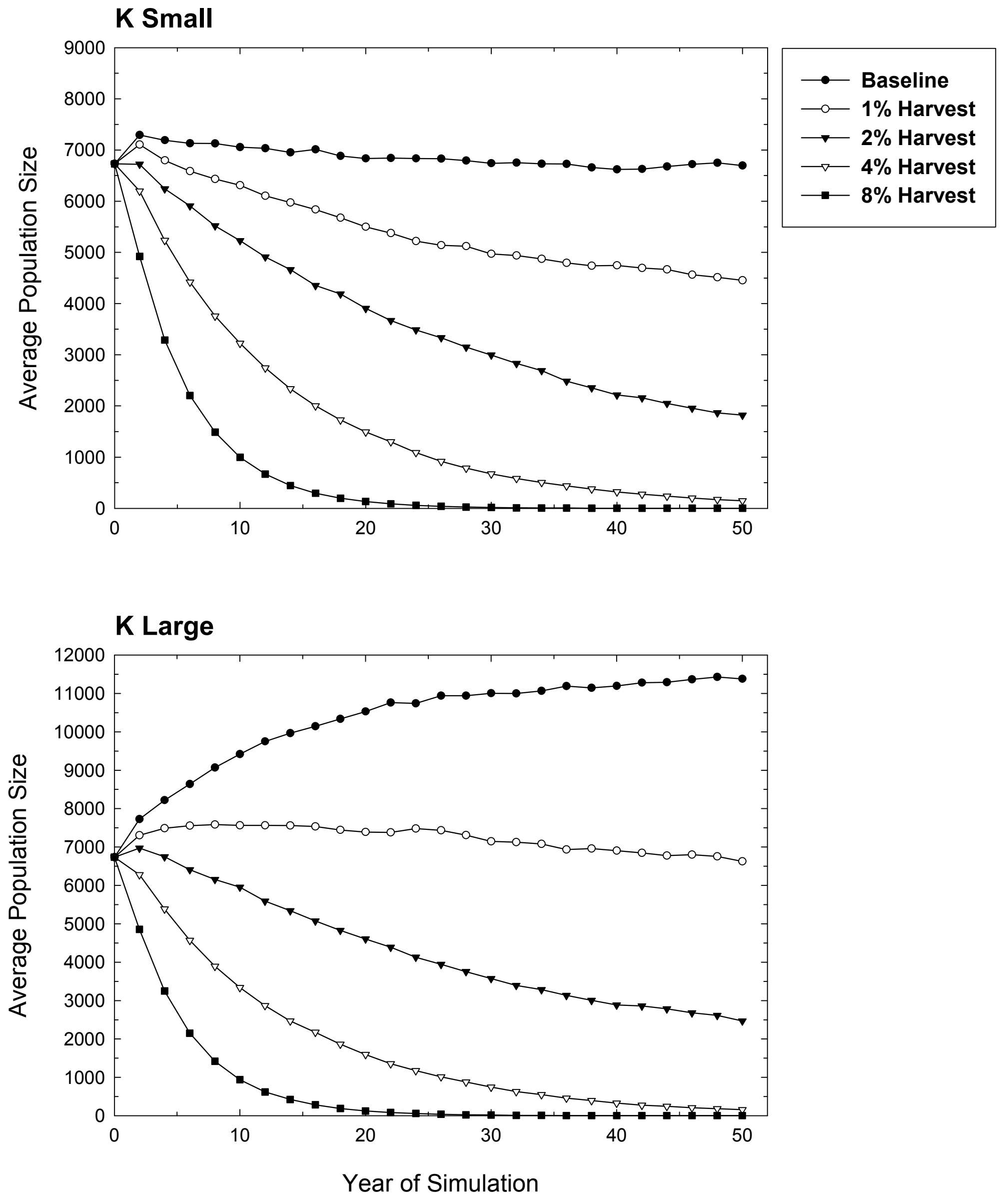
The primary assumption in the harvest analysis was that such a process will directly impact the mortality rates of affected GrSG age-sex classes (see also "Hunting" issue section, pg. 156). We focused on the NP population for this analysis. We used detailed data on harvest composition (based on wing receipts) from Jackson County (NP population), which date 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 2000-2004. 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 GrSG age-sex classes (the data showed no bias in age or sex of birds harvested), during each year of the simulation.

Results indicate 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 (Fig. 34). 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 NP population models. This carrying capacity, estimated to be about 8,300 individuals, might be low enough to drive populations to decline as they encounter the restriction to grow beyond the ceiling. To investigate this hypothesis, a second set of models was developed that effectively removed this restrictive ceiling by increasing carrying capacity K from 8,300 to 15,000 individuals.

The removal of the carrying capacity restriction allowed the baseline (unharvested) population to nearly double in size over the 50 years of the simulation (Fig. 34, bottom panel). 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 GrSG population will respond to additional hunting-based mortality.

An important assumption in these analyses is that our simulated harvest represents 100% additive mortality on top on natural mortality acting on the population (see "Hunting" issue section, pg. 156). 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 (a more likely scenario), which would serve to reduce the overall magnitude of added mortality on the population. There is considerable controversy on the degree of compensatory versus additive mortality in game species such as GrSG (see "Hunting" issue section, pg. 156).

Fig. 34. Average projected size of simulated NP GrSG population under different levels of harvest. Top panel: population projections in the presence of a restrictive carrying capacity set at 8,300 individuals; bottom panel: same projections when the restrictive carrying capacity is lifted (allowing essentially unrestricted population growth throughout the simulation). See Appendix K for more information on model construction and results.



Oil and Natural Gas Development

There are no data evaluating the effects of oil and gas development on GrSG in Colorado, so we based our estimate of impacts on 2 studies in Wyoming (Lyon and Anderson 2003, and especially Holloran 2005; see also "Energy and Mineral Development" issue section, pg. 109; "Energy and Mineral Development: Avoiding and/or Mitigating Impacts", pg. 292; and Appendix H, "Literature Review: Oil and Gas Development Impacts on Prairie Grouse"). We recognize that these studies were not designed to be predictive management tools. However, they do provide valuable insights into oil and gas impacts on sage-grouse under some development scenarios. We identified the NP, NWCO, and PPR populations as those likely to be affected by oil and gas development in the next 50 years. We identified and applied a possible demographic impact of oil and gas development (3 different levels), and evaluated 3 different scenarios of the future amount of development.

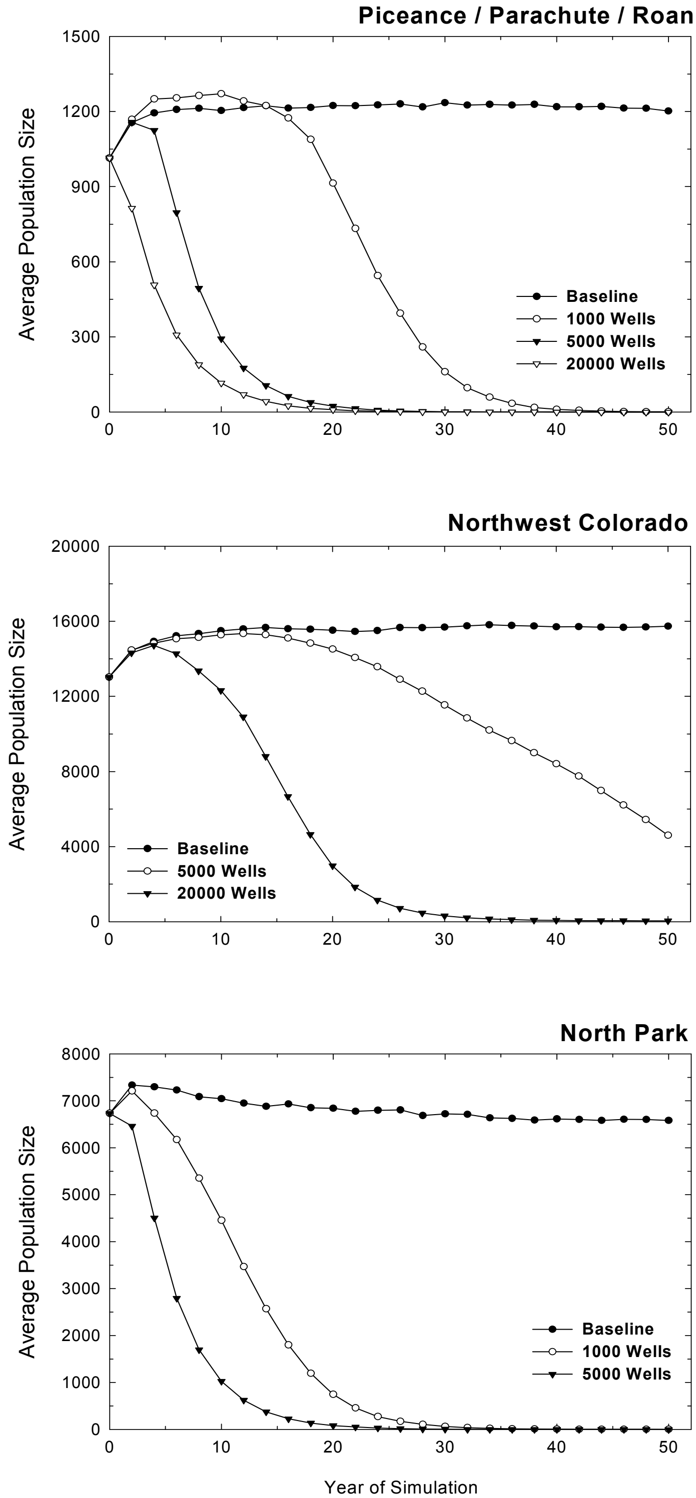
Specifically, we identified 3 levels of potential impact, based on density of oil and natural gas well pads. Leks with ≤8 wells within 2 miles were considered controls (impacts assumed to be minimal). For leks with >15 well pads within 2 miles, we increased adult female mortality by 20%, increased yearling female mortality by 6.4%, and decreased nest initiation by 24% (based on data in Holloran 2005). Leks with 8 - 15 wells/lek were considered to have intermediate levels of demographic impacts. For the "intermediate" leks 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.

Three future development scenarios (1,000; 5,000; and 20,000 additional wells) were intended to represent reasonable low, medium, and high levels of potential development over the 50-year life of the PVA model. For purposes of this modeling exercise we assumed 1 well per well pad within the analysis area. The total number of wells in each scenario was reached by year 50 in the simulation, with new wells being added linearly each year until the total was reached at year 50. It should be noted that in some areas such as the Piceance Basin, it is reasonable to assume the addition of 20,000 wells in the area may be better reflected by the 5,000 well pad scenario in the model. This would assume an average of 4 wells per well pad, where the majority of new well pads in this area can accommodate 16 - 28 wells. The purpose of this exercise is to reflect a "worst–case" scenario of different levels of energy development within important sage-grouse population areas.

To evaluate development intensity, in each population area we randomly plotted new wells for each development scenario and then counted the number of wells (current and future) within each 2-mile lek buffer. These counts were then averaged across each population or zone, and the demographic impact of the new density of wells was applied to the population simulation.

The results of our analysis of oil and natural gas development, and its impact on GrSG populations suggest that the impact may be severe on future GrSG population viability (Fig. 35). The onset of development leads to strongly negative population growth, rapid population decline and, in all cases but one (lower levels of development in NWCO), nearly certain extirpation of local grouse populations within 50 years.

Fig. 35. Average projected size of simulated GrSG populations in the presence of oil and natural gas development. See Appendix K for more information on model construction and results.



The rather dramatic declines (Fig. 35) are clearly the result of imposing strong demographic consequences on GrSG populations that live and breed near current or proposed oil and natural gas development areas. We conducted a second, revised oil and natural gas development modeling exercise, based on several considerations.

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 (Holloran 2005), 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 development phase, 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 (Fig. 35). This suggests our model oversimplifies the relationship between GrSG populations and oil and gas development.

Third, oil and gas development and GrSG co-exist in several landscapes (including North Park), which also suggests that not all situations are as extreme as we initially modeled.

Fourth, the dramatic results from the initial oil and gas development 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 GrSG and oil and gas development may be derived from exploring other areas of the impact continuum, where the impacts are not so severe.

Therefore, we constructed a more complicated, but 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. Our revised models also allow us to explore how sage-grouse might respond to differing levels of disturbance.

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 GrSG 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 PPR and NWCO areas because they effectively represent, on a comparative scale, high-intensity and low-intensity oil and gas development scenarios, respectively.

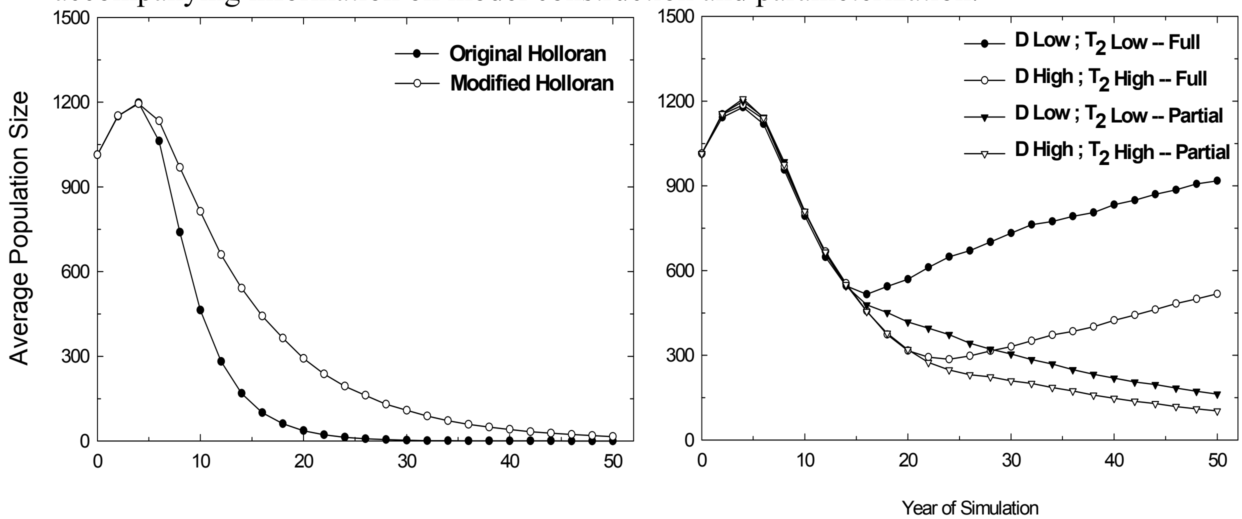
We revised the oil and gas development model to address and incorporate (1) the probable changes in level of disturbance to GrSG throughout the oil and gas development process; (2) the potential positive impacts to GrSG of well-field mitigation, some of which may occur before development is complete; and (3) the possibility that the amount of disturbance estimated in the initial models might have been the highest extreme; we examined how GrSG populations behaved with a reduced level of impact.

In the initial analysis we assumed that once the maximum level of demographic disturbance to GrSG was reached, this high level of disturbance would persist throughout the duration of the simulation. For the more complex model we derived and varied additional parameters that addressed: (1) how quickly impacts began after development was initiated; (2) how long the greatest impact period lasted; (3) how quickly the impacts diminished as development entered the production phase; (4) whether or not the demographic parameters returned to normal levels after development was completed; and (5) the amount of demographic impact caused by development. The details of this complex analysis are provided in Appendix K.

Using the new parameters, a “best-case” scenario exists where the duration of the maximum impact to GrSG is short, the population demographic parameters return to their original levels in the shortest possible period, and the maximum impact is 50% of the original estimated impact (Fig. 36, right panel, “D low; T_2 Low-Full”). Under this scenario, 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. Population growth rates may remain highly negative for the first 15 - 20 years but can rebound for the remaining 30 - 35 years of the simulation. Note that the PVA model does not evaluate whether this best-case scenario is achievable.

On the other end of the spectrum a worst-case scenario exists where the duration of impact is long, demographic rates do not return to their original levels, and any recovery in demographic parameters is slow (much like the original analysis).

Fig. 36. Average projected size of simulated GrSG populations in the PPR area under revised analysis of the impact of oil and natural gas development. The left panel illustrates the original estimated impact compared with a modified impact level (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 Appendix K for accompanying information on model construction and parameterization.



With respect to maintaining viability of GrSG populations in the presence of oil and natural gas extraction, we conclude that 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;
- Minimizing the time period of maximum demographic impact (D);
- Minimizing the time period over which demography recovery is achieved (T_2).

It is important to recognize that in our models oil and natural gas development are expected to impact 2 important GrSG demographic parameters: adult female breeding success and mortality. Those 2 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 over large areas, can have a much more severe impact on the stability and future viability of local sage-grouse populations than activities such as housing development, which we believe act solely to reduce the quantity and/or quality of available sagebrush habitat.

Reproductive Success Mitigation

Conservation management could potentially have positive impacts on GrSG reproduction. We investigated how such "reproductive mitigation" might ameliorate the impacts of previously discussed risks to GrSG: housing development, surface mining, harvest, and oil and natural gas development. Mitigation activities that might increase sage-grouse reproductive success include improving habitat quality and/or availability (for discussion, see "Off-site Mitigation of Impacts", pg. 299), population augmentation (see "Population Augmentation, pg. 235), or predator mitigation (see "Predation" issue section, pg. 183). Note that "predator mitigation" does not necessarily mean "predator control" in the typical sense. Predator mitigation can also be at least partially achieved through, for example, habitat modifications that make predation on nesting sage-grouse less likely.

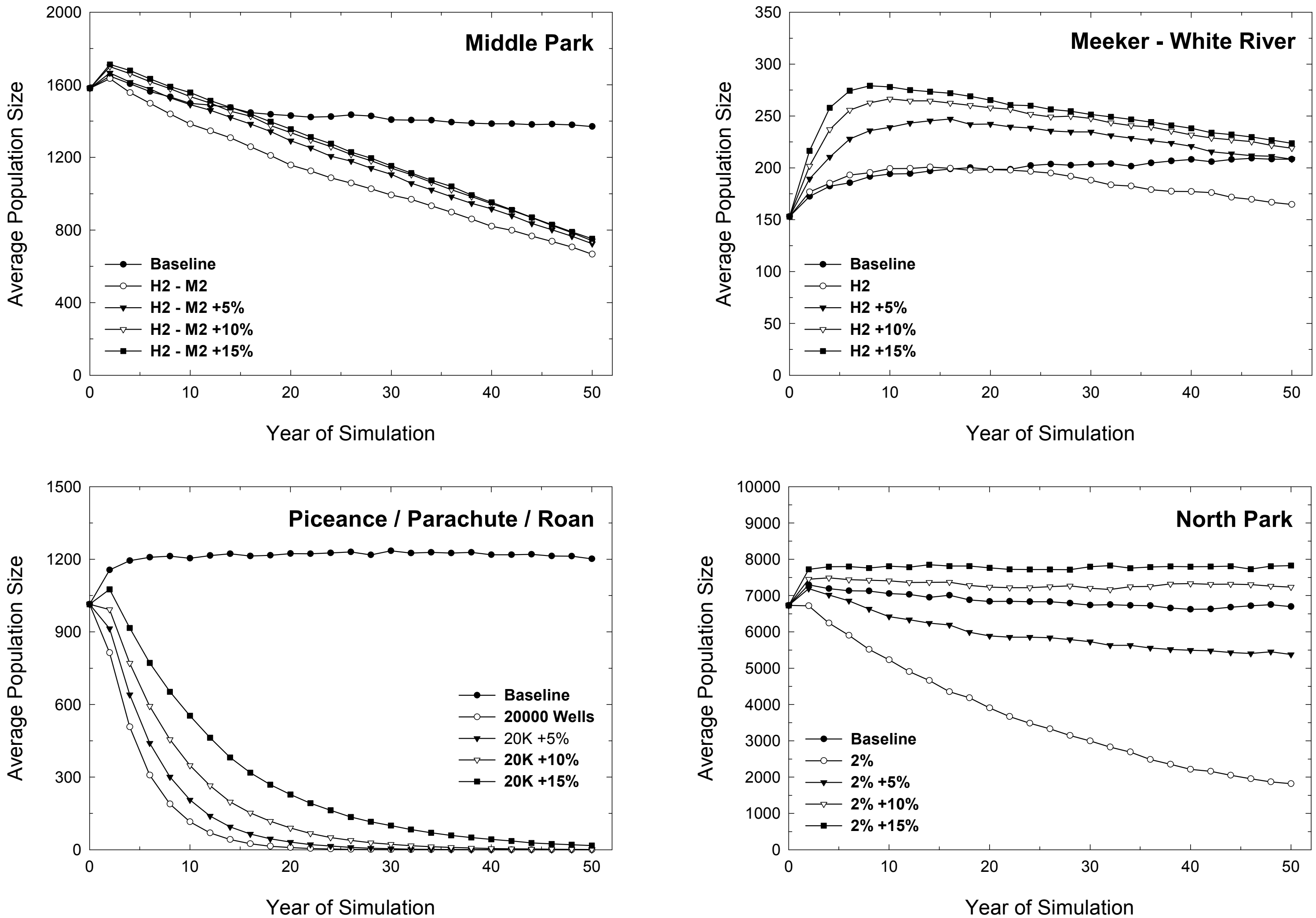
We simulated 3 levels of reproductive mitigation by increasing the percentage of breeding-age GrSG that successfully reproduce in a given year by 5%, 10%, or 15%. Reproductive mitigation was simulated in the large majority of models described earlier that included one or more human activities.

The efficacy of reproductive mitigation as a management tool for GrSG 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 (Fig. 37).

For example, in MP, where housing and surface mining 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 (Fig. 37). This is because housing development and surface mining activities act to reduce carrying capacities, while leaving the underlying GrSG 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 MWR, 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 GrSG 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 (Fig. 37). 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.

Fig. 37. Average projected size of simulated GrSG populations in the presence of region-specific human activities and with varying levels of reproductive mitigation. “H2” and “M2” = high levels of habitat loss through housing (H) and surface mining (M) activities, respectively, in MP and MWR; “20000 Wells” = a given level of oil and natural gas activity in the PPR area; and “2%” = specific level of harvest mortality through hunting in NP. 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 Appendix K for additional information.



The effects of reproductive mitigation can be much more pronounced under moderate levels of harvest mortality, as demonstrated in NP (Fig. 37). 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 3 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.

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 PPR example (Fig. 37; this is the worst-case scenario described earlier), 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.

However, under the revised oil and gas development analysis, if we assume the best-case scenario described earlier, reproductive mitigation enhances the population's performance considerably (Compare Fig. 38, panel "A"; with Fig. 36, right panel). 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. Even if demographic recovery is only partial (Fig. 38, panel "C", low levels of reproductive mitigation are sufficient to offset the impacts of well-field development. 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 (Fig. 38, panels "C" and "D").

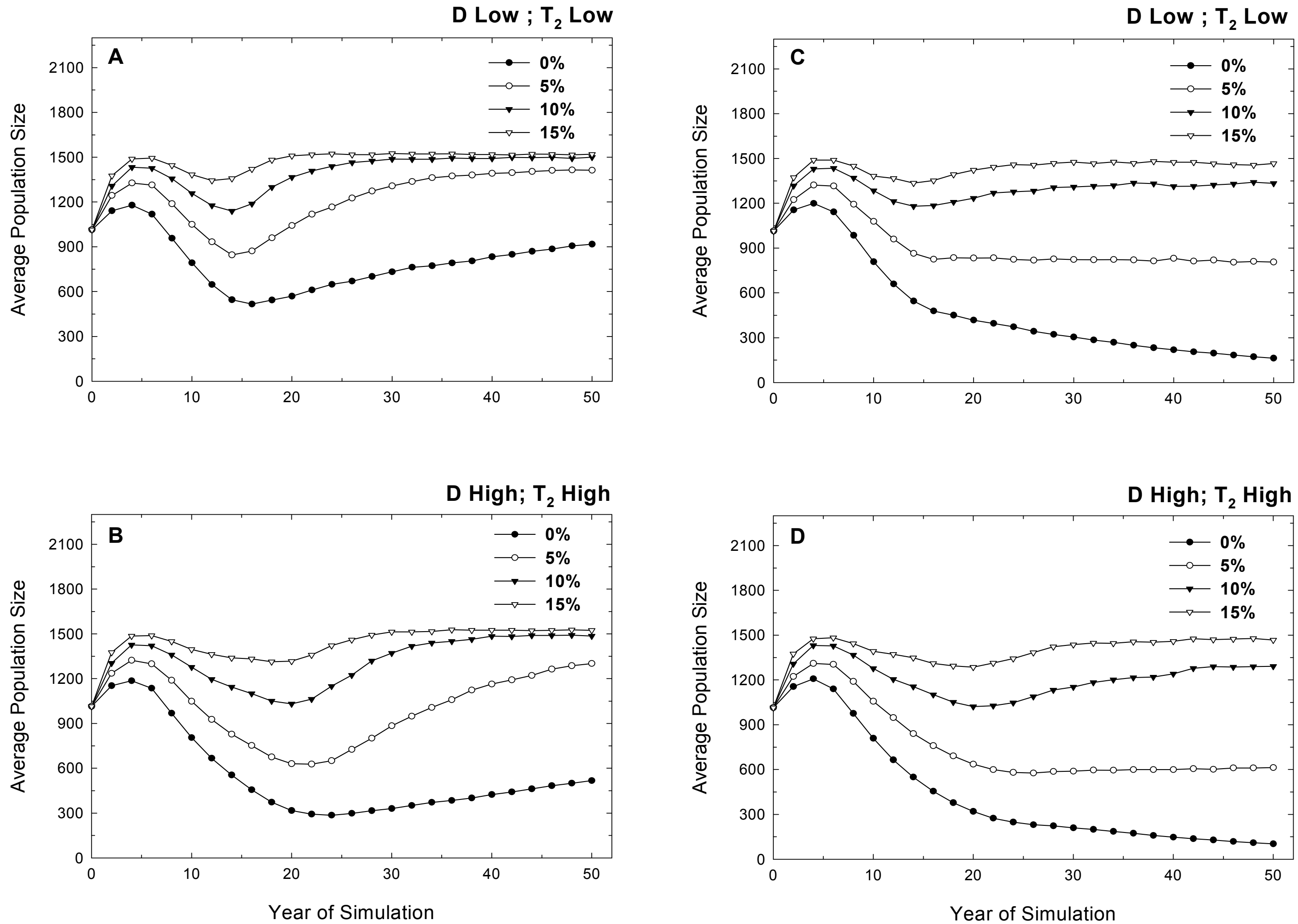


Fig. 38. Average projected size of simulated GrSG populations in the PPR area, in the presence of alternative scenarios of well field development and mitigation, and reduced overall impacts from development, along with reproductive mitigation. Reproductive mitigation is simulated through a 5%, 10% or 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 Appendix K for model details.

