May 15, 2020

Submitted via eplanning.blm.gov

Bureau of Land Management
Wyoming State Office
Attn: Jenny Marzluf, Greater Sage-Grouse State Implementation Lead
5353 Yellowstone Road
Cheyenne, WY 82009

Re: Wyoming Greater Sage-Grouse Draft Supplemental Environmental Impact Statement

Dear Sir/Madam:

Western Energy Alliance and API (the Trades) support the Bureau of Land Management’s (BLM) Wyoming Greater Sage-Grouse (GrSG) draft supplemental environmental impact statement (DSEIS). We urge BLM to complete the environmental review in an expeditious manner, while making certain additions and clarifications outlined below. We believe these edits will clarify that BLM is relying on the best available science in its management plans for the GrSG.

The Alliance represents over 300 companies engaged in all aspects of environmentally responsible exploration and production of oil and natural gas in the West. Alliance members are independents, the majority of which are small businesses with an average of fourteen employees.

API represents more than 600 member companies involved in all aspects of the oil and natural gas industry, including exploration and production, refining, marketing, and transportation of petroleum and petroleum products in the United States. Together with its member companies, API is committed to ensuring a strong, viable U.S. oil and natural gas industry capable of meeting the energy needs of our nation in an efficient and environmentally responsible manner.

The Trades believe that the GrSG management plans finalized by BLM in 2019 in seven western states achieve BLM’s objective of conservation of GrSG habitat in combination with management flexibility, adequate provision for access to public lands, and alignment with state plans to enable the agency to effectively manage sage grouse on the lands it administers. The comprehensive environmental review being undertaken in this DSEIS and in related reviews in the other affected states demonstrate the extensive analysis BLM has completed over the last decade.

Much of that analysis commenced in response to various court orders from the District Court of Idaho, and this review is no different. Western Energy Alliance has intervened in litigation challenging BLM’s plans, and the Trades share BLM’s continued contention that the 2019 plans are legally sufficient. Our comments in this letter do not alter that belief, nor do they imply that the decision from the District Court of Idaho precipitating this review was correct.
However, we believe it is imperative that BLM clarify how the 2019 plans relied on the best available science, a critical component of the decision in the district court. As such, we request that BLM update and supplement its review of the scientific information on which it relies for conservation of sage grouse habitat and management of those federal lands.

Specifically, BLM must take into account scientific information that has been developed since the reports prepared by the National Technical Team (NTT)\(^1\) in 2011 and the Conservation Objectives Team (COT)\(^2\) in 2013, including over 150 scientific papers and reports prepared since 2014 that are described and referenced in the materials we submit as attachments to this letter (Attachment B and F below). These reports make clear that the NTT and COT reports are no longer the best available science, contra the district court’s assertion.

We commend BLM for the analysis of the relevance of these two reports in Appendix F of the supplemental review and wholeheartedly support the conclusions reached therein. We believe the documentation provided in the attachments to this letter supplements this analysis and can help buttress the legal foundation for those conclusions.

Much of this more recent scientific information was undertaken during an era of enhanced voluntary conservation efforts in sage grouse habitat, adoption and enforcement of more stringent state and federal regulatory measures, the implementation of new technologies and practices by the oil and natural gas industry that reduce the effects from operations on its habitat, and higher quality data and improvements in statistical analysis.

The Trades previously argued that BLM’s reliance in the 2015 Land Use Plan Amendments (LUPAs) on the U.S. Fish and Wildlife Service’s COT Report and BLM’s NTT Report in determining stipulations, restrictions, and conservation measures for operations in sage-grouse country was arbitrary and capricious under the Administrative Procedures Act. The NTT Report and the COT Report failed to utilize the best available science; failed to adhere to the standards of integrity, objectivity, and transparency required by the agency guidelines implementing the Data Quality Act, and suffered from inadequate peer review (Attachment A below).

The NTT Report fails to adequately support its propositions and conclusions. For example, the NTT Report provided no scientific justification for the three percent disturbance cap, which was described in the 2015 LUPAs. Rather, the disturbance cap was based upon the “professional judgment” of the NTT authors and the authors of the studies they cited, which represents opinion, not fact.

The noise restrictions and required design features in the 2015 LUPAs, also recommended by the NTT report, are likewise based upon studies that