Conclusions

We conclude our analysis of GrSG 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 GrSG populations in Colorado?*
  Our retrospective demographic analysis indicates that we are capable of building such models. However, reliance on the absolute outcome predicted by any one modeling scenario must always be interpreted with caution due to the inherent uncertainty in model input parameterization. A comparative analysis between models, in which a single factor (or at most 2 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 GrSG populations in Colorado?*
  Our demographic sensitivity analysis indicates that models of GrSG 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 GrSG in Colorado to extinction under current management conditions? How small must a population become to increase its risk of extinction to an unacceptable level?*
  We did not directly address this question, but the analyses presented here provide some preliminary insight into this issue. For example, the rather small MWR 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 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 high level of population stability and, by extension, a low probability of population extinction.

- *What are the predicted impacts of current and potential future levels of housing development on selected GrSG populations in Colorado?*
  This activity, manifested largely through reductions in available sagebrush habitat, appears to have comparatively minor impact on the long-term demographic viability of GrSG 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 (see also "Housing Development" issue section, pg. 154; and "Predicted Future Housing Development and GrSG Habitat Protection", pg. 268).

- *What are the predicted impacts of current and potential future levels of mining and other surface activities on selected GrSG populations in Colorado?*
  This activity, also manifested largely through reductions in available sagebrush habitat, appears to have comparatively minor impact on the long-term demographic viability of GrSG 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 (see also "Energy and Mineral Development" issue section, pg. 109).

- *What are the predicted impacts of current and potential future levels of hunting on selected GrSG populations in Colorado?*
  Current levels of GrSG harvest in NP appear sustainable. However, the analyses presented here suggest that even relatively low levels of additional harvest mortality, if sustained for long periods of time (i.e., 10 - 20 years), 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 GrSG population, is recommended before specific adjustments to harvest quotas are made (see also "Hunting" issue section, pg. 156).

- *What are the predicted impacts of current and potential future levels of petroleum and natural gas development on selected GrSG populations in Colorado?*
  Oil and natural gas development, manifested through direct impacts on demographic performance of individual birds, may have major and severe consequences for GrSG populations in Colorado. This conclusion is based on models that use data from research studies on GrSG in nearby areas within the same ecoregion (Wyoming Basin; see also "Energy and Mineral Development" issue section, pg. 109; "Energy and Mineral Development: Avoiding and/or Mitigating Impacts", pg. 292; and Appendix H, "Literature Review: Oil and Gas Impacts on Prairie Grouse"). We further explored the potential population impacts of oil and gas development in modeled populations (see next point).

- *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?*
  Our analysis of projected oil and natural gas development activity in the PPR area suggests that well-field mitigation can potentially be effective in reducing the demographic disturbance to GrSG 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 (see final point), 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 (see also "Energy and Mineral Development" issue section, pg. 109; and "Energy and Mineral Development: Avoiding and/or Mitigating Impacts", pg. 292).

- *To what extent will the demographic behavior of our simulated populations of GrSG change if we assume a less severe direct impact to GrSG demographics through oil and gas development, even in the absence of mitigatio*n?
  Our analyses indicate that even if the impacts on GrSG 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. Developing a more thorough understanding of the detailed demographic impacts of oil and natural gas development in Colorado is critical to the formulation of specific well-field mitigation strategies.

- *Can reproductive mitigation improve the viability of GrSG populations in Colorado in the face of other anthropogenic processes?*
  Improving reproductive success through alternative mitigation activities could possibly lead to significant increases in GrSG 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.

B. Population Augmentation

Translocation

Translocation of GrSG has been proposed as a means to augment small populations. A donor population would provide birds to augment either the population size or the genetic diversity of a smaller recipient population, or to establish a new population. Current techniques for transplanting prairie grouse are labor intensive, expensive, and only moderately successful (Toepfer et al. 1990). The typical approach for transplanting sage-grouse has been to obtain birds during the spring. The grouse are captured at night on or near leks, using spotlights and long-handled nets (Giesen et al. 1982, Wakkinen et al. 1992). Birds are transported to the release area and released at daybreak the following morning, using a "soft-release" technique (Musil et al. 1993). This involves placing the birds in a release box on a lek and remotely opening the door when display activity begins at dawn. Ideally, birds walk out of the box and associate the release area with breeding activity.

CDOW has had some success with this technique with GuSG (Nehring and Apa 2000, Gunnison Sage-grouse Rangewide Steering Committee 2005), as have others (Musil et al. 1993), but capturing sufficient numbers of individuals can be difficult. In addition, adult males captured in the spring have already established a territorial affiliation with leks. Some transplanted males have been depredated when they move long distances in an apparent attempt to return to these leks. Juvenile males move much less and appear more willing to accept the release lek and area, presumably because they have not yet established a behavioral affiliation with a lek. Transplanting only juveniles makes obtaining sufficient numbers of birds even more problematic because there are relatively few of them, and they tend not to roost on and near leks where they can be more easily captured.

To date, female sage-grouse translocated in the spring have not attempted to nest during the year of capture, whether caught early or late in the breeding season (CDOW, unpublished data). Thus, translocated hens must survive for a year from release to contribute to population growth. With an average adult female survival of about 65% and nest success of 50% or less, many hens must be moved for a transplant to result in females successfully breeding and further augmenting the recipient population. It is apparent that removing females during spring will reduce recruitment of young. Because mortality is already high in early life stages for sage-grouse (eggs, chicks), removing individuals in any of these stages for transplantation will likely not add to the population-level mortality rates of that stage. Thus, moving eggs, chicks, or young of the year, instead of yearling and adult birds during the breeding season, would be far less likely to adversely impact a donor population.

Captive Breeding

Captive breeding could also be used to provide birds for transplant or augmentation purposes. Extensive experience by Colorado and many other states has illustrated that although raising some gallinaceous birds in captivity is relatively easy, establishing wild populations from these captive-reared birds is very difficult, expensive, and only rarely successful. Failures are usually due to extremely poor survival and reproduction of captive-reared birds (Trautman 1982, Krauss et al. 1987, Leif 1994).

Excessive mortality is usually blamed on behavioral differences between captive-reared and wild-reared birds. Leif (1994) showed that even when captive-reared female pheasants were held over winter and released into high quality habitats just prior to nesting, high mortality and nest abandonment meant they produced only 9% as many young as wild hens in the same habitat. Liukkonen-Anttila (2001) studied differences in morphology and physiology of captive- and wild-reared birds in an attempt to explain the high mortality of released birds. He found significant differences in morphology and physiology caused by captive conditions and diets that may increase mortality of released birds. His findings suggest that some increases in survival might be possible if birds are exposed to more natural diets and allowed adequate space to develop flight and cardiac muscles prior to release.

Sage-grouse

Captive rearing and release programs for grouse are relatively uncommon compared to efforts with turkeys or exotic game birds like pheasants. Bump et al. (1947) raised about 2,000 ruffed grouse in captivity. Even after 12 years of refinement of techniques the authors still noted a propensity for captive-reared chicks to die in large numbers in the first month of life, a trait common to all captive efforts studied, and to the wild.

A recent study in Colorado reported successful husbandry and captive breeding of wild-caught GrSG (Oesterle et al. 2005). Hatch-year birds were captured in Nevada in October, transported to a facility in Colorado, and maintained for 8 months. Diet included native food such as sagebrush and yarrow, but also various types of commercial feed. The mortality rate associated with captive conditions (as opposed to handling stress) was 16.7% (Oesterle et al. 2005). Breeding behavior occurred, 13 eggs were laid by 4 different females, and 11 of the eggs were fertile (Oesterle et al. 2005). Incubation by females was not successful; harassment by other grouse hampered normal incubation in some cases. Factors that appear important to successfully maintaining and breeding sage-grouse include: (1) using hatch-year birds (possibly more behaviorally flexible than adult birds); (2) a large outdoor flight pen; (3) multiple, widespread feeding stations; and (4) visual barriers.

Other efforts to rear sage-grouse have been less successful, though instructive. In 1958 a Texas game bird breeder obtained 30 eggs of GrSG from Wyoming (Pyrah 1960). Twenty-four of the 30 eggs collected hatched (80%), and 17 chicks reached approximately 4 weeks of age. Losses were attributed to accidents, stomach worms, coccidiosis, and inversion of the proventriculus. Only 2 grouse survived to 8 months.

Idaho began a sage-grouse captive breeding program in 1960. Efforts included having captive hens produce young, rearing chicks from eggs collected in the wild, and testing various nutrition plans on sage-grouse (Pyrah 1963, 1964). Success in egg incubation was variable (Pyrah 1963, 1964), and many first-year birds succumbed to disease (salmonellosis, *Pseudomonas aeuginosa*, and aspergillosis; Pyrah 1963). Attempts at captive mating were largely unsuccessful (Pyrah 1963). Survival of the few chicks produced by captive hens was poor and was attributed to poor maternal nutrition during laying (Pyrah 1963). Hatching of eggs collected in the wild was better (87%), and 61% of the chicks hatched survived through the summer (Pyrah 1963). Chick mortality resulted from accidents, disease, and vitamin E deficiency. Wild-caught chicks were more difficult to handle than captive-reared chicks, and “ate sparingly of prepared feed and gained little weight because of it” (Pyrah 1963:8). A diet of pelleted ration with 20% protein, supplemented with “greens and mealworms” was most successful.

Batterson (1997) described successfully propagating sharp-tailed grouse and sage-grouse in captivity in Oregon, without providing details. Batterson and Morse (1948) described an artificial propagation experiment, where 9 eggs were obtained from an abandoned sage-grouse nest and placed under a bantam hen on April 20, 1942. Seven chicks hatched, of which 1 was stepped on and killed by the hen the first day. The 6 survivors were successfully reared to 6-weeks of age when they were released. No information was obtained on subsequent survival.

Wiseman and Bird (1969) conducted a study to develop a ration that would maintain sage-grouse in captivity. They collected 9 eggs from a wild nest in Sweetwater County, Wyoming, and successfully hatched 9 chicks. One chick had its leg severed by the incubator and another had extremely short legs and was destroyed.

Huwer (2004) used sage-grouse chicks hatched and imprinted in captivity to evaluate the extent to which forb abundance affects chick growth rates. She collected 44 eggs from wild sage-grouse nests in spring of 2002 in Middle Park, and successfully hatched 36 (82%) in an incubator. These chicks were imprinted to humans, and subsequently exposed, beginning at 3-days of age for a total of 29 days, to sites with high, medium, or low forb abundance. Mortality during the first week was high; survival to 30-days was 25%. In 2003, 46 of 68 eggs hatched (68%), and survival of chicks through the entire 54-day study period was 68 %.

Other Prairie Grouse

There have been numerous published reports on attempts to propagate other prairie (lekking) grouse in captivity, including lesser prairie chickens (Coats 1955), greater prairie chickens (Trautman et al. 1933, Handley 1935, Ramey 1935, Etter 1963, Shoemaker 1964, McEwen et al. 1969, Kruse 1984), and sharp-tailed grouse (McEwen et al. 1969). Some of these efforts to breed adults and rear young in captivity were successful, although fertility and hatchability rates were often below those seen in the wild; but survival after release was not reported.

Recently, extensive research has been conducted on the endangered Attwater’s prairie chicken, in an attempt to develop methods for reintroduction in Texas. In 1990, research began into captive breeding of greater prairie chickens as surrogates for lesser prairie chickens (Jurries et al. 1998). Researchers encountered photoperiod and temperature problems, but ultimately had 3 of 4 hens successfully breed. Eggs collected from wild Attwater’s prairie chicken nests were also successfully hatched. However, problems arose with the deaths of 2 wild males brought into captivity, (who died from impaction of the gastrointestinal tract resulting from dietary supplements). Another grouse died of avian pox. The facility also suffered an outbreak of the viral disease, avian reticuloendotheliosis, and was quarantined. Data from this facility and other captive-breeding facilities in Texas indicate the source of the disease was from the outside, likely from migratory birds.

Captive breeding of Attwater's prairie chickens also occurred at the Fossil Rim Wildlife Center and Houston Zoological Gardens. In 1992, eggs collected from wild nests hatched, but most chicks were lost to toe and leg deformities or to an outbreak of infectious enteritis (Smith 1993). Only 5 of the 42 chicks produced survived to breeding age. During 1995-96, 14 hens laid 126 eggs, egg viability was 48%, hatching success was 80% (49 chicks) and 21 chicks were raised to at least 8 weeks of age. Three birds were lost to great-horned owl depredation in the pens and 9 birds were released on the Attwater's Prairie Chicken National Wildlife Refuge.

At the Houston Zoo, 8 females produced 165 eggs, of which 154 were viable; 108 chicks hatched, and 78 chicks survived to 8 weeks. Sixty Attwater's from the Houston Zoo were ultimately released into the wild. A pilot release of 13 males occurred in August of 1995, of which 2 survived to March of 1996. "Refined techniques" resulted in the survival of 31 of 69 Attwater's released in 1996 to the 1997 breeding season. Fifty chicks were released in 1997, supplementing a wild population of 58 birds. There are now captive breeding facilities in Abilene, College Station, Houston, San Antonio, and Tyler, Texas. Ultimately, over 500 eggs were produced.

Recently, several adult pairs of Attwater's prairie chickens were released into individual protected enclosures. This approach has not been successful; the prairie chickens have suffered nest abandonment, depredation of eggs and young by snakes and fire ants, and loss of young to unknown causes. Survival of captive-reared Attwater's prairie chickens released in August to the following spring has been as low as 15% and averaged only 36% despite refinement of release techniques (Preisser and Yelin 1999).

Summary

The literature survey on this topic suggests it is likely, given a substantial commitment of funds and staffing, that GrSG could be successfully bred and raised in captivity. Production capability would not be large because sage-grouse don't breed well in captivity (and as a result they tend to lay infertile eggs), and they are determinate layers who won't continue to lay as eggs are removed (A. D. Apa, CDOW, personal communication). Research into methodologies to collect sperm and artificially inseminate captive hens, or pen construction that would facilitate captive breeding would be beneficial to increase the proportion of eggs that are fertile. There is very limited information on sage-grouse to indicate how likely captive-produced young would be to survive in the wild. However, there is a great deal of relevant information from research on other gallinaceous birds to suggest it will be very low, unless innovative strategies are developed and tested.

Potential Approaches for GrSG

There may be other manipulative strategies to enhance genetic diversity or increase populations of grouse that fall short of captive breeding and release, but that have a higher likelihood of success and would contribute to conservation of these species. We briefly evaluate 5 of these ideas, roughly in order of decreasing potential for success and increasing risk to existing populations.

(1) Transplant Eggs to Populations in Need

One alternative to transplanting adult females could be to use radio-transmitters to locate nests during laying, and transfer eggs from the source population or from captive production to nests in populations that need demographic rescue or augmentation to enhance genetic diversity. Clutch size in birds with precocial young that do not require parental feeding may be regulated by nutrition of the hen at the time of laying. Sage-grouse clutch sizes typically range from 7 - 9, but it is possible that hens could brood and raise substantially larger clutches. This would require further investigation. The technique would require radio-marking females so their nests could be located. Artificial eggs could be placed in the nest bowls so that some eggs remain and prevent abandonment. Other eggs lost to predators could then be replaced with eggs produced in captivity. This would be a means of "ensuring" successful nesting. Given the substantial investment in this approach, it may be worthwhile to evaluate techniques to protect nests from predators.

(2) *Incubate Eggs in Captivity to Reduce Depredation Losses*

Nest success in grouse seldom exceeds 50%, and can be substantially lower. Another possible method to increase nest success could be to remove eggs from grouse nests and incubate them in captivity, then replace either eggs or chicks in the nest. This strategy was used very successfully with peregrine falcons where egg-shell thinning was the main problem. Hard plastic eggs were substituted when the real eggs are removed so the female continued to incubate. Huwer (2004) found that GrSG hens in Colorado readily accepted chicken eggs (which are larger and a different color than sage-grouse eggs) when their eggs were removed, continuing to lay and ultimately incubating the clutch. Four of 4 GrSG, and 3 of 3 GrSG hens accepted hard plastic eggs the same size, shape, and color as wild eggs (A. D. Apa, CDOW, personal communication). Using this approach, eggs could be replaced 2 - 3 days prior to hatch so that normal imprinting occurs, or experiments could be conducted to see if hens accept newly hatched chicks and vice-versa. Pilot studies with GrSG suggest chicks less than 5-days old readily accept, and are adopted by, wild hens (A. D. Apa, CDOW, personal communication).

(3) *Supplement Wild-reared Broods with Captive-produced Young*

For this strategy to be successful, a key assumption is that hens must be willing to adopt captive-reared chicks. There is substantial evidence, only recently collected, to suggest that this technique is possible. The CDOW released 3, 14-day old GrSG chicks to another brood hen when a radio-marked brood hen died. Those chicks were successfully adopted. In a pilot study conducted in the spring of 2004, 17, 1-7 day-old captive reared GrSG chicks were released with wild females with chicks of similar age (A.D. Apa, CDOW, unpublished data). The survival rate at 50 days was 0.42, similar to the survival rate of wild chicks at 50 days (0.38; A.D. Apa, CDOW, unpublished data). CDOW researchers have also observed brood mixing where radio-marked chicks joined broods of different hens. This has also been observed with radio-marked chicks and hens in Oregon (M. Gregg, personal communication) and Idaho (N. Burkepile, personal communication). CDOW researchers have also observed an instance where radio-marked chicks from a depredated hen were adopted by a non radio-collared hen. Apa (CDOW, personal communication) described a hen, known to be unsuccessful in her nesting attempt, who adopted and successfully raised a chick from another brood. Research with radio-marked GrSG chicks in Idaho indicates there is brood mixing among sage-grouse hens (N. Burkepile, personal communication). This suggests that captive-produced chicks can be released into existing broods. The big advantage to this approach is that only broods, not nests, need to be located or disturbed. It is not known whether chicks produced in captivity will accept brood hens, to what extent this might be dependent on chick age at time of release, or whether survival would be similar to wild chick survival. As mentioned above, preliminary information suggests that chicks less than 5-days old readily accept, and are adopted by, wild hens (A. D. Apa, CDOW, personal communication). This will be further evaluated through research.

(4) *Raise Grouse in Captivity and Release to Populations in Need*

This option would be an operational captive breeding and release program. It would require extensive research to evaluate the best methods for raising grouse, including pen construction, diets, artificial insemination, and disease prevention, as well as the best way to reintroduce grouse to the wild. It is the highest risk technique, in that probability of success is low, and there is potential for either introducing disease into existing populations or shifting genetic frequencies over time. The rapid expansion of both chronic wasting disease and whirling disease show how easily release or escape of captive-reared wildlife can create serious disease problems in the wild. If this option is explored it must be under extremely tight disease prevention protocols. Rearing facilities should be placed within the area where release will occur, and the source of birds must be local as well to minimize risk of spreading disease (see "Disease and Parasites" issue section, pg. 103).

(5) *Maintain a Captive Flock as a Genetic Diversity Bank*

The NP and NWCO populations are the largest GrSG populations in Colorado, and are genetically diverse enough to maintain the genetic diversity needed to offset genetic drift and to ensure that in Colorado the species can adapt to future challenges. At least conceptually, these 2 populations could serve as a source of genetic diversity and individuals that could be used to augment low diversity or population size in case of catastrophic events in other populations. Nevertheless, in case of a widespread catastrophic event (e.g., disease, severe extended drought), it may be prudent to explore the feasibility of maintaining a captive flock or flocks (zoos serve this purpose for other species) with diverse genetic makeup to allow us to introduce these genotypes or bring populations back in case of crisis.

C. Habitat Model Analysis: GrSG Population Size in Relation to the Amount of Available Habitat

One of the key questions for the conservation and management of GrSG is how much habitat is needed to sustain a given population size over time. We examined this relationship using the mean of annual high male counts at leks and the amount of available habitat within each GrSG population.

Model Development

High male counts were used instead of population estimates that are derived from adjusted lek counts. Adjusted lek counts make assumptions that may introduce additional error that cannot be accounted for in model estimates (see “Abundance”, pg. 50). We only used the lek count data for which there was a consistent effort for counting leks (MP, NP, and most NWCO management zones). We did not include lek counts from PPR, MWR, NESR, or Management Zones 2 and 7 of the NWCO population, due to either lacking or inconsistent lek counts. We used 8 years of lek count data (1998-2005), except for NP, which had 33 years of data (1973-2005; Table 25). Mean high male lek counts were weighted in the regressions by the number of years of counts included in the mean.

A GIS was used to estimate the amount of available habitat within each population. Available habitat is a subset of vegetation cover types within areas defined as "Occupied Habitat" that would potentially be used by sage-grouse (e.g., sagebrush and sagebrush-grass communities; see “GrSG Habitat Mapping Efforts” [pg. 66] and Appendix J, “GrSG GIS Data”).

Table 25. Summary statistics of the number of male GrSG counted on leks. Data are used in the regression for GrSG populations (and management zones) and available habitat. "MZ" = Management Zone in the NWCO population; n = the number of years of lek counts; Mean = average lek count; SD = standard deviation of lek counts; Min = smallest lek count; Max = largest lek count.

Population	n	Habitat Area (acres)	Mean	SD	Min	Max
NWCO / MZ1	8	157,376	166.9	40.31	117	241
NWCO / MZ3A	8	221,386	460.5	196.17	222	825
NWCO / MZ3B	8	243,624	530.5	220.82	195	741
NWCO / MZ3C	8	283,856	108.8	64.88	12	192
NWCO / MZ4A	8	64,658	112.6	94.08	20	267
NWCO / MZ4B	8	208,884	70.0	37.73	36	153
NWCO / MZ5	8	353,625	317.4	85.75	184	428
NWCO / MZ6	8	223,486	384.8	75.50	303	503
MP	8	239,446	272.8	42.60	190	313
NP	33	403,972	889.9	315.87	466	1,521

We used linear and nonlinear models to examine the relationship between mean high counts of males on leks and the amount of available habitat (Fig. 39). A linear model assumes a constant relationship between population density and the amount of available habitat. The relationship should be linear as long as (1) there is no change in the behavior (e.g., movement patterns) or spatial correlation of sage-grouse as the amount of habitat changes; and (2) the quality of habitat is fairly consistent among populations.

However, because the wide variation in mean lek counts among populations does not clearly suggest a linear relationship (Fig. 39), we examined the possibility of a non-linear relationship, using both quadratic and exponential models. We restricted the number of nonlinear models to these 2 in order to avoid over-fitting the 10 GrSG populations/management zones. Nonlinear models would be more likely to describe the relationship between population density and amount of available habitat if the behavior and spatial correlation of individuals changes as the amount of available habitat changes. For instance, habitat in smaller populations may be of poorer quality and therefore may have a lower than predicted population density. Populations with large amounts of available habitat may have a lower than predicted population density if individuals do not use all available habitat, or if space-use by individuals increases with increasing available habitat.

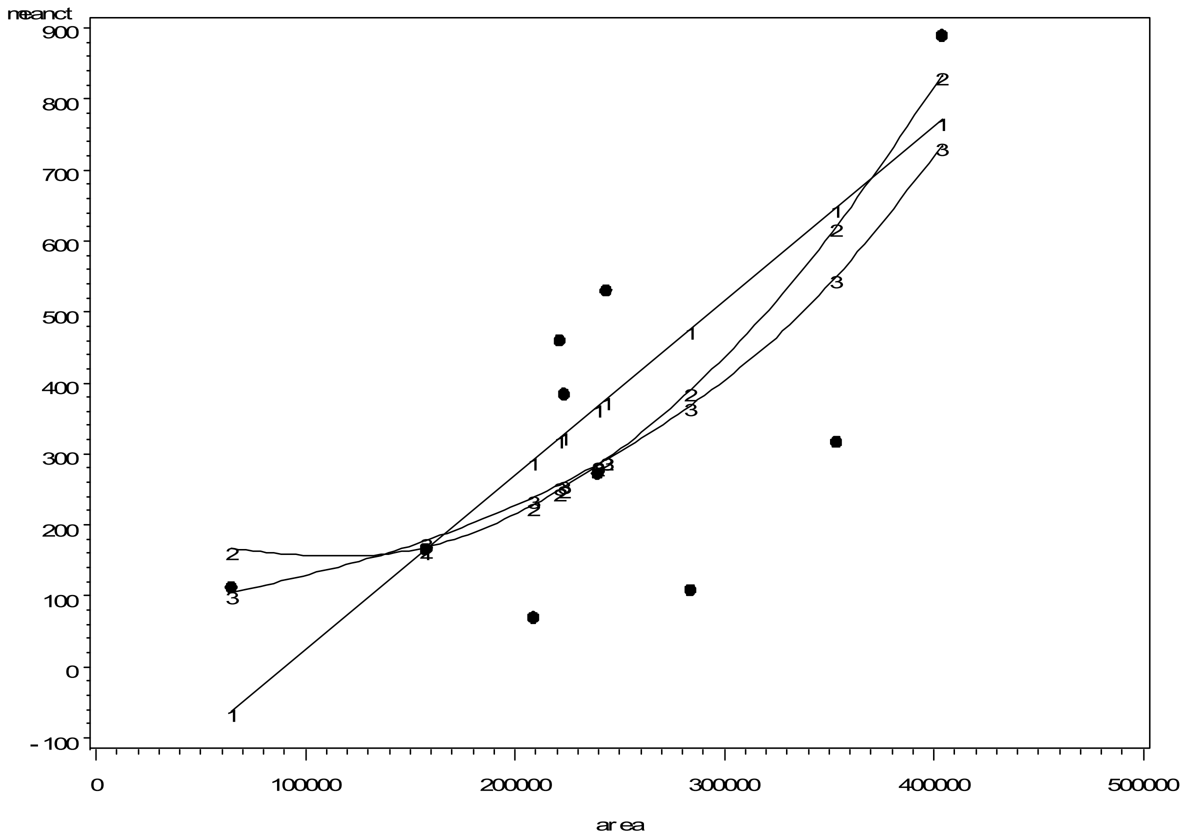


Fig. 39. Linear and nonlinear models relating the number of males (mean high count at leks) within each of the 10 GrSG populations or management zones (● = mean high count of males at leks for each population; area is in acres). 1 = linear model, 2 = quadratic model, 3 = exponential model. See Table 25 for the area and mean lek count for each population and number of years included in the mean. Mean high male lek counts were weighted in each model by the number of years of counts included in the mean.

Model Selection

We used an information-theoretic approach (Akaike 1973, Burnham and Anderson 1998) to evaluate which model best describes the relationship between the high male counts and the amount of available habitat. Akaike Information Criterion (AIC) is a refinement of maximum likelihood techniques for parameter estimation and is derived from the Kullback-Leibler distance used in information theory (Kullback and Leibler 1951). The Kullback-Leibler distance is a measure of the difference between the data ("reality") and the model used to estimate reality.

More specifically, AIC is the maximum log-likelihood for a model with a set of parameters (θ) for a given set of data (y) (AIC = $-2\ln[L(\theta|y) + 2\text{ K}]$, where K is the number of parameters in the model). As the number of parameters in the model increases, the precision of the model increases and the difference between the model and a given set of data typically decreases (i.e., $-2\ln[L(\theta|y)$ gets smaller). However, additional parameters do not always contribute significant information to a model. AIC takes into account the number of parameters used to fit the data (i.e., 2K gets bigger while $-2\ln[L(\theta|y)$ gets smaller). The objective is to select a model that does not over-fit (large number of parameters and highly precise) or under-fit (a simple model with few parameters but not very precise) a given set of data. The model with the smallest AIC value is considered the most parsimonious model (i.e., the best balance between simplicity and precision) and therefore, the most reasonable model for a given set of data.

Due to the small number of GrSG populations used in the analysis, we used the corrected AICc (Hurvich and Tsai 1989) to rank the models. Since AIC (and AICc) is a relative ranking technique, we computed the Akaike weight (w_i) to illustrate the relative likelihood of each model (Akaike 1978). Note that the Akaike weights sum to 1.0. The larger the weight, the more reasonable the model for making inferences based on the data. All models were log-transformed in order to better meet the assumption of homogeneity of variances across dependent variables (area), and to make the residuals of the linear and nonlinear models comparable for model selection. The original (real scale) data were used to compute the parameter estimates for each model.

The AICc and Akaike weights (w_i) suggest that the linear model is the best model for relating the mean high male lek counts to the amount of available habitat for GrSG (Table 26). However, no model clearly outperformed all other models. This is due to the wide variation in the mean number of males on leks among the populations, and because there were only 10 populations/ management zones included in the analysis. The linear ($w_i = 0.48$) and exponential ($w_i = 0.36$) models appear to outperform the quadratic model ($w_i = 0.16$). However, there is little difference between the linear and exponential models. The exponential model suggests an interesting possibility that, given the opportunity, sage-grouse can respond rapidly to habitat expansion. However, the linear model is more intuitive given the negative *y*-intercept, which implies a minimum area of available habitat is necessary to support a sage-grouse population (see Fig. 39; note β_o in Table 26, B). Furthermore, since the exponential model likely over-parameterizes the current data, the linear model is the most parsimonious and reasonable model for describing the relationship of the number of males for a given amount of habitat.

Table 26. Results for models using log-transformed and real scale data. A) Regression and model selection results for log-transformed data, and B) regression results using real scale data for parameter estimates. Data are the mean high count at leks for a given amount of habitat within each GrSG population.

A. Log-transformed data Model	d.f.	SSE	F	P>F	R^2	AICc	w_i
1. (linear) $\ln(\hat{y})=\ln(\beta o+\beta 1x)+\varepsilon$	8	41.57	6.93	0.03	0.464	19.96	0.48
2. (quadratic) $\ln(\hat{y})=\ln(\beta o+\beta 1x+\beta 2x)+\varepsilon$	7	33.79	4.54	0.05	0.565	22.17	0.16
3. (exponential) $\ln(\hat{y})=(\ln\beta o+ *area)+\varepsilon$	8	44.06	10.23	0.01	0.461	20.54	0.36

B. Real scale data Model	β_o	β_1	β_2	γ
1. (linear) $\hat{y} = \beta o + \beta 1x + \varepsilon$	-220.85	0.0025	-	-
2. (quadratic) $\hat{y} = \beta o + \beta 1x + \beta 2x2 + \varepsilon$	244.77	-0.0017	<0.0001	-
3. (exponential) $\hat{y} = \beta oe * area + \varepsilon$	55.32	-	-	0.0068

Using parameters from Table 26, B, the discrete linear model for estimating the average number of males on leks ($\hat{y}$) for a given amount of habitat (area) is:

$$\hat{y} = -220.85 + 0.0025(\text{area}) + \varepsilon$$

Table 27. Regression results using real scale data for parameter estimates. Data are the mean high count at leks for a given amount of habitat within each GrSG population.

Model	d.f.	MSE	F	P>F	R^2	β_o	β_1
$\hat{y} = \beta o + \beta 1x + \varepsilon$	8	436,576.96	16.01	0.0039	0.667	-220.85	0.0025

Using information from Table 27, the 95% Confidence Interval (C.I.) for the estimated average number of males is computed as:

$$\text{C.I.} = \hat{y} \pm t_{0.5,d.f.} \sqrt{MSE\left[\frac{1}{n} + \frac{(xi - \bar{x})^2}{SS(X)}\right]}$$

where $\hat{y}$ is the predicted number of males on leks for a given amount of available habitat, $t_{0.5,d.f.}$ is the critical value for the *t*-distribution for a given number of degrees of freedom ($t_{0.5,8} = 2.306$), *MSE* is an estimate of variance (MSE =49,057.9663), *n* is the number of populations ($n = 10$), x_i is the amount of habitat being used for the estimate, $\bar{x}$ is the mean available habitat computed from values in Table 25 ($\bar{x} = 240{,}028.6$), and *SS(X)* is the sum of squares for available habitat across all populations (*SS(X)* = 80,896,676,122).

For example, for 250,000 acres of habitat, the predicted average number of males on leks ($\hat{y}$) is estimated as,

$$\hat{y} = \beta_o + \beta_1(x_i)$$
$$\hat{y} = -220.88 + 0.0025(250{,}000)$$
$$\hat{y} = 404$$

Using the values given above, the 95% C.I. range for expected number of males (Fig. 40) is computed as,

$$\text{C.I.} = 404 \pm 2.306\sqrt{436{,}540.7\left[\frac{1}{10} + \frac{(250{,}000 - 240{,}031.3)^2}{80{,}893{,}177{,}628}\right]}$$
$$= 404 \pm 162.5$$

Therefore, in this example, the expected mean number of males could potentially range from 242 to 567 males.

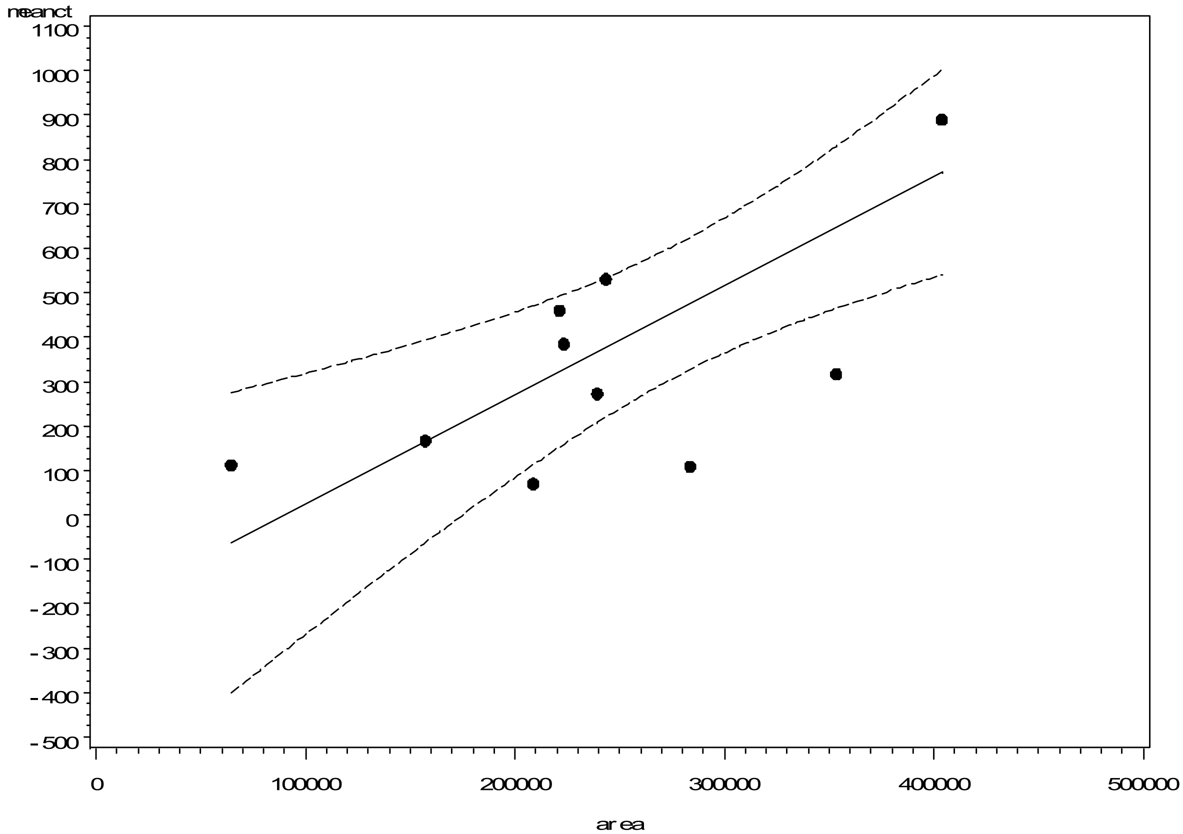


Fig. 40. Linear model (with 95% C.I.) relating the number of males (mean high count at leks) within each of the 10 GrSG populations or management zones (● = mean high count of males at leks for each population, area is in acres). See Table 25 for the area and mean lek count for each population and number of years included in the mean. Mean high male lek counts were weighted in each model by the number of years of counts included in the mean.

D. Colorado GrSG Population Management Zones

Population Management Zone Development

There are several challenges to developing population targets, or “population management zones” for sage-grouse. First, lek counts are the only current means of estimating population status and trends. However, there are limitations to using lek counts as indicators of a given population’s status (see summary of population estimation in “Conclusions”, pg. 55), and as a result, trends in lek counts should be considered relative, not absolute, indicators of population trends. Note that, for the purposes of this plan, we estimate only the number of breeding GrSG males in each local population, not the total population size (see Table 7, pg. 56; for locations of populations, see Fig. 5, pg. 49).

Second, many of the counts of strutting males are not normally distributed over time (from a statistical perspective), and counts are skewed to earlier or later counts. We chose to use the median of the raw annual lek data to evaluate long-term trends in lek counts, rather than using the arithmetic average (mean) of the data. The median is the mid-point of the data, with ½ of the data falling above it and ½ below. Typically, the median is a preferred descriptive statistic for data sets with a skewed distribution because it better represents the central tendency of a population than does the mean.

Third, the reliability of lek counts in individual populations and among years varies, depending on many factors, such as (1) weather conditions; and (2) the relative effort afforded to conducting lek counts in a given year and for a given population. We developed population management zones for GrSG that are based on a series of the most reliable strutting male counts for each population. In some cases the most reliable counts were from only the last 3 years (PPR population), but in other cases it was 8 (NWCO and Management Zones, NESR), 18 (MP), or 33 (NP) years.

Fourth, a reasonable approach for establishing population management zones for GrSG must take into account that sage-grouse populations naturally fluctuate over time with changes in environmental conditions. A good example of natural population fluctuations is seen in North Park, Colorado, where GrSG habitat has been relatively stable for 30 years, and where lek counts have been monitored with similar intensity of effort for over 30 years (Fig. 41). The average number of males counted on leks was 862, but that average was punctuated by counts as low as 497 (1986) and counts as high as 1,521 (1979; Fig. 41). Thus, even in an area of relatively stable habitat, 2 - 3 times more males were counted in high years than in low years. The total number of males counted in low and high years was 60 and 176% of the long-term average, respectively. Given this variation, lek counts in most years can be substantially above or below the long-term average (Fig. 41).

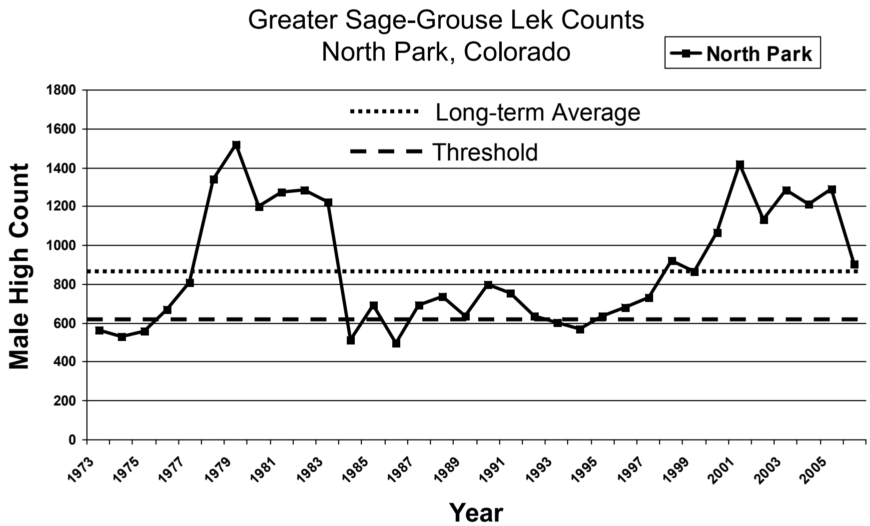


Fig. 41. Historical lek counts in North Park, Colorado. "Threshold" refers to the 25% quartile.

Because counts fluctuate widely, we used additional descriptive statistics to help accommodate this fluctuation and to assist in population management zone development. First, we recommend that the fluctuations in annual counts be dampened by using a 3-year running average (the average of the most recent 3 years of lek counts), instead of the raw lek count data. In addition, we use the range of data in designating a population management zone, rather than choosing a single, specific number. To develop population management zones we employed the "quartiles" of the data, which are the boundaries between 4 equal divisions of the data. That is, the 25% quartile is the point below which ¼ of the lek count data fall, and the 75% quartile is the point below which ¾ of the data fall. The long-term median is the same as the 50% quartile, below which ½ of the data fall.

Population Management Zone

We recommend that the population management zone be a numerical range, bounded on the lower extreme by the 25% quartile of the number of strutting males and on the upper extreme by the 75% quartile (Fig. 42). This range is termed the "Population Management Zone". This represents the normal range of variability that can be expected within this population based on the counts used. The 75% quartile is not intended as a population limit, but rather describes the upper bound of the range of the number of males, taking into account normal fluctuation in number of males over time (based on the lek counts used). If local areas can achieve male numbers in excess of the upper 75% quartile, the population becomes more secure and has a security buffer during periods of decline. It is assumed that the farther the number of males stays above the median (regardless of the upper quartile), and the longer the period it is above the median, the more secure the population.

For example, in a theoretical population with 10 years of counts, the median is 182 males (Fig. 42). The raw annual counts range from 55 - 380 males and the 3-year running average ranges from 118 - 352. The zone is bounded by the 25% quartile of 109 males and the 75% quartile of 294 males (Fig. 42).

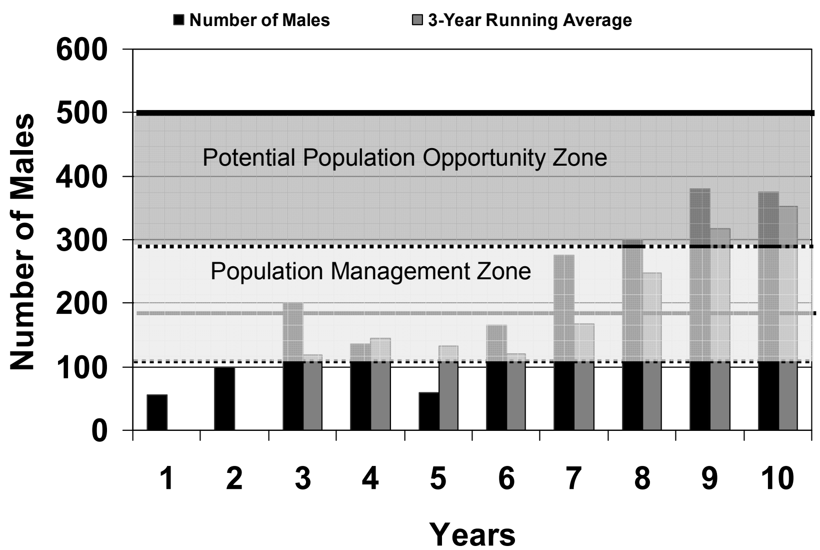


Fig. 42. Theoretical population management zones.

If a series of lek counts for a given population declines toward, through, and below the median, managers should increase efforts to evaluate the decline. If the decline is systemic and consistent, conservation actions should be implemented before the population passes through and below the 25% quartile threshold (e.g., below 109 males in Fig. 42).

Our choice of the 25% quartile as the lower threshold for the Population Management Zone was based on the performance of the GrSG population in North Park, Colorado. In the North Park data set, the number of GrSG males counted on leks declined below the 25% quartile threshold (approximately 600 males) in 6 of 31 years (Fig. 41). Since NP is a relatively stable population, this threshold creates an error rate (false-positives) of 19% (6/31). However, if the first 3 years of the data set are excluded (a reasonable exclusion because many lek locations were still being discovered at that time), then male counts fell below the threshold in only 3 of 28 years, yielding a false positive rate of about 11%. Thus, the 25% quartile threshold seems to give a reasonable probability of detecting real long-term declines while protecting against panic when population declines are within normal ranges of variation (Fig. 41).

Another value reported for each population is the estimated number of males generated by the habitat model discussed earlier (i.e., how many GrSG males are predicted to occur in the population areas, based on the number of acres of occupied habitat; see "Habitat Model Analysis", pg. 241). We also report this estimate's range, or 95% confidence interval, to elucidate the variability that is assigned to the prediction (Table 28). The number of males predicted by the model was not used in establishing the population management zones, and is not a target or goal. It is, however, instructive to see this value as compared to the range of values in the Population Management Zone itself, which are based on lek counts.

Potential Population Opportunity Zone

We examined whether it is possible for any of the GrSG populations to have opportunity to grow and/or expand. In some GrSG populations, there appears to be vacant and potentially suitable habitat available (see "GrSG Habitat Mapping Efforts", pg. 66). The location and extent of vacant and potentially suitable habitat was identified through a GIS analysis and modified by expert opinion of CDOW biologists. Future additional ground verification of potential habitat should be conducted at the local level to ascertain where specific opportunities for population growth truly exist; GIS mapping may infer an opportunity for growth that may not be possible if vegetation community conditions on the ground differ markedly from the GIS map.

Due to the existence of currently unoccupied habitats, some populations have opportunity for growth, termed the "Potential Population Opportunity Zone" (Fig. 42). This zone should not be interpreted as a population target for current conditions. This zone is a hypothetical zone of opportunity based on what could occur if (1) vacant habitat becomes occupied (or is found to be occupied); and/or (2) potential habitat is converted to optimal GrSG habitat (e.g., conversion of piñon-juniper back to sagebrush communities) and becomes occupied. To have GrSG populations grow and persist in potential population opportunity zones would require tremendous inputs of resources and funding. In some cases, due to possible inaccuracies in the GIS vegetation layer classification, it may be unrealistic, impractical, or impossible to convert those communities identified as potential habitat into occupied habitat.

The Potential Population Opportunity Zone is bounded at the lower extreme by the 75% quartile (the upper boundary of the Population Management Zone). To estimate the upper boundary of this zone, we used the habitat model to statistically estimate the number of GrSG males anticipated if the vacant and potential habitat became occupied by GrSG (see "Habitat Model Analysis", pg. 241). Thus, the upper boundary is the number of males predicted to occur in the combined occupied, vacant, and potential habitat categories (Table 28). In addition, the 95% confidence intervals around this predicted value are provided to illustrate the range of the estimate of potential additional males (Table 28).

Although the Population Management Zone and Potential Population Opportunity Zone should be modified as conditions change, the lower threshold of the Population Management Zone is based on current conditions and will not change. That is, we consider current population and habitat conditions to be the baseline for evaluating future GrSG trends, as well as the basis for determining whether to expedite conservation activities even as population levels increase.

Adaptive Management of Population Management Zones

The population zone approach we use incorporates the normal expected population fluctuation. **Since population management zones are based on current population estimates and potential habitat conditions, the upper bounds could be modified upward as habitat conditions and availability change, but lower bounds would remain constant.** We do not know, and can not predict, the effect of changes in landscape features (e.g., habitat composition, patch configuration, and land use patterns) on GrSG behavior and population dynamics; therefore, population management zones should be modified as knowledge improves about landscape features and how they are used by GrSG (see "Adaptive Management " pg. 10). We anticipate that implementation of the habitat management strategies described within this plan will result in increases in population levels and management zones, minimizing the likelihood of endangerment of individual GrSG populations or of the species in Colorado.

Individual GrSG Populations

For each GrSG population in Colorado, and for each management zone within the NWCO population, we defined the population zones described, if there were adequate data to do so. The boundaries of the Population Management Zone were examined and compared to (1) the number of sage-grouse predicted to be in the area, based on an analysis of the amount of habitat using the habitat model (see "Habitat Model Analysis, pg. 241); and (2) the initial population size used in the baseline PVA analysis, the resulting extinction risk for the population, and the implications (see "Population Viability Analysis", pg. 210). We also evaluated whether there was opportunity for population growth, and if so, identified a Potential Population Opportunity Zone.

Meeker – White River Population

No population zones have been set for the MWR population because lek counts have not been adequate for establishing a reliable long-term median. Strutting male counts have fluctuated around 25 strutting males, and it is estimated that there are 39,627 acres of occupied habitat and 51,125 acres of vacant and potential habitat available (Table 28). Because the habitat acreages are low, the habitat model's predictive ability is inadequate to provide a predicted value of the number of male GrSG (Table 28). Although there appears to be a substantial area of potential habitat available for GrSG, most of the habitat is in private ownership. According to the population viability analysis, the probability of extinction at 50 years is not equal to zero (PE_{50} = 0.016; Appendix K, pg. K-14) for the MWR population, assuming an initial population of 28 strutting males.

Table 28. Estimated habitat in each GrSG population area in Colorado, by habitat category, and the number of GrSG males predicted by the habitat model (see pg. 241) to occur in combined habitat categories (habitat categories are defined and described on pg. 66).

Population	Habitat Estimates (acres)			# GrSG Males Predicted for Combined Habitat Categories (estimated by Habitat Model; see pg. 241) [a]					
	Occupied	Vacant	Potential	Occupied		Occupied + Vacant (total)		Occupied + Vacant + Potential (total)	
				Range	Value	Range	Value	Range	Value[b]
Meeker – White River	39,627	5,713	45,412	0 - 271	–	0 - 276	–	0 - 315	–
Middle Park	239,446	4,741	5,725	205 - 529	367	217 - 540	379	230 - 555	393
North Park	403,972	0	0	435 – 1,107	771	same	same	same	same
N. Eagle – S. Routt Counties	85,463	8,155	96,236	0 - 310	–	0 - 318	–	60 - 430	245
Northwest Colorado	1,768,117	47,801	72,462	1,372 – 6,869	4,121	1,403 - 7,073	4238	1,451 - 7,380	4,416
NW - MZ 1	157,366	0	0	0 – 385	166	same	same	same	same
NW - MZ 2	560,195[c]	0	0	c					
NW - MZ 3A	221,370	0	0	158 – 488	323	same	same	same	same
NW - MZ 3B	243,615	0	0	216 – 539	377	same	same	same	same
NW - MZ 3C	283,871	0	0	296 – 656	476	same	same	same	same
NW - MZ 4A	64,653	0	6,413	0 – 292	–	–	–	0 – 297	–
NW - MZ 4B	208,884	16,877	14,966	121 – 463	292	170 – 497	333	208 - 532	370
NW - MZ 5	353,618	5,768	46,782	387 – 907	647	393 – 930	662	437 - 1,116	776
NW - MZ 6	223,491	25,156	4,301	163 – 492	328	227 – 552	390	237 - 563	400
NW - MZ 7	11,250	0	0	–	–	–	–	–	–
Parachute – Piceance – Roan[d]	262,811	84,909	187,498	d					

[a] In cases where the estimated habitat acreage is low, the habitat model's predictive ability may be inadequate to predict a value and/or range of number of male GrSG (denoted by " – ").
[b] Note that the estimated value for this combined habitat category is the upper bound of the Potential Population Opportunity Zone (Table 29).
[c] Acreage for MZ 2 includes the total acreage of all vegetation classes (not just selected classes) within the occupied range; it is not included in the total occupied habitat for NWCO. Because there may be inaccuracies in the GIS data used to define occupied habitat for MZ 2, the habitat-based model was not used to make predictions of number of males.
[d] The habitat areas defined for PPR need to be field-validated; there may be inaccuracies in the GIS data used to define these areas. Thus, the habitat-based model was not used to make predictions of number of males for PPR.

<u>*Middle Park Population*</u>

The Population Management Zone for MP has a median of 250 strutting males and ranges from 185 - 286 (Fig. 43, Table 29). The habitat model ("Habitat Model Analysis", pg. 241) predicts that MP could have 367 strutting males, with a range of 205 - 529, in 239,446 acres of occupied habitat (Table 28). The results from the PVA suggest that the Population Management Zone is sufficient to maintain the MP population in perpetuity. According to the PVA, the probability of extinction at 50 years is zero (PE_{50} = 0.000; see Appendix K, pg. K-14) for the MP population, assuming an initial population (290 strutting males) that is slightly above the upper end of the Population Management Zone. If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented.

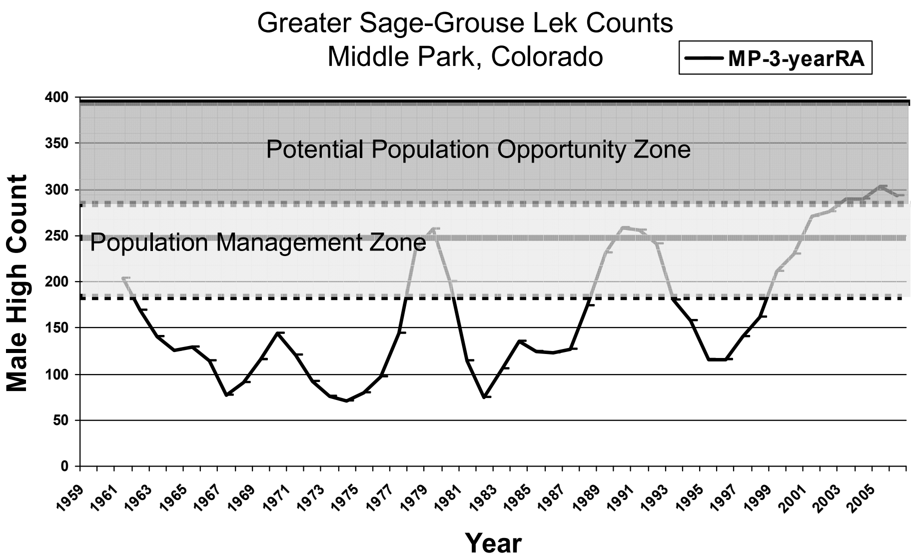


Fig. 43. Population management zones for MP GrSG population.

According to the GIS habitat analyses, it is estimated that there are 10,466 acres of habitat in the vacant and potential habitat categories in MP (Table 28), allowing an opportunity for population growth. If the vacant and potential habitats become occupied habitat, the habitat model predicts that 393 strutting males (range of 230 - 555) could occur in the MP area (Table 28). Thus, the Potential Population Opportunity Zone is from 286 - 393 strutting males (Fig. 43, Table 29); there appears to be habitat to sustain a small amount of growth in this population.

Table 29. Population Management Zones for GrSG in Colorado.

Population	Population Management Zone			Potential Population Opportunity Zone	
	25% Quartile	Median	75% Quartile	Lower Bound[a]	Upper Bound[b]
Meeker – White River	-	~25	-	-	-
Middle Park	185	250	286	286	393
North Park	639	756	1,214	-	-
N. Eagle – S. Routt Counties	90	97	102	102	245
Northwest Colorado	2,019	2,144	2,254	2,254	4,416
NWCO - MZ 1	136	164	183	-	-
NWCO - MZ 2	-	-	-	-	-
NWCO - MZ 3A	346	436	534	-	-
NWCO - MZ 3B	351	627	698	-	-
NWCO - MZ 3C	65	126	155	-	-
NWCO - MZ 4A	51	66	167	-	-
NWCO - MZ 4B	48	53	83	83	370
NWCO - MZ 5	258	310	383	383	776
NWCO - MZ 6	333	353	441	-	-
NWCO - MZ 7	-	-	-	-	-
Parachute – Piceance – Roan	176	178	202	-	-

[a] Note that the lower bound of the Potential Population Opportunity Zone is also the upper bound (75% quartile) of the Population Management Zone.
[b] The upper bound of the Potential Population Opportunity Zone is the number of male GrSG predicted by the habitat model for occupied + vacant + potential habitat (see Table 28).

North Park Population

The Population Management Zone for the NP population has a median of 756 strutting males and ranges from 639 - 1,214 (Fig. 44, Table 29). The habitat model (see "Habitat Model Analysis", pg. 241) predicts that NP could have 771 strutting males, with a range of 435 - 1,107, in 403,972 acres of occupied habitat (Table 28). Results from the PVA suggest that the Population Management Zone appears sufficient to maintain NP GrSG in perpetuity. According to the PVA, the probability of extinction at 50 years is zero (PE_{50} = 0.000; see Appendix K, pg. K-14A) for the entire NP population, assuming an initial population (1,234 strutting males) that is very close to the upper bound of the Population Management Zone. If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented. Based on the GIS habitat analyses, there are no opportunities for population growth in the NP population (Table 28; no vacant or potential habitat).

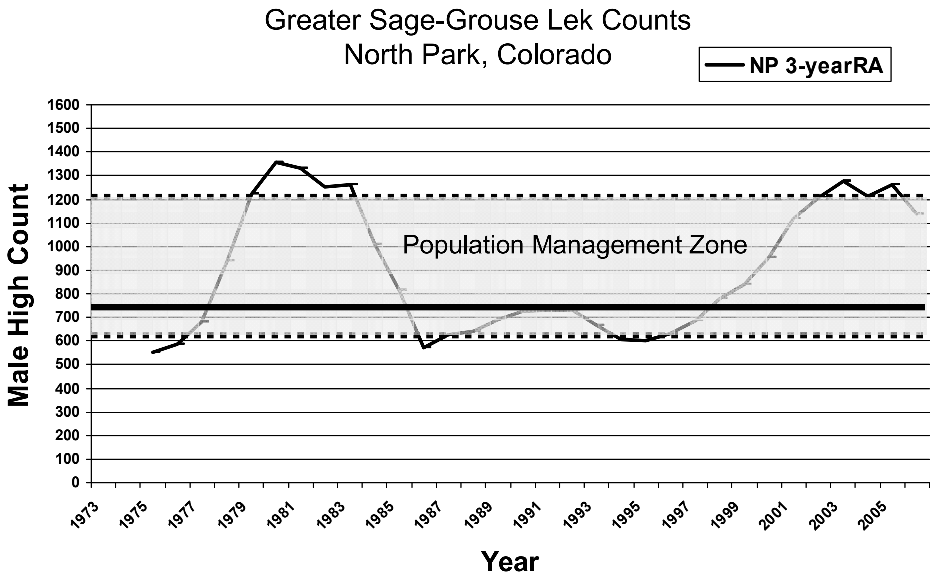


Fig. 44. Population management zones for NP GrSG population.

Northern Eagle – Southern Routt Counties Population

The Population Management Zone for the NESR population has a median of 97 strutting males and ranges from 90 - 102 (Fig. 45, Table 29). The habitat model (see "Habitat Model Analysis", pg. 241) predicts that the NESR area could sustain 0 - 310 strutting males in 85,463 acres of occupied habitat (because the habitat acreages are low, the habitat model's predictive ability is inadequate to provide a single predicted value of the number of male GrSG; Table 28). Results from the PVA suggest that the Population Management Zone is sufficient to maintain the NESR population in perpetuity. According to the PVA, the probability of extinction at 50 years is zero for the NESR population (PE_{50} = 0.000; see Appendix K, pg. K-14), assuming an initial population (104 strutting males) that is very close to the upper bound of the Population Management Zone. If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented.

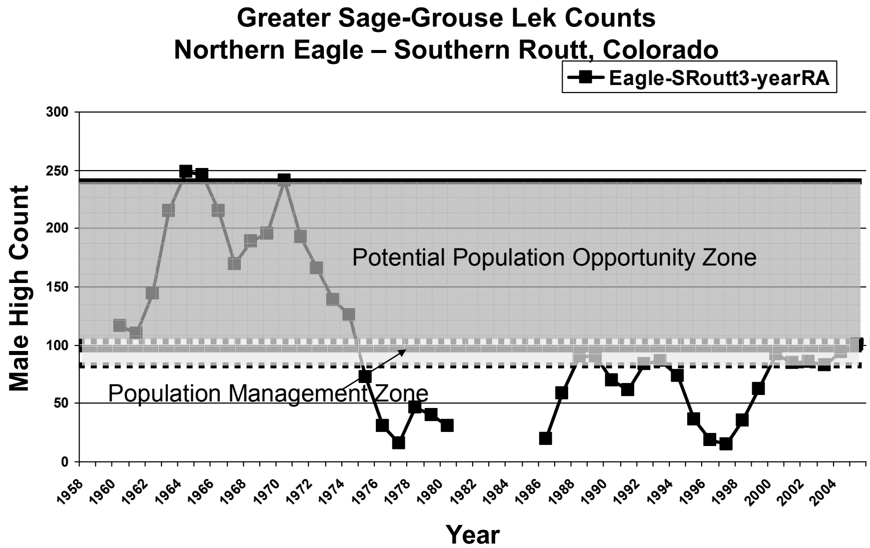


Fig. 45. Population management zones for NESR GrSG population.

According to the GIS habitat analyses, it is estimated that there are 104,391 acres of habitat in the vacant and potential habitat categories (Table 28), allowing an opportunity for population growth in the NESR population. If the vacant and potential habitats become occupied habitat, the habitat model predicts that 245 strutting males, with a range from 60 - 430 males, could occur in the NESR area (Table 28). Thus, the Potential Population Opportunity Zone ranges from 102 - 245 males (Fig. 45, Table 29); there appears to be habitat to sustain a possible doubling of the NESR population.

Northwest Colorado Population

The NWCO population is divided into 10 geographic areas called "management zones" (NWCOCP 2006; see Fig. 16, pg. 88). Because in this section we use the term "Population Management Zone" to represent a population target, there might be confusion about the similar terms. Therefore, in this section, we refer to the 10 management zones in the NWCO area by acronyms (MZ). For example, "Management Zone 1" is "MZ 1".

Population management zones were derived for the entire NWCO population and also separately for each MZ. Because counts were conducted inconsistently earlier than 1998, only 8 years of lek counts (1998-2005) were used to calculate population management zones. More consistent lek counts were conducted for 8 years in MZ 1, and portions of MZ 3A, 3B, and 3C, 4A, 4B, 5 and 6. Less consistent counts have been conducted in MZ 2 and 7 of the NWCO population.

The Population Management Zone for NWCO has a median of 2,144 strutting males, with a range from 2,019 - 2,254 (Fig. 46, Table 29). The habitat model predicts that 4,121 males, with a range from 1,372 - 6,869, could be supported within 1,768,117 acres of occupied habitat (Table 28). Results from the PVA suggest that the Population Management Zone is sufficient to maintain the NWCO population in perpetuity. According to the PVA, the probability of extinction at 50 years is zero (PE_{50} = 0.000; see Appendix K, pg. K-14) for the NWCO population, assuming an initial population size (2,387 strutting males) that is close to the upper bound of the Population Management Zone. If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented.

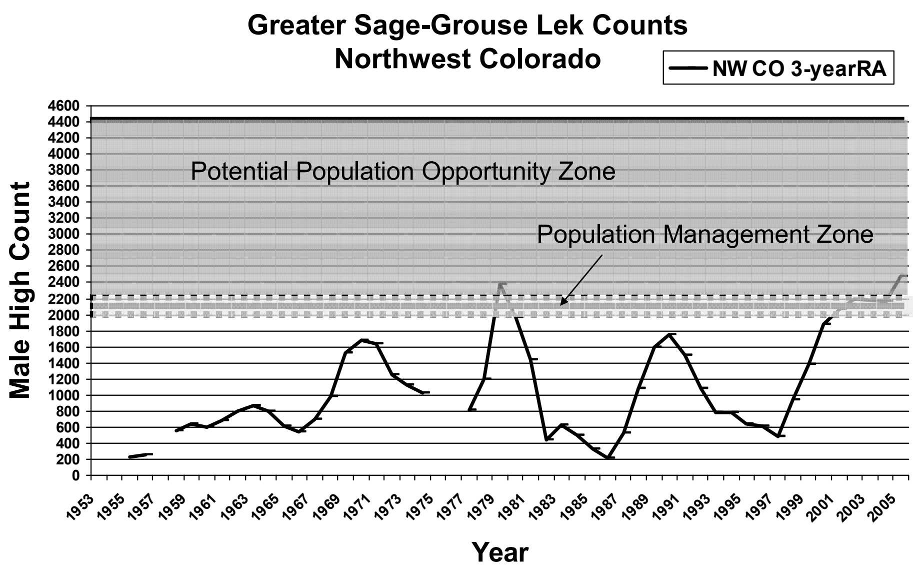


Fig. 46. Population management zones for NWCO GrSG population.

According to the GIS habitat analyses, it is estimated that there are 120,263 acres of habitat in the vacant and potential habitat categories (Table 28), allowing an opportunity for additional males in the NWCO population. If the vacant and potential habitats become occupied habitat, the habitat model predicts that 4,416 strutting males (range of 1,451 - 7,380) could occur in the NWCO area (Table 28). Thus, the Population Opportunity Zone ranges from 2,254 - 4,416 strutting males (Fig. 46, Table 29). The analysis suggests that the habitat opportunity for the NWCO area is located in MZs 4A, 4B, 5, and 6 (Table 28).

NWCO MZ 1 -- The Population Management Zone for NWCO MZ 1 has a median of 164 strutting males and ranges from 136 - 183 (Fig. 47, Table 29). The habitat model (see “Habitat Model Analysis”, pg. 241) predicts that MZ 1 could support 166 males, with a range from 0 - 385, in 157,366 acres of occupied habitat (Table 28). Results from the PVA suggest that the

Population Management Zone is sufficient to maintain the MZ 1 population in perpetuity. According to the PVA, the probability of extinction at 50 years is zero for the MZ 1 population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population of 153 strutting males. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 2, 3A, 6, and 7). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented. Based on the GIS habitat analyses, there is no opportunity for population growth in the Potential Population Opportunity Zone (Table 28; no vacant or potential habitat).

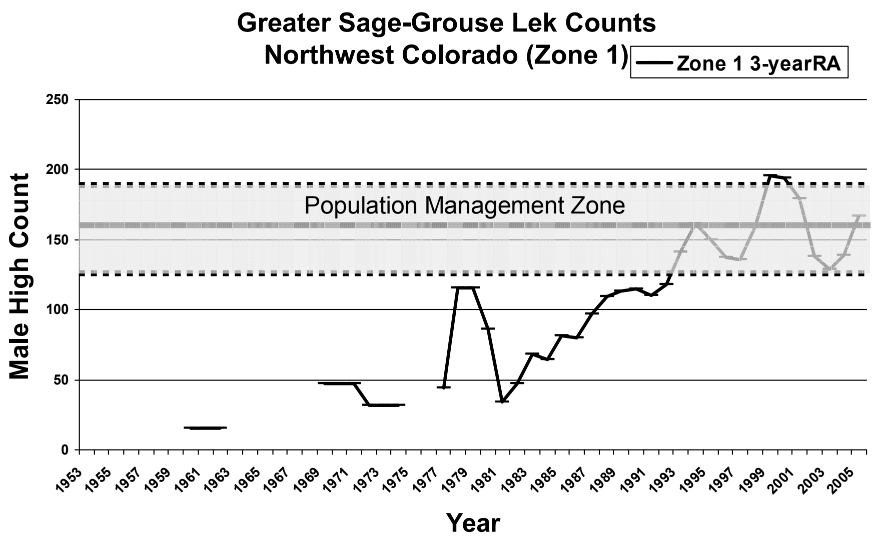


Fig. 47. Population management zones for MZ 1 of the NWCO GrSG population.

NWCO MZ 2 -- No population management zones have been developed for NWCO MZ 2 because lek counts have not been adequate to establish a reliable long-term or short-term median. Strutting male counts have varied between 10 - 54 males over the last 8 years and have occurred in an area that is estimated to have 560,195 acres of occupied habitat (Table 28). However, after closer analysis it is clear that the majority of occupied habitat in MZ 2 (identified by the GIS as sage-grouse habitat) is dominated by salt desert shrub communities, with only small outcrops of Wyoming big sagebrush, which has limited quality and may serve as winter habitat for GrSG. Despite this, the small population in MZ 2 is expected to persist under current conditions. The probability of extinction for the entire NWCO population at 50 years is zero (PE_{50} = 0.000; see Appendix K, pg. K-21), and the model allows for emigration and immigration to and from other areas in the vicinity (MZs 1, 3A, 3B, 3D, 5, 6 and 7).

NWCO MZ 3A -- The Population Management Zone for NWCO MZ 3A has a median of 436 strutting males and ranges from 346 - 534 (Fig. 48, Table 29). The habitat model (see “Habitat Model Analysis”, pg. 241) predicts that NWCO MZ 3A could support 323 males, with a range of

158 - 488, in 221,370 acres of habitat (Table 28). Results from the PVA suggest that the Population Management Zone is sufficient to maintain the MZ 3A population in perpetuity. According to the PVA, the probability of extinction at 50 years is zero for the MZ 3A population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population (534 strutting males) that is within the Population Management Zone. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 2, 3B, 3C, 5, and 6). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented. Based on the GIS habitat analyses, there is no opportunity for population growth in the Potential Population Opportunity Zone (Table 28; no vacant or potential habitat).

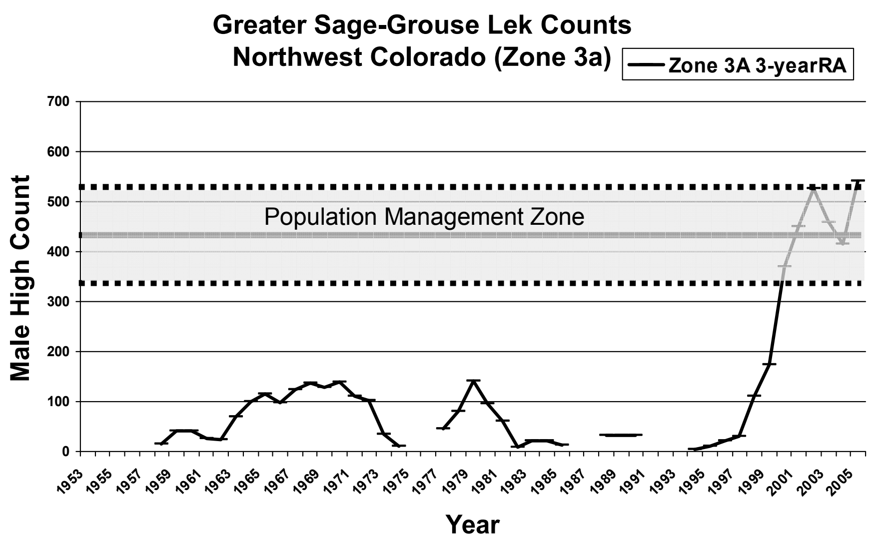


Fig. 48. Population management zones for MZ 3A of the NWCO GrSG population.

NWCO MZ 3B -- The Population Management Zone for MZ 3B has a median of 627 strutting males and ranges from 351 - 698 (Fig. 49, Table 29). The habitat model ("Habitat Model Analysis", pg. 241) predicts that MZ 3B can support 377 strutting males, with a range of 216 - 539, in 243,615 acres of occupied habitat (Table 28). According to the PVA, the probability of extinction at 50 years is zero for the MZ 3B population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population (625 strutting males) that is within the Population Management Zone. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 2, 3A, 3C, 4A, and 5). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented. Based on the GIS habitat analyses, there is no opportunity for population growth in the Potential Population Opportunity Zone (Table 28, no vacant or potential habitat).

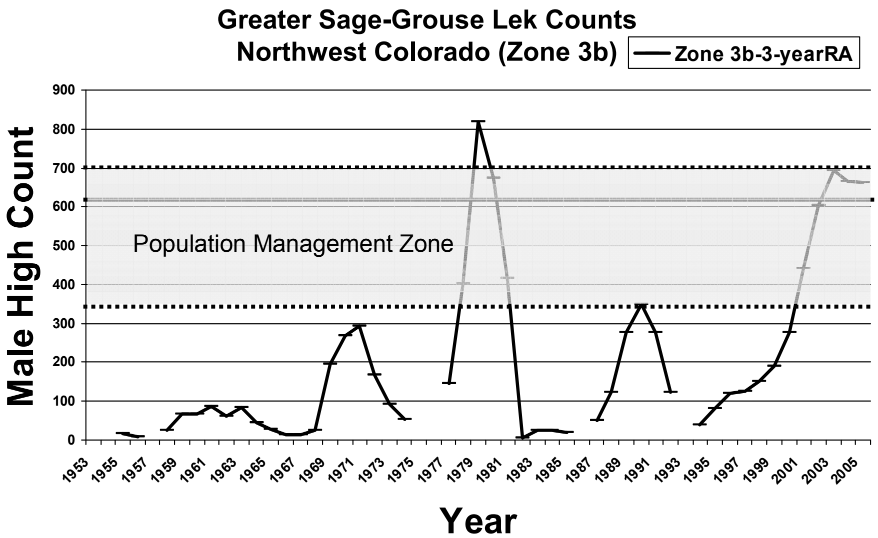


Fig. 49. Population management zones for MZ 3B of the NWCO GrSG population.

NWCO MZ 3C -- The Population Management Zone for MZ 3C has a median of 126 strutting males and ranges from 65 - 155 (Fig. 50, Table 29). The habitat model ("Habitat Model Analysis", pg. 241) predicts that MZ 3C can support 476 males, with a range of 296 - 656, in 283,871 acres of occupied habitat (Table 28). According to the PVA, the probability of extinction at 50 years is zero for the MZ 3C population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population (139 strutting males) that is within the Population Management Zone. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 3A, 3B, 4A, 4B, and 5). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented. Based on the GIS habitat analyses, there is no opportunity for population growth in the Potential Population Opportunity Zone (Table 28, no vacant or potential habitat).

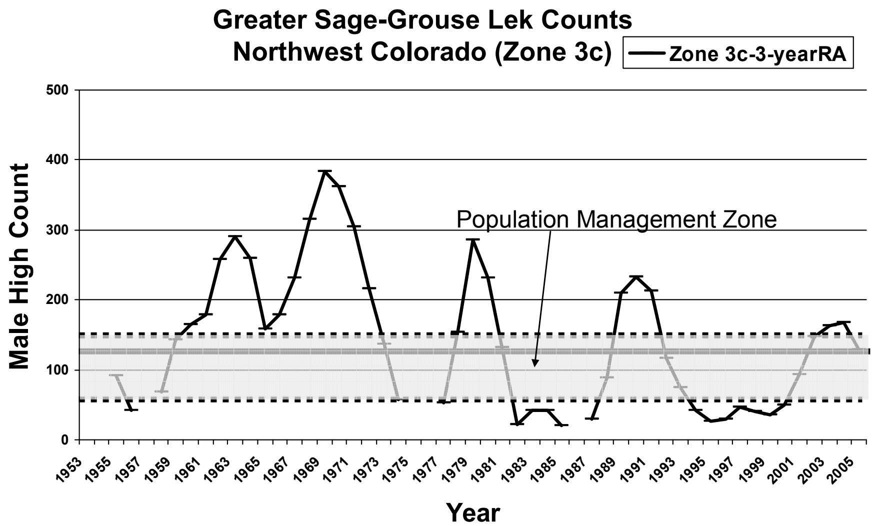


Fig. 50. Population management zones for MZ 3C of the NWCO GrSG population.

NWCO MZ 4A -- The Population Management Zone for MZ 4A has a median of 66 strutting males and ranges from 51 - 167 (Fig. 51, Table 29). The habitat model (see "Habitat Model Analysis, pg. 241) predicts that a very small grouse population could occur (range from 0 - 292) in 64,653 acres of occupied habitat in MZ 4A (Table 28). According to the PVA, the probability of extinction at 50 years is zero for the MZ 4A population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population of 217 strutting males. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 3B and 4B). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented. Because of the limited amount of potential habitat (6,413 acres; Table 28), there is very little opportunity for population growth in MZ 4A; no Potential Population Opportunity Zone was identified.

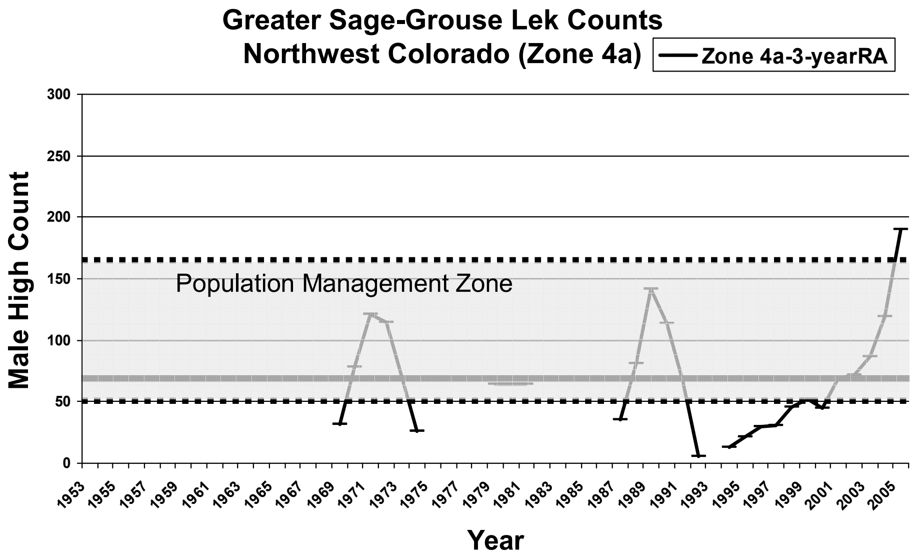


Fig. 51. Population management zones for MZ 4A of the NWCO GrSG population.

NWCO MZ 4B -- The Population Management Zone for MZ 4B has a median of 53 strutting males and ranges from 48 - 83 (Fig. 52, Table 29). The habitat model (see "Habitat Model Analysis", pg. 241) predicts that MZ 4B could sustain 292 strutting males, with a range of 121 - 463, in 208,884 acres of habitat (Table 28). According to the PVA, the probability of extinction at 50 years is zero for the MZ 4B population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population (76 strutting males) that is within the Population Management Zone. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 3C, 4A, and 5). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented.

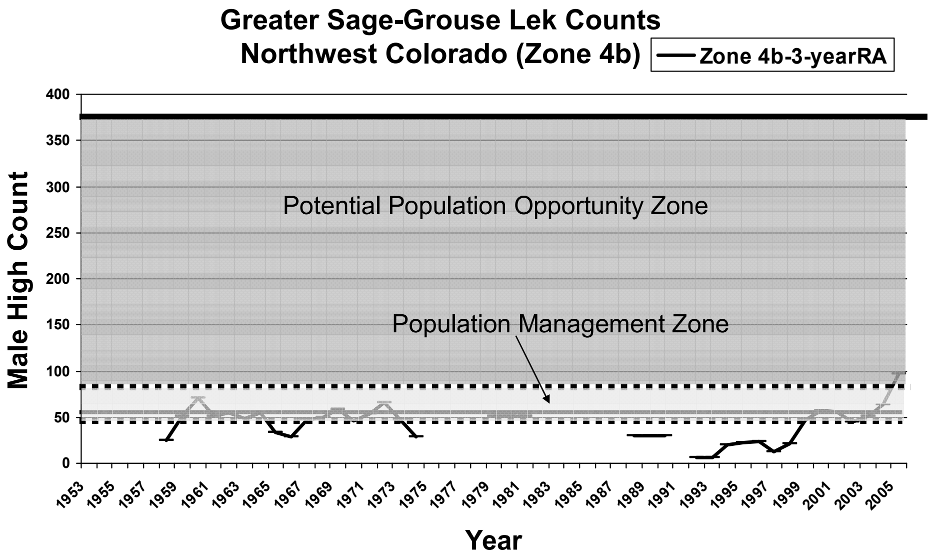


Fig. 52. Population management zones for MZ 4B of the NWCO GrSG population.

According to the GIS habitat analyses, it is estimated that there are 31,843 acres of habitat in the vacant and potential categories (Table 28), allowing an opportunity for population growth in MZ 4B. If the vacant and potential habitat became occupied habitat, the habitat model predicts that 370 strutting males (range of 208 - 532) could occur in MZ 4B (Table 28). Thus, the Potential Population Opportunity Zone ranges from 83 - 370 strutting males (Fig. 52, Table 29); there is opportunity for some population growth within this area.

NWCO MZ 5 -- The Population Management Zone for MZ 5 has a median of 310 strutting males and ranges from 258 - 383 (Fig. 53, Table 29). The habitat model ("Habitat Model Analysis", pg. 241) predicts that MZ 5 could sustain 647 strutting males, with a range of 387 - 907, in 353,618 acres of occupied habitat (Table 28). According to the PVA, the probability of extinction at 50 years is zero for the MZ 5 population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population (294 strutting males) that is within the Population Management Zone. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 2, 3A, 3B, 3C, 4B, and 6). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented.

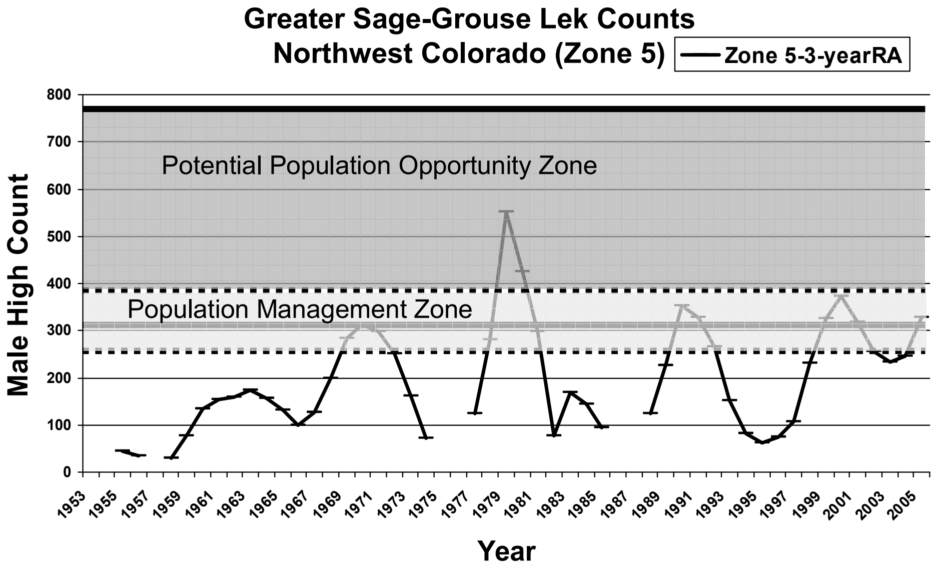


Fig. 53. Population management zones for MZ 5 of the NWCO GrSG population.

According to the GIS habitat analyses, it is estimated that there are 52,550 acres of habitat in the vacant and potential categories (Table 28), allowing an opportunity for population growth. If the vacant and potential habitats become occupied habitat, the habitat model predicts that 776 strutting males (range of 437 - 1,116) could occur in MZ 5 (Table 28). Thus, the Potential Population Opportunity Zone ranges from 383 - 776 strutting males (Fig. 53, Table 29); there may be opportunity for population growth in this area.

NWCO MZ 6 -- The Population Management Zone for MZ 6 has a median of 353 strutting males and ranges from 333 - 441 (Fig. 54, Table 29). The habitat model ("Habitat Model Analysis", pg. 241) predicts that MZ 6 could sustain 328 strutting males, with a range of 163- 492, in 223,491 acres of occupied habitat (Table 28). According to the PVA, the probability of extinction at 50 years is zero for the MZ 6 population (PE_{50} = 0.000; see Appendix K, pg. K-21), assuming an initial population (304 strutting males) that is close to the lower bound of the Population Management Zone. In addition, the model allows for emigration and immigration to and from other areas in the vicinity (MZs 1, 2, 3A, 5 and 7). If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented.

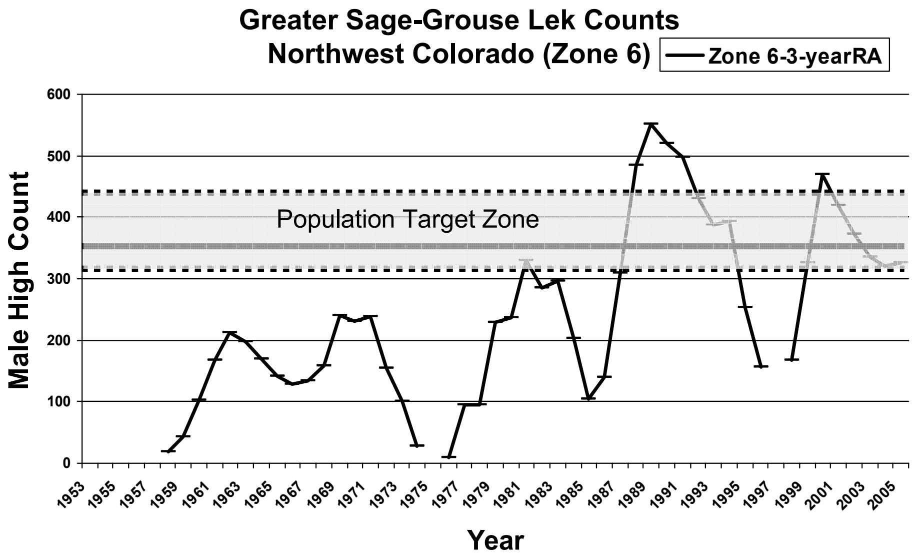


Fig. 54. Population management zones for MZ 6 of the NWCO GrSG population.

According to the GIS habitat analyses, it is estimated that there are 29,457 acres of habitat in the vacant and potential habitat categories, allowing an opportunity for population growth (Table 28). If the vacant and potential habitats become occupied habitat, the habitat model predicts that 400 strutting males (range of 237 - 563) could occur in MZ 6 (Table 28). Because this number falls within the Population Management Zone, there is no identified Potential Population Opportunity Zone; the opportunity for growth in this population is small.

NWCO MZ 7 -- A Population Management Zone has not been established for MZ 7 in NWCO. The lek counts have not been adequate to establish any long-term median. Only 2 years of strutting male counts have yielded between 11 - 23 males over the last 2 years. This MZ is estimated to have 11,250 acres of occupied habitat (Table 28). It is uncertain if MZ 7 can sustain a viable population in isolation and therefore its perpetuity is dependent upon the Utah population of GrSG, although there may be minimal immigration and/or emigration to and from MZs 1, 2, and 6 that would further support this population.

Parachute – Piceance – Roan Population

Recent lek counts in this population have been conducted by fixed wing and helicopter surveys, in addition to the traditional lek counts from the ground (which have been conducted inconsistently since 1963). Using only data from 2005, 2006, and 2007 (the 3 best and most reliable estimates), the Population Management Zone has a median of 178 strutting males and ranges from 176 - 202 (Fig. 55, Table 29). The habitat model was not used to predict the PPR population because of inaccuracies in the GIS portrayal of occupied habitat categories in PPR. Results of the PVA suggest that the Population Management Zone is sufficient to maintain the PPR population in perpetuity, although the model is based on the same limited data used to establish the population management zone. According to the PVA, the probability of extinction at 50 years is zero for the PPR population (PE_{50} = 0.000; see Appendix K, pg. K-14), assuming an initial population (186 strutting males) that is within the Population Management Zone.

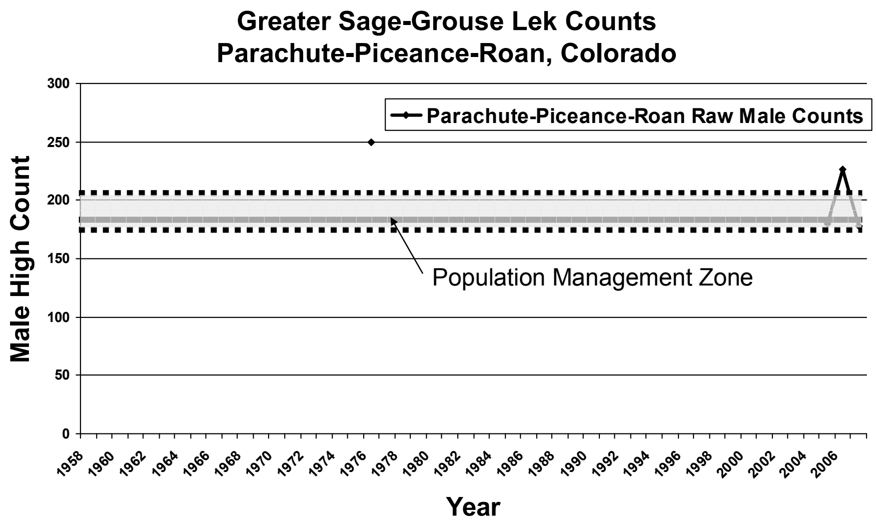


Fig. 55. Population management zones for PPR GrSG population.

If managers document consistent and unabated decline to and below the median (in the Population Management Zone), aggressive conservation actions should be implemented. Due to the irregular topography of the PPR area, further GIS habitat analyses need to be conducted to adequately determine if there is opportunity for population growth in the Potential Population Opportunity Zone.

E. GrSG Habitat-related GIS Analyses

Predicted Future Housing Development and GrSG Habitat Protection

Future Growth in Housing and its Potential Impact on Colorado GrSG Populations

We used U.S. Census Bureau data to examine projected human population increases in GrSG range. The U.S. Census Bureau projected population growth between 2000 and 2020 for each county in the United States (Colorado Department of Local Affairs 2004). The Bureau also projected the increase in housing units that would be expected from this population increase, based on a 10-year average of residents per housing unit. We examined these data for each county with an associated GrSG population (Table 30). It should be noted that county-wide projections only serve as a crude index to permanent habitat loss for GrSG, because growth may be concentrated in urban areas away from currently occupied habitat. The current human density is also provided, to scale the impact; i.e., a 50% increase in population may be more significant from a baseline of 50 people/mi^2 (rising to 75), than it is for a population of 2 people/mi^2 (rising to 3).

In conjunction with human population growth, the amount of private land in a population area will also influence the risk of habitat loss from housing development. Public lands are generally safe from housing development pressure (regardless of human population growth), and private lands are not (unless they are protected by easement). We summarized the amount of private lands within the 3 mapped habitat categories for GrSG: Occupied, Potential, and Vacant/Unknown (for habitat category definitions, see "GrSG Habitat Mapping Efforts" pg. 66).

Using these data, as well as local knowledge of the ongoing development processes in each population area, we established a relative level of risk to the population from housing development (Table 31). This table better portrays the issue of development for GrSG on private lands because the boundary for analysis is the habitat area itself, not the county boundary. Many populations (Table 30) cross county boundaries, making comparison of county level information to GrSG populations less meaningful. However, some conclusions can be drawn based on these data and development activity within each county and population. (For an analysis of the predicted location of future housing development see "Predicted Location of Future Housing Developments", pg. 273.)

Table 30. Summary of human population growth and housing development statistics in GrSG counties.

County	GrSG Population(s) Affected	Projected Population Growth [a]	Projected Growth in Housing Units [b]	Current People/sq. mile [c]
Eagle	Northern Eagle – Southern Routt	57%	9,082	27
Garfield	Parachute – Piceance – Roan	73%	12,220	15
Grand	Middle Park	75%	4,083	7
Jackson	North Park	17%	116	1
Moffat	Northwest Colorado	23%	1,182	3
Rio Blanco	Northwest Colorado, Meeker – White River, Parachute – Piceance – Roan	27%	648	2
Routt	Northwest Colorado, Northern Eagle – Southern Routt	52%	4,278	8
Summit	Middle Park	60%	6,273	42

[a] Based on Census Bureau projections for county population resides in, 2000-2020.
[b] Calculated by dividing population projections by the 10-year average of residents per housing unit.
[c] Calculated by using 2000 Census populations divided by total square miles in county, acquired from CDOW CoMap, Version 4

Table 31. Amount of private land within occupied, potential, and vacant/unknown GrSG habitats, and overall potential risk from human development.

GrSG Population	Private Land [a]			Potential Risk to GrSG from Human Development
	Occupied Habitat – Acres (% of total)	Potential Habitat – Acres (% of total)	Vacant-Unknown Habitat – Acres (% of total)	
Meeker – White River	36,834 (90%)	91,312 (78%)	2,663 (39%)	Moderate
Middle Park	148,675 (57%)	6,073 (94%)	3,905 (76%)	High
North Park	206,671 (52%)	0 (0%)	0 (0%)	Low
Northern Eagle – Southern Routt	67,480 (71%)	52,256 (41%)	10,880 (95%)	High
Northwest Colorado	1,046,147 (41%)	16,742 (48%)	30,832 (60%)	High in Zone 4B, remainder Low
Parachute – Piceance – Roan	199,212 (65%)	76,673 (35%)	14,6983 (15%)	Low

[a] Based on CDOW 2005 GIS species mapping and CDOW CoMap, Version 4

Meeker – White River Population

The MWR population is entirely within Rio Blanco County, a county projected to experience a 27% increase in human population between 2000 and 2020 (Table 30), which is at the lower end of the increases expected in other counties containing GrSG habitat. However, this small population exists nearly entirely on private land (Table 31) that is at considerable risk from development pressures. Ninety percent of occupied GrSG habitat is privately owned (Table 31) and relatively close to the town of Meeker, which in recent years has been experiencing growth due to the recent dramatic increase in energy development. Protection of existing range through conservation easements would be beneficial and may be necessary to sustain this small population.

Middle Park Population

The majority of the MP population is within Grand County, with a small segment of the occupied range extending south into Summit County. Both Grand and Summit counties have high projected increases in human population (75% for Grand and 60% for Summit, Table 30). The primary cause of this population increase is the proximity to major Colorado ski resorts, including Breckenridge, Keystone, and Winter Park. Ski industry employees in the Silverthorne/Frisco area are commuting farther to obtain affordable housing. In addition, the outstanding recreation opportunities in Grand County, primarily around Granby and Grand Lake, lure additional development to the area. Grand County currently has a density of 7 people/mi^2, while Summit County has a density of 42 people/mi^2 (Table 30). Private land makes up 57% of currently occupied range in the MP population (Table 31).

Over the past 20 years, Grand County has seen significant changes in the demographics and growth of its population. While western Grand County remains largely rural in nature, the eastern part of the county has seen a major shift from production agriculture to commercial and residential development. Approximately 60% of the homes in Grand County are considered second homes. Because of the area's close proximity to Denver, this trend is expected to continue. Many of the larger private holdings have been subdivided for housing or commercial use. The remaining ranches in the area now provide most of the sage-grouse habitat. Risk to this population from human development is high (Table 31). At-risk parcels important to GrSG should be identified and protected through conservation easements.

Northern Eagle – Southern Routt Counties Population

The NESR population straddles 2 rapidly developing counties, Routt and Eagle. The human population in Routt County is expected to grow 52% by 2020 and has a density of 8 people/mi^2; Eagle County is projected to grow by 57% and has a density of 27 people/mi^2 (Table 30). Seventy-one percent of occupied GrSG habitat in this population is on private land (Table 31). The primary influence affecting growth in the Eagle Zone of the population is caused by Vail and Beaver Creek ski resorts located in the Eagle Valley. Development has likely impacted sage-grouse habitat in the area, because some formerly occupied habitat in Eagle County no longer supports sage-grouse. Impacts to currently occupied habitats is expected to increase as subdivision of ranches for residential and second-home development occurs, driven in part by increased housing costs for resort and other service employees.

Unlike in the Eagle River Valley, ranching remains strong in the Routt Zone of this population. The towns of Phippsburg, Toponas, and Yampa are small and have grown relatively little in recent years, although new residences are beginning to appear in the area. These towns are relatively close ($\leq$40 miles) to Steamboat Springs and the tourist/resort economy found there, increasing the potential for this area to become a bedroom community as the cost of living rises in Steamboat Springs. Growth could be somewhat tempered in this area by the fact that winters are even harsher than in Steamboat and communities west and downstream of Steamboat Springs. An additional risk comes from second home development, which may occur far from Steamboat Springs. Overall, risk to this population from human development is high (Table 31).

Northwest Colorado Population

The NWCO population occurs in 3 counties (Moffat, Routt, and Rio Blanco), but the majority of the currently occupied range is in Moffat County. Moffat County is projected to increase population by 23% by 2020 and has a low density of 3 people/ mi^2 (Table 30). In comparison, Routt County, projected to grow 52% by 2020, has a density of 8 people/ mi^2 (Table 30). Rio Blanco County is projected to grow by 27% and also has a very low human density of 2 people/mi^2 (Table 30). Forty-one percent of the GrSG occupied habitat in this population occurs on private land (Table 31). The primary area of human development lies in the east portion of the population, between Craig and Steamboat Springs and surrounding areas, including Hayden. Risk from human development in the bulk of the population area is negligible. The central and western portions of this population (Zones 1, 2, 3A, 3B, 5, and 6) are amongst the most remote and sparsely populated areas of the state. The same zones also contain the highest numbers of GrSG in the population; hence human development pressure is not seen as a high risk to the GrSG core population in NWCO. Although risk of human development is relatively low in the entire population, it is high in Zone 4B (Table 31), and protection of key habitat in this area is important.

North Park Population

The NP population is located entirely in Jackson County. Human growth in this county is projected to increase only 17% by 2020, making it the slowest growing county within the Colorado range of GrSG (Table 30). In addition, the human density is also lowest at 1 person/square mile (Table 31). Fifty-two percent of occupied habitat in NP occurs on private land (Table 31). Ranching remains the largest use of private lands in this population. However, Jackson County is located close to Larimer County and may experience an increase in second home development. Total population in the entire county was estimated at 1,577 in 2000 (Colorado Department of Local Affairs 2007). Risk to GrSG from human development in this county is currently considered to be low (Table 31).

Parachute – Piceance – Roan Population

The PPR GrSG population lies within 2 counties, Garfield and Rio Blanco. Garfield County is experiencing a rapidly increasing human population growth (estimated to grow 73% by 2020; Table 30), due to multiple factors including serving as a bedroom community for the Aspen-Snowmass resort area, and energy development. However, while 65% of the occupied habitat for this population is on private land (Table 31), the potential for typical housing development is not as high as might be expected. Primary ownership of private parcels in this population is by energy companies. The likelihood of human development within the occupied habitat of GrSG is small; the primary impact to habitat loss in this GrSG population is through energy development, not housing development. Nevertheless, the energy industry is contemplating building worker camps in close proximity to the well fields within occupied grouse range. The motivation for such camps is to save commuting time for workers in the remote high plateaus and ridges where future energy development will occur. These camps could potentially house large numbers of workers during well field development periods. Over the longer term, they might be removed or reduced in size to accommodate a smaller work force during the production life of a well field.

Predicted Location of Future Housing Development in GrSG Population Areas

We used 2 methods to further explore the risk of additional housing development in GrSG habitat (see also "Housing Development and Surface Mining" in the PVA analysis, pg. 217). The intent of this analysis is to identify specific areas where risk of housing development is important, in order to help agencies and work groups with habitat protection efforts.

Dr. David Theobald, Natural Resource Ecology Lab, Colorado State University, developed a Spatially Explicit Regional Growth Model (SERGoM v2), designed to depict the location and density of current and projected future private land housing units across the coterminous U.S. Although the current version of the model has not been published, the general procedure and rationale for a previous version of the model are described in Theobald (2005). Future growth in housing units was based on Census Bureau county-level projections for population growth. The number of housing units this growth was apportioned to was determined using the county-level average of people/household, taken from 2000 census data. Growth in housing units was allocated spatially using a formula that considered recent (1990-2000) housing growth rates for a specific location and accessibility to the nearest urban core. Assumptions of this approach are that: (1) future growth patterns will be similar to those found in the past decade; (2) people/household in the future will match that in the 2000 census data; (3) future growth is likely to occur nearby current high growth areas or "hot spots"; (4) housing units cannot occur on public land, water areas, etc.; (5) growth will be concentrated in areas closer (in terms of travel time, not just distance) to urban core areas over major roads; and (6) housing density will not decline over time (housing growth projections are additive to current housing densities).

We applied Dr. Theobald's model and resultant predicted housing density dataset in a GIS analysis to evaluate the potential acreage impacted by development in 2020 for each population of GrSG. We are not aware of any published work that indicates what level of housing development impacts or eliminates sage-grouse use of habitat. In this initial analysis we chose 320 acres/housing unit as the threshold below which we expect impacts to GrSG, and above which we do not. This estimate was used in the Gunnison Sage-grouse Rangewide Conservation Plan (Gunnison Sage-grouse Rangewide Steering Committee 2005) with the following rationale: (1) in 2000, over 38,500 acres within 1.86 miles of leks in the Gunnison Basin had more than 1 housing unit/320 acres, yet grouse use has continued; (2) only 4 of 41 active leks have no housing units within 1.86 miles; and (3) 35 of 41 active leks are adjacent to an area with housing density greater than 1 unit/320 acres. This threshold was chosen keeping in mind the large amount of public (and therefore protected) habitat in the Gunnison Basin. It is not suggested that if the large block of public land in the Gunnison Basin were developed at this density (1 housing unit/320 acres) that grouse would not be impacted.

A similar analysis was attempted in GrSG occupied habitat areas, but the GrSG areas experiencing the highest development had already lost key leks and data were not available to replicate the analysis. However, in examining the data for GrSG areas, it was clear that parcels 320 acres or smaller followed a pattern of regularly being subdivided into smaller parcels, presumably for eventual housing development. The 320 acres/housing unit threshold is thought to be an adequate fit to GrSG and was used for this analysis.

The challenge in wisely allocating habitat protection dollars is to protect important areas where development will occur at a density that precludes use by, or will significantly impact, sage-grouse. At the same time, there is little point in allocating resources to areas already impacted so as to preclude grouse use, or to areas where housing densities will be so low as to have negligible impact to grouse. Thus, having set the threshold impact as 320 acres/housing unit, we identified areas projected to increase from housing densities of 320 acres or more per housing unit, to housing densities with fewer than 320 acres per housing unit. The modeled housing density in 2000 is shown in Fig. 56, while projected housing densities (without intervention) in 2020 are shown in Fig. 57 (note that white areas are the protected lands, i.e., public). Areas of growth in housing between these periods are identified in Fig. 58.

The model predicting development to unsuitable housing densities seemed to underestimate development in areas where second home development or proximity to resort centers is occurring, such as in the corridor between Steamboat Springs and Craig (Fig. 58). In some cases, the model suggested little or no future development in areas already platted with lots marketed for sale. Clearly, we have a long-term need to develop better predictive models which take these factors into account. In the interim, we used another approach to identify habitats at greatest risk of development in the next 3 - 5 years.

As mentioned earlier, land is typically subdivided into smaller parcels prior to sale and development. It is these smaller (<80 acres) parcels that are probably most immediately susceptible to development to densities that would adversely impact grouse. Larger parcels may be subdivided, but they will often be subdivided a second time before development, and the entire process will occur over a longer time horizon, allowing more time to respond. For the 3 areas with the greatest apparent risk of housing impacts (MWR, MP, and NESR; Table 32 [pg. 282]), we mapped private land parcels by parcel size categories for each population as a tool to aid agencies, work groups, and land trusts in assessing development risk and prioritizing habitat protection efforts for GrSG (Figs. 59 - 61).

Prioritization of Habitat Protection Efforts from Loss Due to Human Development

We considered the information from Table 31 (pg. 270) and Figs. 56 - 61, estimated the relative GrSG population size and population trend, and used all this information to develop for each population a relative priority for protection from human development (Table 32, pg. 282). This priority ranking is not absolute; individual properties in populations with a medium priority may have greater importance than individual properties in higher ranking populations. Also, county boundaries, administrative boundaries, and other factors influence rankings at those levels. Rankings are relative to one another; a medium ranking is not meant to imply that habitat protection is not important in that population. Rather, habitat loss from human development is likely to be less of an immediate issue for a population with a medium ranking than in a population with a high ranking. This table and the rankings within are intended as a guide to assist agencies in planning, and ultimately in maximizing the efficiency of habitat protection efforts. Any attempt at prioritizing the importance of populations for habitat protection purposes is likely to be polarizing, yet it is necessary to ensure that scarce resources accomplish the greatest good towards the protection of the species.

It is apparent from this analysis that the risk of permanent or long-term habitat loss for GrSG due to housing development is substantial, but it varies widely across populations. Extensive public lands in the NWCO, NP, and MP populations will help mitigate some of these development risks, as will no-development easements held by CDOW, NRCS, and non-governmental organizations (NGOs). Conversely, substantial portions of the NESR and MWR populations are privately owned and are located in areas where population growth is expected. Some increase in housing and other development can probably be accommodated in these areas without significantly impacting GrSG, but we hypothesize that densities much in excess of 1 housing unit/320 acres will cause GrSG populations to decline. Greatest impacts are likely when seasonal habitats most important to GrSG, such as areas used during moderate or severe winters, or lek/nesting/brood-rearing areas, are lost. For instance, a large portion of the lower elevation lands that may be valuable to GrSG in harsh winters is privately owned. Proper planning of land use and placement of development on private lands can help mitigate the losses and decrease impacts. In small populations such as NESR and MWR, because of small size and existing or potential fragmentation, any loss of habitat may adversely impact grouse.

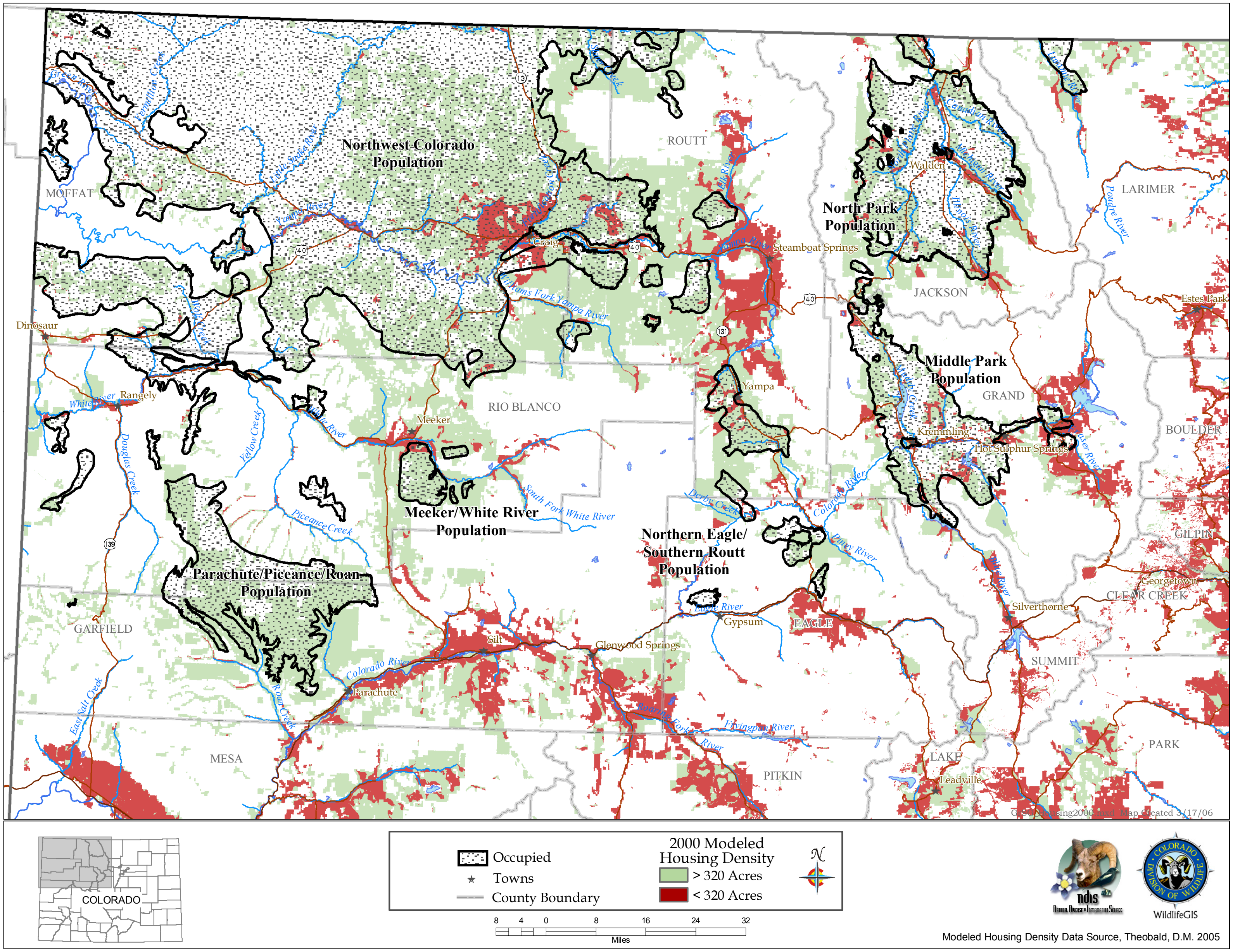


Fig. 56. Modeled housing densities in Colorado GrSG population areas, 2000.

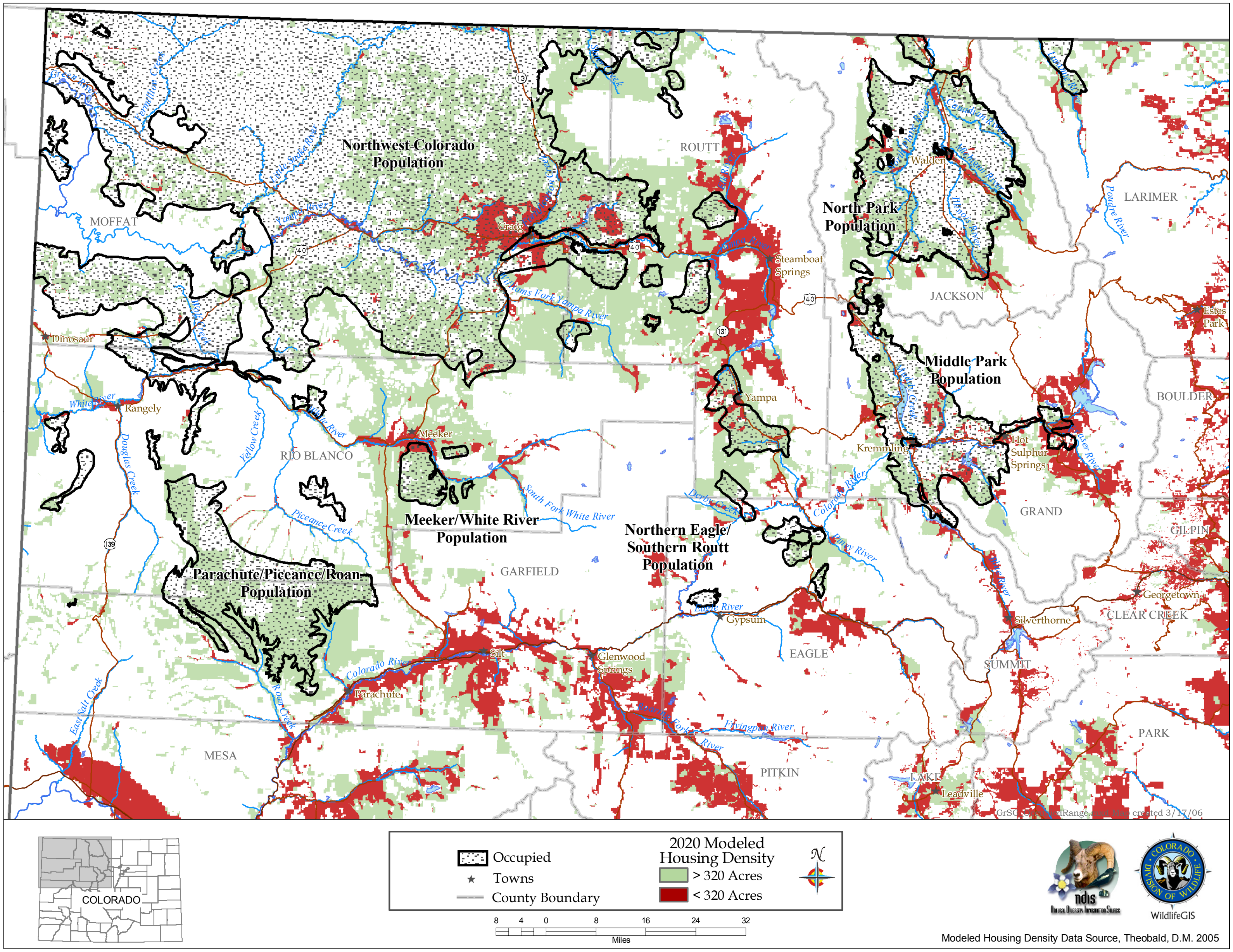


Fig. 57. Projected housing densities in Colorado GrSG population areas, 2020.

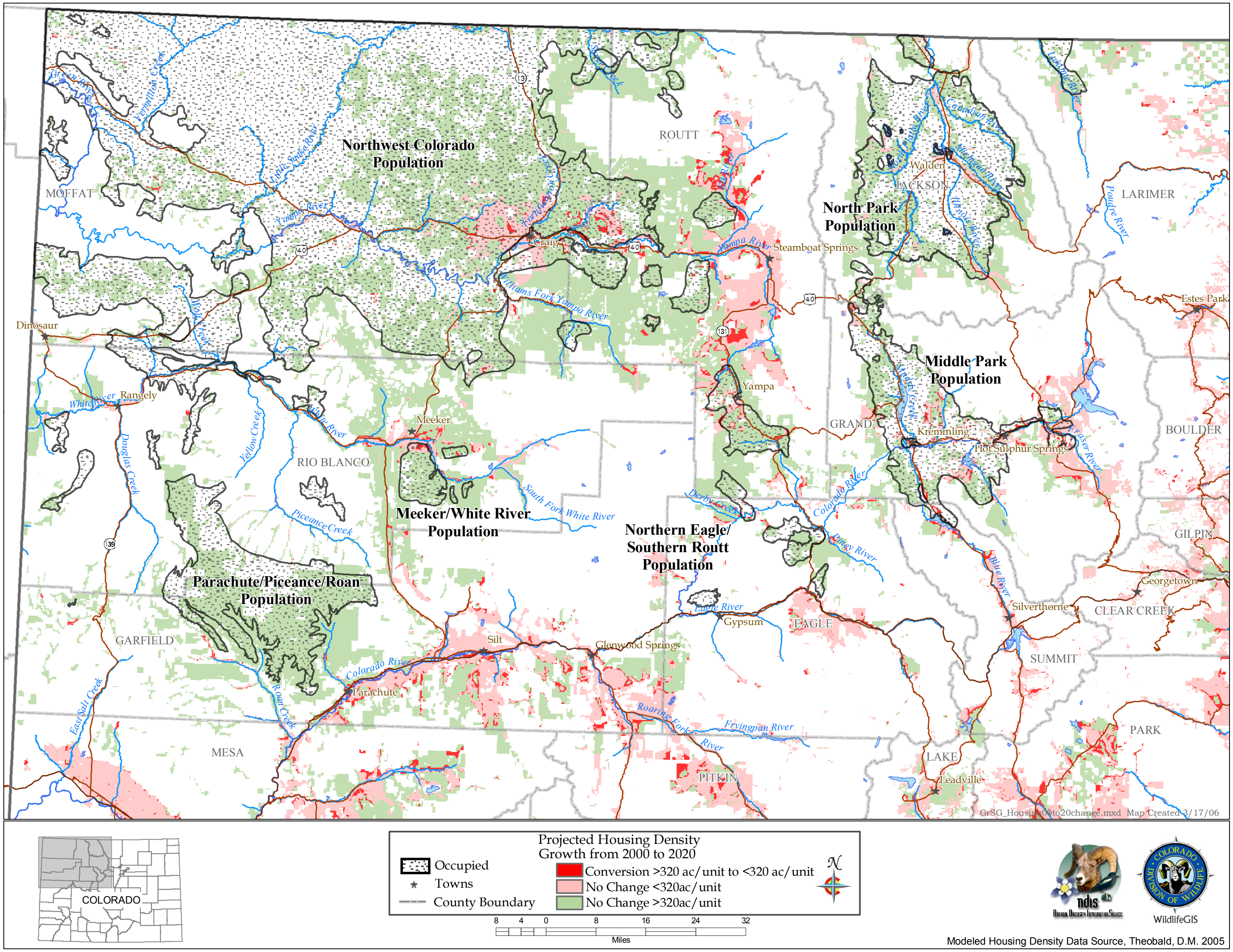


Fig. 58. Areas of growth in housing densities from modeled year 2000 to projection in 2020.

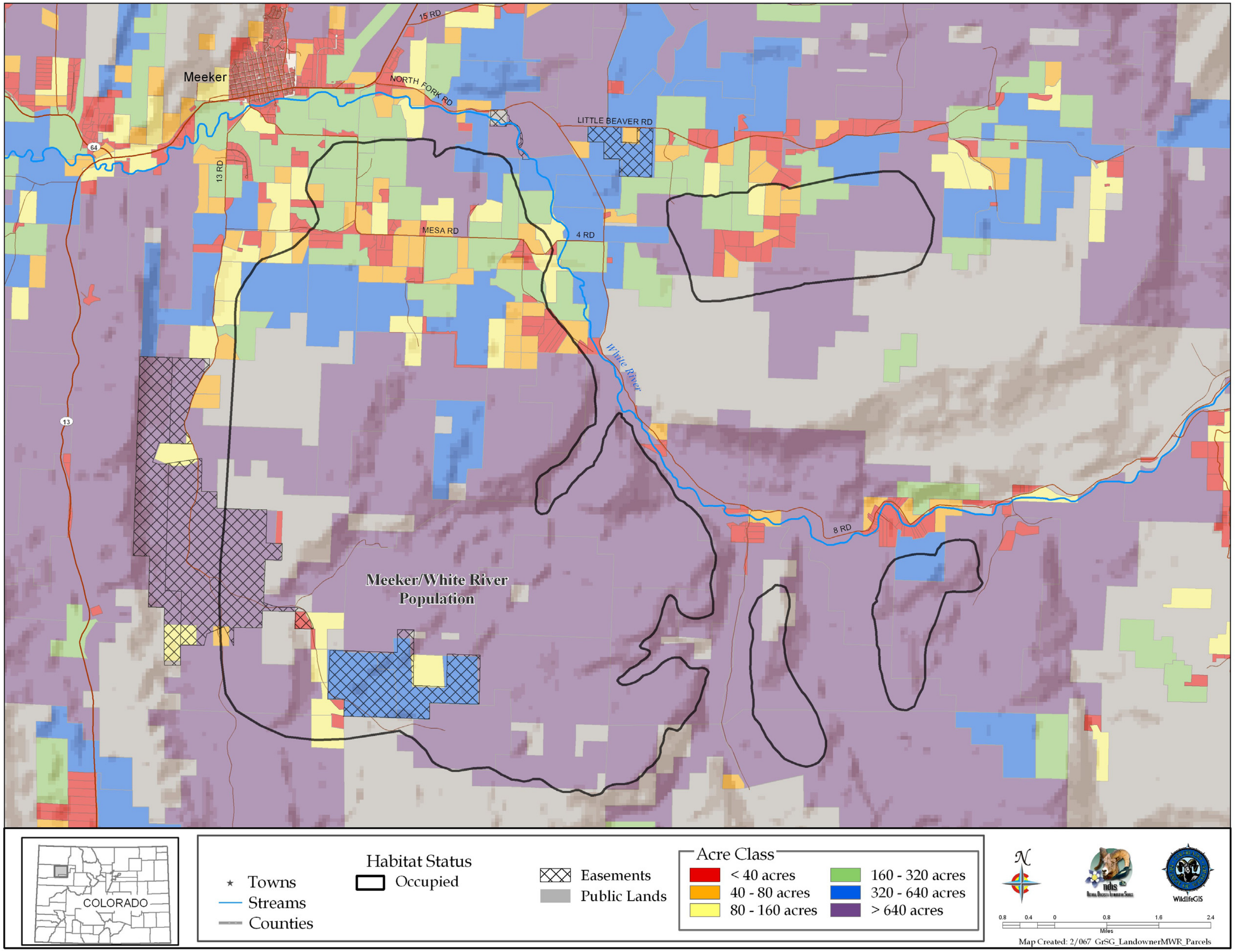


Fig. 59. Private land parcels, by parcel size, in Meeker – White River GrSG population area.

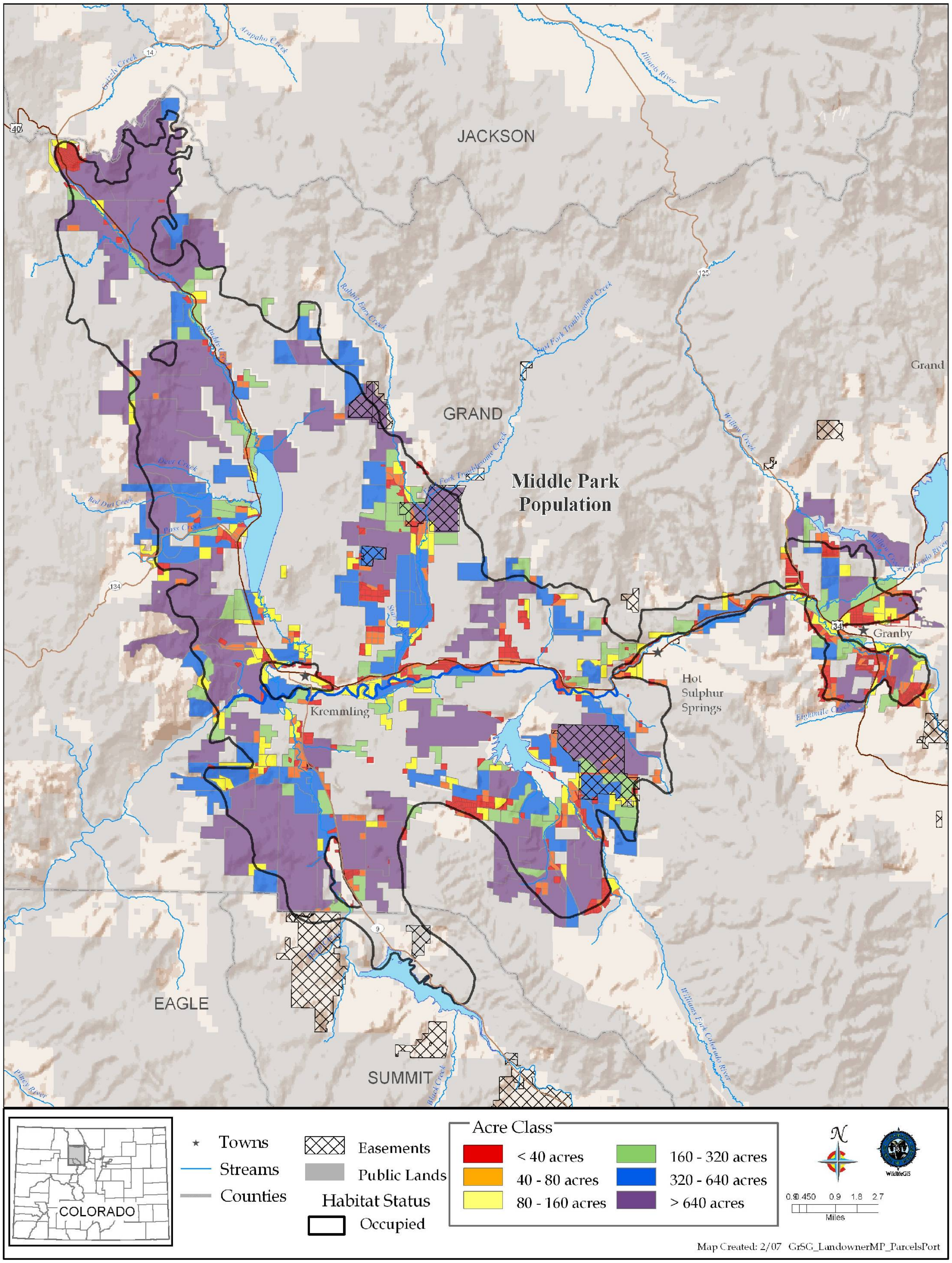


Fig. 60. Private land parcels, by parcel size, in Middle Park GrSG population area.

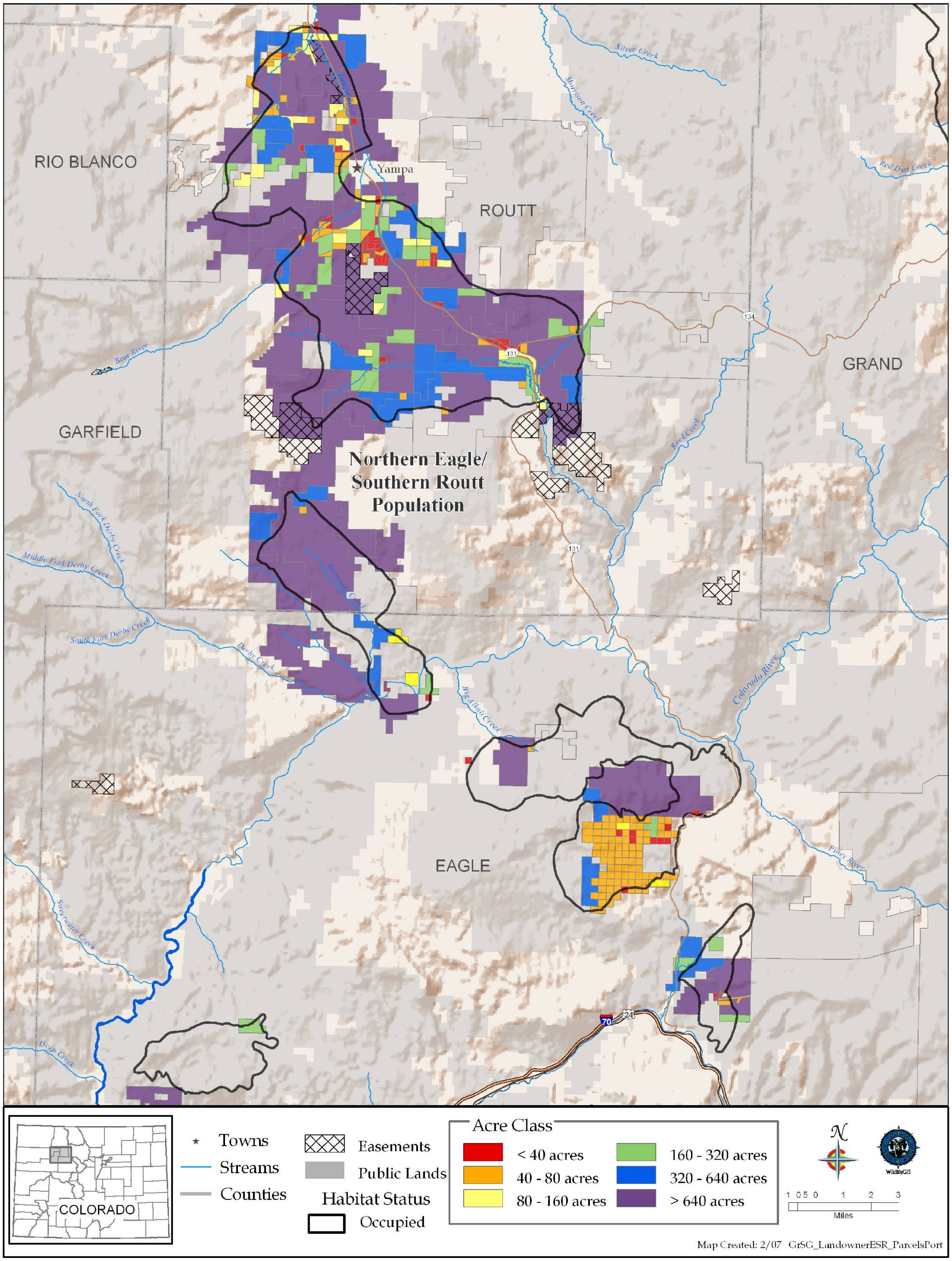


Fig. 61. Private land parcels, by parcel size, in NESR GrSG population area.

Table 32. Protection priority ranking from habitat loss due to housing development among populations of GrSG.

Population	GrSG Population Trend	Risk and Trend of Habitat Loss from Housing Development	Private Land, not Protected within Occupied Habitat, Acres (%)	Protection Priority from Habitat Loss Due to Housing Development
Middle Park	Stable	High - Increasing	146,255 (56%)	High
Meeker – White River	Stable to declining	Moderate	36,837 (89%)	Moderate
North Park	Stable to Increasing	Low - Increasing	209,236 (51%)	Low
Northern Eagle – Southern Routt	Stable to Declining	High - increasing	67,478 (71%)	Very High
Northwestern Colorado	Stable to Increasing	High/increasing in Zone 4B; remainder Low/increasing	1,044,148 (41%)	High – Zone 4B, (Remainder = Low)
Parachute – Piceance – Roan	Stable to declining	Low	76,673 (35%)	Low

The NESR population rated the highest in terms of protection priority, by virtue of it having a stable to declining GrSG population, high projected increase in human population, and a large percentage of the occupied habitat in private land (i.e., available for development; Table 32). The MP population rated high in terms of protection priority. The risk of impacts from human development is high and increasing in this GrSG population and over ½ of the occupied range is in private ownership (Table 32). Zone 4B in the extreme east portion of the NWCO population is also ranked high in terms of protection priority (Table 32). This area is experiencing increasing increase in human population from the Steamboat Springs, Craig, and Hayden communities. Isolation and fragmentation of habitats is occurring within this zone and birds in portions of the zone may now be isolated from the main core of the NWCO population. The remainder of the NWCO population is ranked low for protection from human development, due to the relatively low projected increase in human population growth (Table 32).

Even though the MWR population is primarily tied to private lands, it ranked moderate for protection priority from human development, due to the current moderate increase in human population expected in the area (Table 32). Key ranches having sage-grouse habitat in this population area should not be overlooked for protection. The PPR population has the lowest percentage of private land within occupied habitat and the risk of impacts from human housing development is low in this population (Table 32). However, if one were to consider in this analysis the expected habitat loss from energy development, the story would be much different. In this section we only evaluate and prioritize the need for protection from housing development impacts. The NP population has relatively low protection priority, both because it has a low risk of housing development and because it does not have a high percentage of private land (Table 32).

GrSG Habitat Loss: Roads in Colorado

We conducted an analysis of the number of acres of habitat lost from current roads in each GrSG population. A complete GIS roads dataset is unavailable for the state, necessitating a combination of data sources for our analysis. Colorado Department of Transportation (CDOT) road GIS data were used for highways, paved, bladed, and gravel categories. U.S. Census Bureau Tiger data (U.S. Census Bureau 2001) were then used to fill in the remaining roads not shown in the CDOT layer. For analysis purposes, the Tiger roads categorized as A4 were assumed to be minor gravel (i.e., "Graded") roads. Tiger roads classified as A5 and A7 were lumped into the 4WD and access road category.

Widths of the road classes were determined broadly, using GIS analysis. CDOT road widths by road classes for Moffat, Rio Blanco, and Grand counties were measured and averaged for paved, improved surface, and graded road types. For utilized Tiger road widths, aerial imagery from the National Agriculture Mapping Program (U.S. Department of Agriculture 2005) was used and road widths were measured and averaged.

Gelbard and Belknap (2003) documented a distance from the edge of different classes of roads, termed a verge, where the native vegetation is destroyed and often replaced with exotic species. This affected verge distance was added to the physical width of the road, from center line to road edge, to provide the total width of habitat lost (Table 33) in our analysis.

Table 33. Road buffers for analysis of GrSG habitat lost to roads.

Road Category	**Road Width Buffer [a] (feet)**	**Road Verge Buffer [b] (feet)**	**Habitat Loss Buffer [c] (feet)**
Paved	47.6	23.0	70.5
Improved Surface	39.4	13.9	53.3
Graded	34.4	9.8	44.3
4WD/Access Roads	16.5	3.3	19.7

[a] Total road width was divided in half in this column, to account for a buffer beginning at the center line of road.
[b] Road verge (Gelbard and Belnap 2003) was divided in half in this column to account only for one side of road (buffer originates at center line of road).
[c] Road Width Buffer was added to the Road Verge Buffer to derive Habitat Loss Buffer

Total acreages lost by population from roads are listed in Table 34. While the total amount of acreage compared to overall occupied range may seem minimal, the replacement cost of those same acreages through protection avenues such as conservation easements would be cost-prohibitive. In addition, the number and magnitude of roads on the landscape (Fig. 62) indicate that GrSG populations are already exposed to the effects of existing roads, at least at a relatively broad scale. Potential future impacts should be carefully considered when additional roads are proposed.

Table 34. Occupied GrSG habitat lost to roads in Colorado.

GrSG Population Area	**Total Occupied Habitat (acres)**	**Occupied Habitat Lost to Roads (acres)**	**% Occupied Habitat Lost to Roads**
MWR	41,160	430	1.0
MP	259,019	7,666	3.0
NP	413,915	11,755	2.8
NESR	95,388	2,241	2.3
NWCO	2,563,033	56.270	2.2
PPR	304,588	7,331	2.4
Statewide total	3,677,103	85,693	2.3

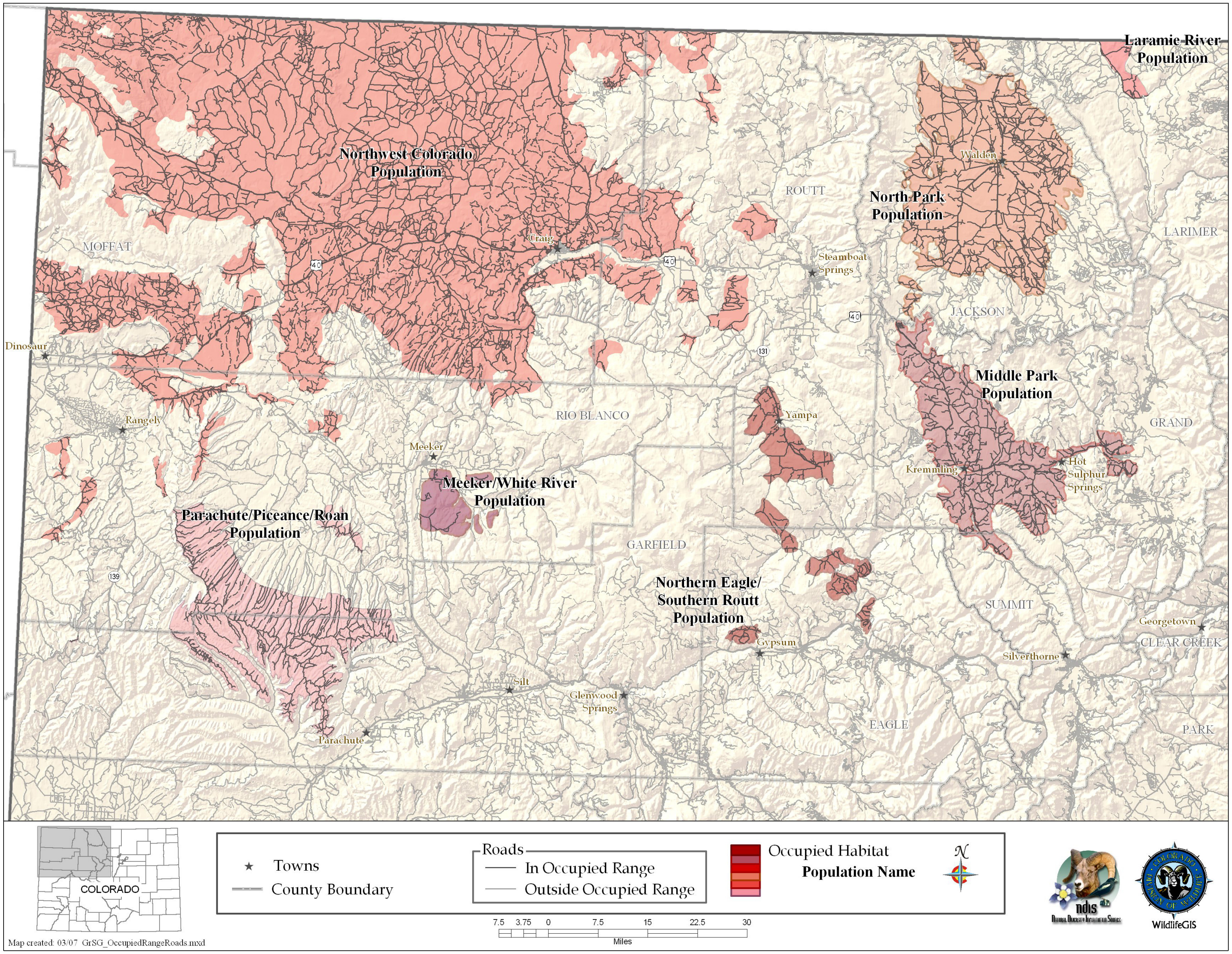


Fig. 62. Distribution of roads in GrSG populations in Colorado.

GrSG Habitat Linkages in Colorado

Theory and Background

Using corridors to link isolated populations is often proposed as a conservation strategy for species in fragmented landscapes (Mann and Plummer 1995, Meffe and Carroll 1997, Rosenberg et al. 1997). It is assumed the habitat linkage will increase movement between populations and will decrease the probability of extinction of the species by stabilizing population dynamics (i.e., reducing the threat of demographic stochasticity), and reducing the possibility of inbreeding depression. However, studies have been unable to demonstrate that individuals actually use corridors, much less whether corridors influence the demographic parameters that increase the probability of survival of the species (Simberloff and Cox 1987, Hobbs 1992, Beier and Noss 1998).

Habitat linkages do not necessarily mean corridors. Corridors are defined as narrow, linear strips of habitat typically used by a species, that connect larger blocks of habitat and are surrounded by unsuitable (unused) habitat (Turner et al. 2001). We defined linkages as a heterogeneous landscape, within the historical range of GrSG, composed of isolated patches of landcover types frequently used by sage-grouse (for a list of landcover types see Table 35 [pg. 289]). Habitat within linkages is composed of a mosaic of contrasting land forms, landcover types, and land uses.

The effectiveness of a potential linkage will depend on the ability of GrSG to move among the isolated patches in a landscape (i.e., the relative "connectivity" of patches in a landscape; Taylor et al. 1993). The ability of sage-grouse to disperse may be influenced by the landscape composition (how much of the suitable landcover types are present in the landscape), configuration (the size and shape) of the patches, distance between patches in the landscape (Dunning et al. 1992), and the physical nature (land forms) of the landscape that can either facilitate or impede dispersal (Henein and Merriam 1990). These factors are not completely independent. Increased habitat composition is typically correlated with increased patch size and decreased distance between patches. The effectiveness of a potential linkage will also depend on the quality of the habitat in the isolated patches and the relative ability of sage-grouse to use (or move through) the surrounding unsuitable habitat. The effectiveness of linkages may also depend on predator behavior. The linear nature of corridors or fragmented patches of habitat between larger core areas may lead to greater predator foraging efficiency (Phillips et al. 2003).

Methods are available for quantifying landscape composition and configuration (Turner 1989, Turner and Gardner 1991, McGarigal and Marks 1995) and connectivity (Fahrig and Paloheimo 1988*a*, *b*; Heinen and Merriam 1990). There are very few empirical data on the connectivity of landscapes for a given species; however, the idea has led to the development of increasingly complex percolation (or diffusion) models (Czaran 1998). These models involve generating 2-dimensional grids ("landscapes"). Each cell of the grid is assigned a particular landcover type (most models use only 2 landcover types: “used” and “not used”). The arrangement of the cells within the grid is manipulated to represent varying degrees of patch size, shape and distribution. By varying movement capabilities (dispersal distance), the models can be used to analyze the ability of a hypothetical animal to move ("percolate") across the grid. These models have shown that changes in landscape composition, patch size, distance between patches, corridor length and width can affect species dispersal, abundance and probability of extinction (Fahrig 1997, 2001, 2002; Haddad 1999; With 2002). These models have also illustrated thresholds in habitat fragmentation that affect a species' ability to move through landscapes (With and Crist 1995, With 2002) and the species' probability of extinction (Fahrig 2001, 2002). In these models, increasing fragmentation has little effect on movement and species persistence until a critical threshold of fragmentation impedes the ability of individuals to disperse and survive (i.e., the distances between patches become too large and the amount of habitat in the landscape becomes too small).

Although percolation models are instructive, the question remains whether our proposed linkages contain the appropriate habitat to be effective avenues for movement between populations by sage-grouse. Seasonal movement and dispersal patterns of GrSG are not understood well enough to be able to predict whether the birds will use linkages, or if they do, what composition and configuration of landcover types within the linkage will best facilitate movement and keep confounding factors (such as predation) to a minimum. Our GIS analysis has identified extensive potential areas for linkages between current populations (see "Mapping Potential GrSG Habitat Linkages", following), but the quality of the landcover types, relative to movement requirements, remains unknown. It is also not certain that sage-grouse will restrict dispersal movements to landcover types frequently used during seasonal movements, or if they will use atypical sage-grouse habitats (e.g., agricultural lands and right-of-ways).

Furthermore, it is not clear what the effect of current population distributions will have on the probability of individuals using linkages. Individuals from small populations, like NESR, may be less likely to disperse across linkages (i.e., behave more like a non-migratory population) than individuals from larger populations, like NWCO, that may already exhibit migratory behaviors. Understanding the effect of landscape structure on dispersal patterns of GrSG is a critical step toward evaluating the effectiveness of the proposed population linkages.

<u>*Mapping Potential GrSG Habitat Linkages*</u>

We used GIS data to describe potential habitat linkages among GrSG populations in Colorado. In addition, we identified some linkages within populations that have experienced separation of smaller areas of occupied habitats from the larger population core. Data used for Colorado were recently available through the CVCP (Colorado Division of Wildlife 2004*b*). In this data set, vegetation layers were derived from 30-m Landsat TM satellite imagery. In addition, topography was utilized in a general sense to help refine linkage areas. Soils data layers would have been beneficial in the delineation, but these data are not available in digital format in all areas.

We selected vegetation classes that contain current sagebrush communities, as well as those classes that may have contained sagebrush communities historically (e.g., piñon-juniper - sagebrush mix). Linkages are comprised of a non-contiguous and patchy mix of the classes (Table 35).

Potential linkages were added to existing mapped areas that include occupied, potential, and vacant/unknown habitats (Fig. 63). Hence, a habitat identified as a linkage may not in and of itself link existing occupied habitat polygons, but the combination of linkage, vacant/unknown, and potential habitats will link occupied habitat polygons. These linkages should be considered only as potential areas for movements between populations.

Table 35. Vegetation classes from the Project used to identify GrSG habitat linkages in Colorado (Colorado Division of Wildlife 2004*b*).

Class Category	Class Name	Class Description
AGRICULTURE	Agricultural Land	Row crops, irrigated pasture and hay fields, dry farm crops.
	Dryland Ag	Dryland crops and fields.
	Irrigated Ag	Irrigated crops and fields.
RANGELAND	Rangeland	Consists of grass/forb range, shrub/brush range, or mixed range
	Disturbed Rangeland	Consists of grass/forb range, shrub/brush range, or mixed range.
	Grass/Forb Rangeland	Perennial and annual grasslands.
	Shrub/Brush Rangeland	Consists primarily of sagebrush, saltbrush, greasewood, and snakeweed.
	Bitterbrush Community	Shrubland principally dominated by bitterbrush. Often associated with rabbitbrush, sagebrush, greasewood, various grasses, and mixed cacti.
	Salt Desert Shrub Community	Low-elevation shrublands found on alluvial salt fans or flats. Component species may include: saltbushes, greasewood, sagebrushes, horsebrushes, and spiny hopsage.
	Sagebrush/Grass Mix	Co-dominant sagebrush shrubland and perennial grassland.
	Sagebrush Community	Sagebrush with rabbitbrush, bitterbrush.
	Sagebrush/Gambel Oak Mix	Shrubland co-dominated by big sagebrush and Gambel oak.
	Snowberry/Shrub Mix	Mountain deciduous shrubland dominated by mountain snowberry. Often associated with Saskatoon serviceberry, sagebrush, squawbush, rabbitbrush and Gambel oak.
	Sagebrush/Greasewood	Shrubland co-dominated by sagebrush and greasewood. Secondary species may include rabbitbrush.
	Shrub/Grass Forb Mix	Mixed grass/forb and shrub/grass rangeland.

Table 35. Vegetation classes from the Project used to identify GrSG habitat linkages in Colorado (Colorado Division of Wildlife 2004*b*).

Class Category	Class Name	Class Description
	Sagebrush/Mesic Mountain Shrub	Co-dominant sagebrush mesic mountain shrubland consisting of mountain big sagebrush and any combination of mountain snowberry, serviceberry, squaw apple or bitterbrush often with a grass/forb understory. Understory species may include, among others, elk sedge, bluegrass, needlegrass, arrowleaf balsamroot, lupines, penstemons, Indian paintbrush, and mariposa lily. Often found at the higher elevations of the sagebrush zone, on north facing slopes, in basins, or on other mesic sites.
	Sagebrush/Rabbitbrush Mix	Co-dominant sagebrush and rabbitbrush shrubland. Principal shrub species include basin big sagebrush, Wyoming big sagebrush, rubber rabbitbrush, sticky rabbitbrush, or small rabbitbrush.
	Xeric Mountain Shrub Mix	Deciduous woodland (or tall shrubland) dominated by mountain mahogany or curlleaf mountain mahogany. Associated species may include sagebrush, rabbitbrush, Mormon tea, or scattered piñon pine or Utah juniper.
	Mesic Mountain Shrub Mix	Oak dominant with sagebrush, snowberry, grass.
	Serviceberry/Shrub Mix	Deciduous woodland (or tall shrubland) dominated by Utah and Saskatoon serviceberry. Primary associated shrub species include big sagebrush, mountain snowberry, and Gambel oak.
	Piñon-Juniper-Sagebrush Mix	Co-dominant piñon-juniper and sagebrush.
	Piñon-Juniper--Mountain Shrub Mix	Co-dominant piñon -juniper and oak, mountain mahogany or other deciduous shrubs.
	Juniper/Sagebrush Mix	Co-dominant woodland and shrubland. Woodland consists of Utah juniper at densities around 25%. Big sagebrush grows in the interspaces between the trees and may comprise 25% cover or more.
	Juniper/Mountain Shrub Mix	Co-dominant juniper species and oak, mountain mahogany, or other deciduous shrubs.
	Piñon-Juniper-Oak Mix	Co-dominant deciduous/coniferous woodland. Conifer species are piñon pine and Utah or Rocky Mountain Juniper. Deciduous tall shrubs are dominated by Gambel oak.

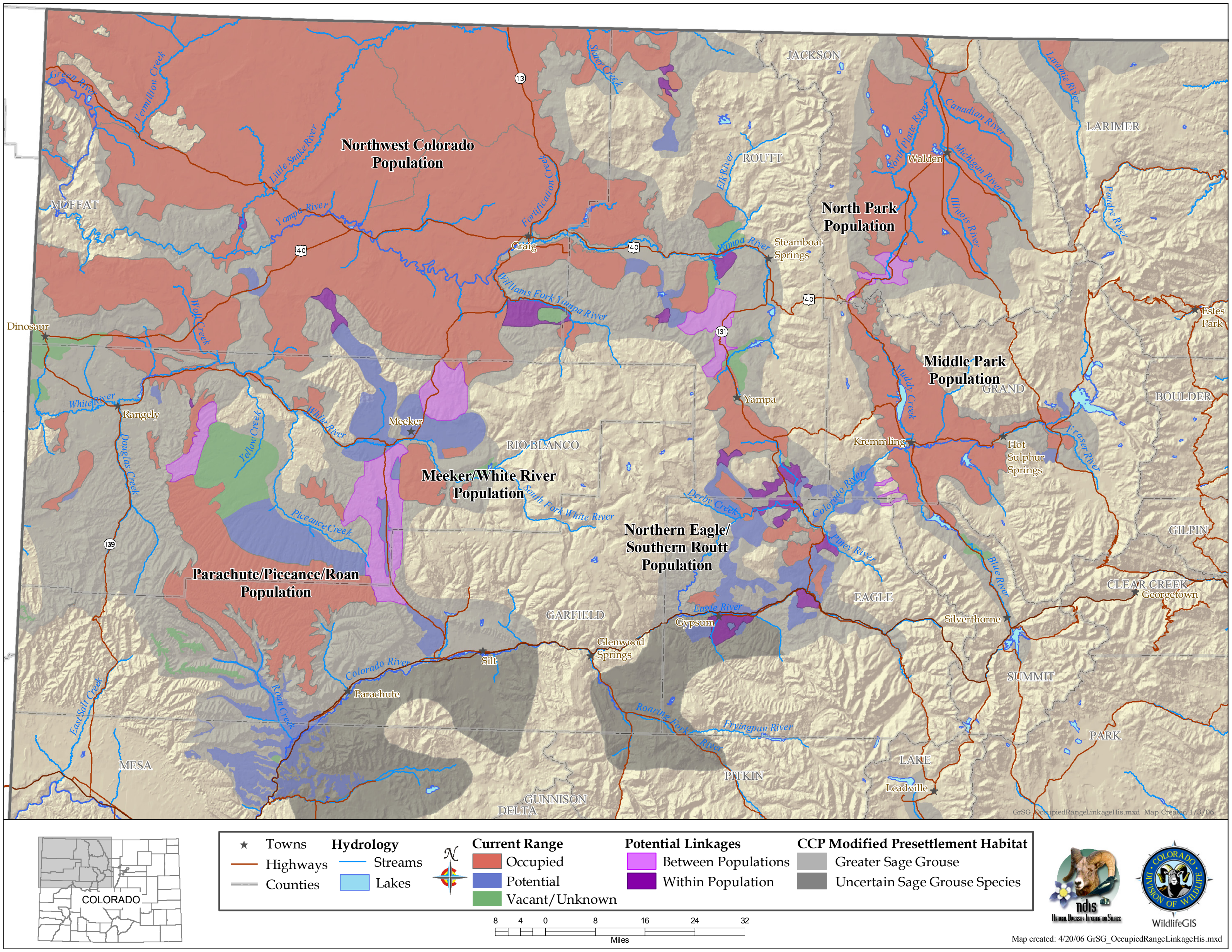


Fig. 63. Potential habitat linkages between and within Colorado GrSG populations.

Energy and Mineral Development: Avoiding and/or Mitigating Impacts

Impacts to GrSG from oil and gas development may be (1) avoided; (2) minimized on-site with BMPs or other measures; or (3) mitigated off-site with habitat improvements or other measures. In this section we present a conceptual analysis in which we discuss some options for (1) avoiding impacts, and (3) off-site mitigation of impacts. We do not address (2) minimizing impacts with on-site BMPs or other measures in this section, but do so elsewhere in the plan; please refer to "Energy and Mineral Development" strategies, pp. 313-333; Appendix B ("GrSG Disturbance Guidelines"); and Appendix I ("Suggested Management Practices Applicable for Oil and Gas Development, within Lease Rights"). In the discussion of (3) off-site mitigation, it is presumed that on-site mitigation will occur first to reduce impacts in areas with development; off-site mitigation is considered supplementary to on-site mitigation efforts.

Note: this section is not designed to evaluate the relative importance of these 3 approaches in addressing energy development impacts, or to recommend a specific approach. Rather, this is an exploration and analysis of the potential feasibility of (1) avoiding impacts and (3) off-site mitigation of impacts for GrSG in Colorado.

Avoiding Impacts: the Refuge Concept – Identifying Core Areas

The current and past approaches to energy development on federal lands and mineral estates have been to minimize impacts to GrSG through stipulations on timing and location of drilling activities near leks (e.g., no surface occupancy within ¼ mile of leks; for a history of the "¼-mile buffer", see Appendix B "GrSG Disturbance Guidelines"; for details of the energy leasing process, see Appendix G, "Energy and Mining Leasing and Development Process"). In recent studies there has been evidence that oil and gas lease stipulations have not been effective in protecting GrSG, at least where drilling is intensive or conducted on a landscape-scale (Holloran 2005, Walker et al. 2007*a*, Doherty et al. 2008; see also Appendix H, "Literature Review: Oil and Gas Development Impacts on Prairie Grouse").

Creating "refuges" is emerging as a potential strategy for avoiding impacts of energy and mineral development on GrSG, while still providing for continued oil and gas development. In the refuge scenario, areas of important GrSG habitat are identified and within them energy development is greatly restricted or prohibited for some period of time, while stipulations may be relaxed, or even eliminated, in areas outside the core refuge, to facilitate and speed energy development.

The potential value of this concept is supported in part by the CCP PVA analysis of oil and gas development. This analysis suggests that when considering GrSG viability in areas of oil and gas development (the example in the model was the PPR population), it might be best to minimize the duration of development phases that produce the greatest disturbance to grouse (well-field development phase; see "Oil and Natural Gas Development" in the PVA section, pg. 223). In contrast, timing stipulations may inadvertently have the opposite effect, resulting in an extension of the development phases during which activities occur that are the most disturbing to GrSG.

To help determine if the refuge concept is a potentially viable strategy for GrSG conservation and energy development in Colorado, the CDOW conducted a GIS mapping analysis to evaluate areas (cores) where GrSG habitat and male densities (based on male attendance on leks) are concentrated and the establishment of a refuge might be most effective in protecting sage-grouse populations (for related strategies, see “Energy and Mineral Development” strategies 3.2.3.1 and 3.2.3.2, pg. 321). This is not to suggest that areas outside of modeled core areas are not important in maintaining GrSG in Colorado.

In order to identify core potential refuge areas for sage-grouse, CDOW mapped intersections of 3 GIS layers: (1) 4-mile buffers around active leks; (2) a measure of sage-grouse density; and (3) sagebrush patch sizes (Boyle and Reeder 2005). These mapped intersections represent areas considered critically important to GrSG and, by extension, presumably to other sagebrush dependent wildlife species.

Areas identified in this first step of 3 intersecting layers were refined and consolidated by (1) eliminating small isolated areas of birds/habitat; (2) considering the importance of areas identified as winter habitat; and (3) selecting an area adequate to protect 50 - 60% of the given GrSG population (as estimated by a function based on lek buffer and GrSG density). In some cases this analysis identified core areas which protected percentages of sage-grouse populations substantially higher than 60%, which would afford flexibility in future development planning efforts.

The results of this GrSG core refuge analysis illustrate that only 10% of the total acreage in the 8 counties was incorporated into core refuge areas (Table 36, Fig. 64). The lack of core areas within MWR and PPR (Fig. 64) is an artifact of the GIS intersection analysis and selection criteria: the male GrSG densities were not high enough and/or the naturally fragmented landscape did not provide for large blocks of sagebrush to allow for identification of core areas within these population areas. This analysis does not discount the importance of these GrSG populations, but rather illustrates a limitation of the analysis criteria.

In addition, the core areas protected 74% of the GrSG (an estimate of the percent of the male population on leks within the core areas, Table 36). The amount of refuge acreage in each county ranged from low, or no, refuge areas in Eagle, Garfield, Rio Blanco, and Summit Counties, to a high of 28% of Moffat County (Table 36). The percentage of each GrSG population that is protected by core areas varies from 0% in MWR and PPR to 88% in NWCO (Table 37).

To assist in providing some insight into the potential implications to energy development in these GrSG core refuge areas, we provide a summary of how much land with high, medium, or low oil and gas potential exists in identified core areas (Table 38).

Table 36. Resources located within identified GrSG core and non-core areas for Colorado counties that have GrSG populations. Grouse = an estimate of males in the population, based on GrSG density function and lek buffers; % Grouse = an estimate of the percent of the male population on leks.

County (GrSG Population)	**Core Areas**				**Non-Core Areas**		**Total**
	Acres	**% Acres**	**Grouse**	**% Grouse**	**Acres**	**% Acres**	**Acres**
Eagle (MP, NESR)	0	0%	0	0%	1,077,742	100%	1,077,742
Garfield (PPR)	0	0%	0	0%	1,892,465	100%	1,892,465
Grand (MP)	109,115	9%	168	56%	1,085,982	91%	1,195,097
Jackson (NP)	198,596	19%	690	53%	837,893	81%	1,036,489
Moffat (NWCO)	857,462	28%	3,173	89%	2,184,948	72%	3,042,410
Rio Blanco (MWR, NWCO, PPR)	0	0%	0	0%	2,064,014	100%	2,064,014
Routt (NESR, NWCO)	96,973	6%	352	87%	1,418,321	94%	1,515,294
Summit (MP)	0	0%	0	0%	395,914	100%	395,914
Total for all 8 Counties	1,262,145	10%	4,383	74%	10,957,280	90%	12,219,425

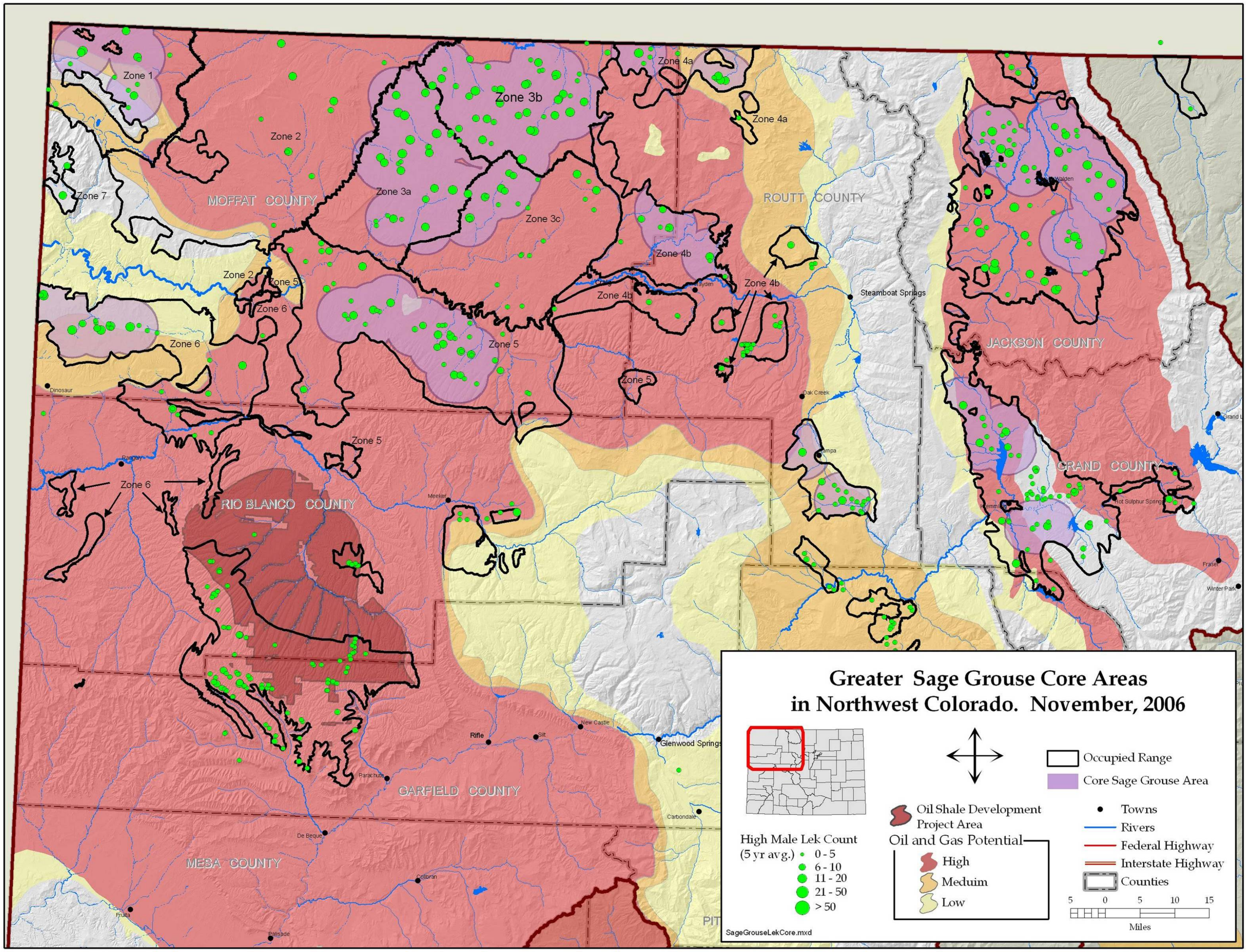


Fig. 64. Greater sage-grouse core refuge areas in Colorado

Table 37. Numbers of GrSG on leks located within identified GrSG core and non-core areas, by population. Grouse = an estimate of males in the population, as associated with habitat surrounding a given lek; % Grouse = an estimate of the percent of the population.

GrSG Population	**Core Areas**		**Non-Core Areas**	
	Grouse	% Grouse	Grouse	% Grouse
MP	168	55%	135	45%
MWR	0	0%	8	100%
NESR	85	80%	21	20%
NP	690	53%	616	47%
NWCO	3440	88%	467	12%
PPR	0	0%	244	100%
Total for all Population Areas	4383	75%	1483	25%

Table 38. Acreage located within identified GrSG core and non-core areas for Colorado counties that have GrSG populations, as distributed among areas of varying oil and gas development potential. Oil and gas resource potential data are from BLM GIS data (see Fig. 20, pg. 112).

County	Oil and Gas Potential	Core Acreage		Non-Core Acreage		Total Acreage
EAGLE	High	0	0%	0	0%	0
	Medium	0	0%	695,717	100%	695,717
	Low	0	0%	198,360	100%	198,360
	None	0	0%	183,665	100%	183,665
EAGLE TOTAL		0	0%	1,077,742	100%	1,077,742
GARFIELD	High	0	0%	1,174,789	100%	1,174,789
	Medium	0	0%	55,030	100%	55,030
	Low	0	0%	343,314	100%	343,314
	None	0	0%	319,332	100%	319,332
GARFIELD TOTAL		0	0%	1,892,465	100%	1,892,465
GRAND	High	73,678	15%	415,396	85%	489,074
	Medium	0	0%	0	0%	0
	Low	4,072	7%	55,869	93%	59,941
	None	31,364	5%	614,718	95%	646,082
GRAND CO. TOTAL		109,115	9%	1,085,982	91%	1,195,097
JACKSON	High	198,596	27%	530,357	73%	728,953
	Medium	0	0%	0	0%	0
	Low	0	0%	57,031	100%	57,031
	None	0	0%	250,415	100%	250,415
JACKSON TOTAL		198,596	19%	837,803	81%	1,036,399
MOFFAT	High	724,813	31%	1,601,093	69%	2,325,906
	Medium	68,309	24%	219,486	76%	287,796
	Low	43,758	17%	210,476	83%	254,234
	None	20,564	12%	153,872	88%	174,436
MOFFAT TOTAL		857,445	28%	2,184,927	72%	3,042,371
RIO BLANCO	High	0	0%	1,628,217	100%	1,628,217
	Medium	0	0%	103,885	100%	103,885
	Low	0	0%	238,585	100%	238,585
	None	0	0%	93,328	100%	93,328
RIO BLANCO TOTAL		0	0%	2,064,014	100%	2,064,014
ROUTT	High	37,482	7%	480,120	93%	517,602
	Medium	54,277	13%	363,334	87%	417,611
	Low	5,215	3%	166,713	97%	171,928
	None	0	0%	408,154	100%	408,154
ROUTT TOTAL		96,973	6%	1,418,321	94%	1,515,294
SUMMIT	High	0	0%	74,656	100%	74,656
	Medium	0	0%	27,314	100%	27,314
	Low	0	0%	96,754	100%	96,754
	None	0	0%	197,189	100%	197,189
SUMMIT TOTAL		0	0%	395,914	100%	395,914
TOTAL for ALL 7 COUNTIES		1,262,128	10%	10,957,168	90%	12,219,297

How the GrSG core areas in this refuge concept will (or will not) be used in future management decisions is beyond the scope of this plan. Much of northwestern Colorado has wildlife resources (for multiple species) ranging in value from moderate to important, as well as significant energy resources. The simultaneous management of both wildlife and energy resources poses a tremendous challenge for land and wildlife managers to find an equitable balance between energy development and wildlife resource protection, while providing successful mitigation practices. Implementation of any refuge concept for GrSG (and other wildlife resources) would require broader discussions, negotiations, and partnerships among multiple stakeholders, including (but not limited to) BLM, CDOW, COGCC, industry, landowners, conservation and sportsmen's groups, and local governments.

There is still a great deal of uncertainty with regards to GrSG management, especially for populations that face the complex issues related to energy development. Although there are few, if any, definitive approaches to GrSG management, management approaches and decisions can not remain idle. Uncertainty is central to the concept of adaptive management and a classic adaptive management program provides for multiple "experimental" scenarios, or management approaches (see "Adaptive Management" pg. 10). The conservation strategy section of this plan is written to accommodate the myriad of possibilities for how a refuge concept might be integrated into management (in particular, see "Energy and Mineral Development" strategy section, Objective 3.2.3., pg. 321). In keeping with an adaptive management approach, we list some possible scenarios that might incorporate the refuge concept, although it is clear that other scenarios likely exist.

Possible management scenarios in the refuge concept within the core areas could include:

1. Prohibiting development within core areas on a permanent basis.
2. Allowing development within core areas after development of non-core areas is completed and habitat is successfully rehabilitated (assuming core populations have been maintained during energy development).

Presumably, future development in the core areas would be guided from research results on new or existing stipulations and/or Best Management Practices (BMPs) that are the most effective in protecting GrSG, as well as the intensity of development that can be tolerated by grouse (see "Research" strategy section, pg. 411). Note, however, that extensive areas of sage-grouse habitat have already been leased for energy development, and there may be limitations on how they can be managed.

The non-core areas (areas outside the core, see Fig. 64) might also have a diversity of potential scenarios. Two possible scenarios are:

(1) Use a staged and clustered approach to development, in which there would be a percentage cap on the amount of the GrSG population outside core areas that is impacted by development at any one time (e.g., see "Energy and Mineral Development" strategies 3.2.3.4, 3.2.3.5, and 3.2.3.7, pp. 321-322). This would presumably mean a certain percentage of areas outside the core could be developed at any one time, but development activities and habitat restoration would be completed before moving to the next block

(e.g., see "Energy and Mineral Development" strategy 3.3.4.8, pg. 328). This scenario would probably be a preferred option in populations where no core area has been identified.

(2) Consider the complete relaxation or suspension of all stipulations (e.g., timing restrictions to benefit GrSG) in the peripheral areas being developed at any one time. Under this scenario the non-core areas would allow for development, while 53 - 88% of the grouse would not be impacted (Table 37) because they are in the core area. This scenario would allow for energy development to occur as quickly as logistically possible, creating a "get in and get out" scenario (see "Population Viability Analysis" [pg. 210] and "Energy and Mineral Development" strategy 3.2.3.7 [pg. 322]). This scenario may be a better option in populations where both core and non-core areas have been identified.

Under either non-core area scenario, industry might be expected to contribute substantial resources to mitigate the impact on- and off-site during energy development and production phases (e.g., see "Energy and Mineral Development" strategy 3.3.2.6 [pg. 326], and strategies under Objective 3.3.4 [pg. 327]).

On-site Mitigation of Impacts

On-site mitigation is not discussed in this analysis, but can be found throughout the CCP (see discussion in "Energy and Mineral Development" strategies, pp. 313-333; Appendix B, "GrSG Disturbance Guidelines"; and Appendix I, "Suggested Management Practices Applicable for Oil and Gas Development, within Lease Rights").

Off-site Mitigation of Impacts

Those concerned about development impacts to wildlife have worked for decades to develop and implement reasonable, practical, and biologically sound off-site mitigation practices. Recently, the energy industry has explored mechanisms to mitigate off-site the impacts of energy development on GrSG and their habitat. Off-site mitigation may be appropriate when dealing with impacts, regardless of land-ownership. The widespread use of compensatory off-site mitigation is not supported by some stakeholders, who prefer that detrimental impacts be avoided or minimized on-site, and that impacted resources not be replaced off-site.

The BLM issued an interim policy for the guidance of off-site compensatory mitigation of oil, gas, geothermal, and energy development. These mitigation measures are "…actions the Secretary can direct to prevent unnecessary or undue degradation of the public lands and protect resources in the approval of surface use plan" (BLM interim policy, February 2005, IM 2005-069, expired 30 September 2006). Specifically, the interim policy stated: "Mitigation as defined by the Council on Environmental Quality for NEPA purposes in 40 CFR 1508.20, may include one or more of the following:

a) Avoiding the impact altogether by not taking a certain action or parts of an action;
b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation;
c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;
d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and
e) **Compensating for the impact by replacing or providing substitute resources or environments** (emphasis added)."

The policy suggests that the BLM could consider off-site compensatory mitigation (point "e" above) in energy authorizations when the mitigation proposal is voluntarily submitted by industry. When an applicant's off-site mitigation proposal is part of the plan of development for an approved permit or grant, the off-site mitigation becomes a requirement of the authorization.

The policy neither establishes any equivalency in acres impacted versus acres enhanced, nor quantifies habitat loss through behavioral displacement (i.e., avoidance). Currently, these determinations are made on a project-specific basis. While the policy indicates that the BLM NEPA analysis should "consider the effectiveness of off-site mitigation in reducing, resolving, or eliminating impacts of the proposed project(s)", there is no technical guidance as to how this could be accomplished.

Mitigation Accounting: Background

A key element proposed in any off-site mitigation proposal involves some form of an accounting, or "conservation credit" system (e.g., "mitigation accounting", "mitigation banking"). Essentially, this is a process of assessing and enumerating what resources (metrics) are lost, and then assigning them some "currency value". The process presumes that there is a good understanding (or will be in the future) of the "costs" of actions that create the debit side of the accounting system. It also assumes that there is an equal understanding of the gain from positive actions, and ultimately a currency (or accounting system) developed to trade debits and credits. In addition to the accounting system or "metric currency", specific mitigation banks could be created. One possible definition of a mitigation bank is the consolidation of many small accounting credits into a large, ecologically valuable area. Mitigation banks require upfront compensation (or investment) prior to impacting the sagebrush community.

Here, we explore the potential for a mitigation accounting system for GrSG and evaluate which off-site mitigation efforts are likely to be most effective.

If mitigation accounting systems and off-site compensatory mitigation techniques are aimed at conserving GrSG populations, then upon what metric or suite of metrics should they be based? The metrics could be based on GrSG habitat use or population demographics (e.g., behavioral responses to disturbance, survival) or sagebrush habitat (quality and quantity). Ideally, we would be able to predict the demographic consequences (e.g., lower nest success or increased mortality) of a permitted action, design off-site projects that could improve those demographic parameters for a GrSG population, and by extension have the project compensate for the specific on-site impact encountered.

In the CCP PVA, we explored the response of populations impacted by energy development to mitigation that directly improved reproductive success (see "Reproductive Success Mitigation", pg. 227). Unfortunately, there is no published literature that scientifically addresses the question of the response of GrSG to habitat modifications in a rigorous (i.e., replicated, controlled, experimental) fashion. Additionally, little is known about the quality, quantity, and/or juxtaposition of mitigated habitat and its compensatory response. In fact, although the principle that habitat improvement will increase population carrying capacity has been a central tenet of wildlife management, there is little experimental evidence to support it, for any wildlife species, largely because limiting factors for populations can be difficult to identify and may vary over time (Romesburg 1981).

Clearly, management experiments that document and evaluate the demographic and population-level response of GrSG to habitat creation and/or improvement are desperately needed. However, since rigorous scientific results may not elucidate the issue in a timely manner, we examine and review non-experimental evidence for GrSG and other species' responses to landscape-level habitat management approaches.

Mitigation Accounting: Population Demographic Rates as a Metric (or "Currency")

The first basic question regarding this metric is: what level of wildlife population gain might be expected from habitat creation or improvement measures? A case study that provides a good example is the CRP (Conservation Reserve Program), and resulting wildlife species responses. This program established almost 35 million acres of mid- and tall grasses in agriculturally-dominated landscapes. In some areas, such as North and South Dakota, this addition of grass habitat provided the addition of taller (ungrazed) grass communities in a matrix of already existing grassland (i.e., a habitat improvement). In other areas, such as Kansas, the program provided tall or mid-grass habitats where no habitat existed. Greater prairie chickens reportedly increased in abundance and/or expanded their range in portions of 5 of 8 states where CRP was provided within their range (Rodgers and Hoffman 2005). However, greater prairie chickens failed to respond to CRP in Colorado, Missouri, and central and eastern Kansas because grass was too short, too tall, or too dense.

Other species also responded to CRP. Lesser prairie chickens increased and expanded their distribution in Kansas (in areas where warm season native grass mixes were planted within 2 miles of native sand sagebrush rangeland). However, lesser prairie chicken populations responded minimally in New Mexico, and did not respond at all in Colorado, Oklahoma, or Texas, where structure of grass communities in CRP was adequate (Rodgers and Hoffman 2005). Plains sharp-tailed grouse expanded their distribution and/or increased in abundance in 10 of 12 states (Rodgers and Hoffman 2005). Columbian sharp-tailed grouse (CSTG) increased in distribution and densities in Washington, Idaho, Utah, and Colorado as a result of the establishment of the CRP program.

Unfortunately, population responses to the CRP program were only qualitatively described and there was no monitoring of demographic rates in the response areas. Population levels were not monitored before and after fields were enrolled in CRP, so population increases could not be evaluated quantitatively. Nevertheless, there are key lessons to be noted. First, the CRP program, which was both extensive and intensive, had a landscape-scale effect. Second, creation of additional habitat did not noticeably increase distribution or abundance unless it was structurally suitable and it addressed limiting factors.

In an attempt to document wildlife species demographic responses to habitat quality, Boisvert (2002) compared CSTG use of, and the demographic performance in, habitats with differing management history. Specifically, she compared CSTG response in CRP habitats versus high quality grasslands that were seeded to a high diversity of forbs and grasses in mine-land reclamation efforts. Boisvert (2002) found that 3 key demographic parameters increased in the high quality grass and shrub cover in mine-land reclamation: (1) adult survival; (2) nest success; and (3) chick survival. Conversely, although CRP grasslands were used for lekking, they appeared to result in less favorable demographics in CSTG. Columbian sharp-tailed grouse using CRP had lower annual survival and lower nest success (14% in CRP versus 68% in mine-land reclamation), due to inadequate concealment cover (Boisvert 2002). Densities of CSTG leks within the mine-land reclamation areas rose to the highest levels recorded range-wide because of the enhanced demographic rates (R.W. Hoffman, retired CDOW, personal communication).

As seen in these examples (none are available specifically for GrSG), possible metrics that could be used in a mitigation accounting method include changes in species survival rates or nest success. In a hypothetical example, an impact-related 10% decline in an adult survival rate might require at least a 10% increase in a survival rate in an off-site mitigation area. Our review here of mitigation accounting with population demographic rates as a metric outlines the difficulty (not the impossibility) of such an approach.

Mitigation Accounting: Habitat Response as a Metric

Despite the evidence from individual descriptive studies that habitat quality and treatments can impact local GrSG population demographic parameters, there is minimal understanding of how GrSG demographic rates will respond to habitat improvements when demographic rates are used as a mitigation accounting method. Thus, mitigation measures would likely have to be based on some multiple of acres of sagebrush habitat impacted versus acres of sagebrush habitat created or enhanced, with an assumption that demographic rates will be improved. In addition, there would also need to be some measure of habitat quality in the habitat areas created or enhanced. In this approach, although the responses of population demographics to mitigation are not directly measured, it is important to try to understand the relationship between habitat and population response. Much work still remains to better understand this relationship for GrSG.

An example of a habitat-based accounting metric is the USFWS's Habitat Evaluation Procedure (HEP). Since the early 1970s, the USFWS has worked on this habitat-based evaluation methodology that was developed for impact assessment and project planning (U.S. Fish and Wildlife Service 1980). The methodology of HEP can be used to document the quality and quantity of wildlife habitat. The primary assumption inherent in HEP is that wildlife habitat selection can be described in the form of a Habitat Suitability Index (HSI; U.S. Fish and Wildlife Service 1980). The index value ranges from 0 - 1.0, with 0 having no value and 1.0 having full value. The HSI can have numerous or very few habitat variables that mathematically represent the HSI score. The HSI is then directly multiplied by the number of acres and a total number of Habitat Units is calculated, thereby producing an accounting metric. The quality and reliability of the HSI is directly related to the quality and quantity of information and data used to establish the HSI. There are several HSI models available for an individual or a suite of species, but there is currently no reliable model specifically for GrSG.

Another approach using habitat response as a metric is the wetland mitigation accounting system. Wetland mitigation accounting systems are based on acre-for-acre replacement of lost wetlands, often at a ratio of 1.5 acres created for each 1 acre lost, though this ratio can vary. A difficulty in these types of conversions is ensuring the ecological equivalency of the wetlands created as compensation for those lost. Complex wetland ecosystems are probably not completely replaceable functionally, and even to attempt to do so requires consideration of scale and an understanding and ability to measure the baseline ecological complexity.

How effective might it be to create new GrSG habitats or improve historic habitats in Colorado? In theory, adding significant amounts of new habitat should increase GrSG densities, commensurate with the amount of new habitat added. However, as with wetlands, the assumption that newly-created habitat would have the same complement of species, ecological functions, and value to GrSG as existing occupied habitat may be invalid, and could cause overestimation of the population response. In addition, potential off-site treatment sites might be a limiting factor in Colorado, if development of a sagebrush accounting system/ratio (such as that used for wetlands) were undertaken.

In most areas there is a reasonable understanding of the structural and floristic characteristics of GrSG seasonal habitats (see "Habitat Requirements", pg. 35). There is also a basic understanding of how to restore sagebrush communities, at least from a vegetation community perspective (Monsen 2005). In contrast, there is not a good understanding of how to remedy habitat deficiencies that clearly benefit GrSG (i.e., how to restore degraded habitats or elevate inherently poor quality habitats to higher levels of quality, *to which grouse populations respond*).

It is vital that any habitat improvement projects be focused on factors that limit populations. If this approach is taken, the alleviation of limiting factors can increase population performance, and not just shift the distribution of grouse. For instance, fertilization of sagebrush was shown to increase nitrogen levels of sagebrush, which GrSG preferentially fed upon (Myers 1992), but no impact to survival, nest success, hatching rates, chick survival, or any other demographic parameter has been demonstrated. Preferential use of habitats by GrSG does not imply that the addition or increase of that habitat type will increase GrSG population performance.

Because of seasonal landscape movements by GrSG, newly created habitat developed through mitigation must be large and intensive enough to restore ecological integrity, so as to avoid a downward spiral of continued functional habitat loss despite compensatory mitigation (Race and Fonseca 1996). For example, habitat creation efforts must be at a sufficiently large scale to avoid population "sink" situations, or ecological traps, where demographic rates like nest success or chick survival actually decline because predators can search the small islands or improved habitats efficiently. Small-scale improvements in duck nesting habitat, for instance, have not always resulted in improvements in nest success rates because duck nesting efforts are concentrated in small areas easily searched by predators (Phillips et al. 2003).

Considerations for Off-site Mitigation

There is considerable uncertainty regarding an effective and sound approach in the development of a mitigation accounting system to mitigate off-site for the impacts to GrSG. If an off-site mitigation approach is adopted, an adaptive management program should be applied (see "Adaptive Management", pg. 10). That is, habitat improvements should be regarded as experiments, the outcomes of which should be monitored for success, both from a sagebrush community viewpoint, and from the perspective of GrSG demographic response.

Given the current understanding of the relationship between GrSG populations and habitat, the following should be considered with respect to the likelihood of success regarding compensatory off-site mitigation of energy impacts. Mitigation efforts should focus in areas where the greatest gains for GrSG can be achieved. Potential habitat-based mitigation approaches (in descending order of priority or effectiveness) are:

1. Establishing new habitat (e.g., converting CRP to sagebrush-grass) or reclaiming lost habitat (e.g., cheatgrass or piñon-juniper sites that were previously sagebrush) will likely have the greatest population and landscape-level response;
    a. Creating habitat in areas not currently occupied ("vacant or unknown" habitat, pg. 66), or those that are potentially suitable (see pg. 66) should concentrate on relatively large-scale efforts, as opposed to numerous small-scale efforts.
    b. Focus efforts to create habitat on areas that (1) have been type-converted, such as cropland, or extensive areas lost to fire; or (2) have successionally progressed to non-GrSG habitat, such as sagebrush that has been replaced by piñon-juniper communities.
2. Restoring healthy plant communities on degraded sites (e.g., mis-managed rangelands or riparian areas) will have the next highest population and landscape-level response;

   a. Focus on degraded sagebrush communities at the landscape-level where habitat improvement can result in restoration of ecological function and biotic diversity. Careful analysis must be given to the root causes of the current community condition, the local site capability, whether ecological thresholds have been crossed (see Monsen 2005 and "Habitat Enhancement" strategy, pg. 349), and likely limiting factors for sage-grouse populations. Treatments should be extensive enough to contribute towards solving the ecological problem, but in occupied habitats, size and distribution of treatments should be designed to minimize impacts to GrSG (see Appendix B, "GrSG Disturbance Guidelines"). Initial GrSG population response to treatments in existing degraded habitat may not be positive.

3. Treating existing and functioning sagebrush communities will have a low or non-measurable population and landscape-level response. If adopted for mitigation, these treatments should be small and distributed irregularly across the landscape (see Appendix A, "GrSG Habitat Structural Guidelines").

Compensatory mitigation efforts must **improve** habitats for GrSG and **compensate** for impacted areas, in order to be effective. For instance, conservation easements are valuable conservation tools, but if used as the sole means to compensate for habitat loss or other impacts, they don't avoid a downward spiral because there is no net increase in habitat quantity or quality at a landscape scale to offset impacts.

Compensatory mitigation must be based on outcomes and performance, and not solely on activities conducted (e.g., acres treated). Therefore, the effectiveness of off-site compensatory mitigation must be continually monitored and efforts adjusted upwards if management goals are not attained (see "Adaptive Management", pg. 10). Assumptions about type and quantity of habitat improvements needed to mitigate a given level of impact must be quantified in an adaptive management framework, and continually evaluated. Any adopted mitigation accounting system must be flexible and accommodate uncertainty. Ultimately, monitoring and evaluation should be of GrSG demographic rates and population responses.

This section is not designed to evaluate the relative importance of any of the 3 approaches identified regarding energy and mineral development impacts on GrSG (i.e., avoid, minimize, mitigate), or to recommend any specific approach. Rather, we have presented an exploration and analysis of the potential feasibility of "avoiding" and "mitigating" impacts. Note that there has been little discussion to date among agencies and stakeholders regarding a mitigation accounting approach within GrSG habitat in Colorado. Substantial work would be required to develop this concept into a proposal, and it is outside the scope of this plan. Proceeding with broad-scale compensatory off-site mitigation as a management approach would require careful consideration and the application of the principles of adaptive management (see "Adaptive Management", pg. 10).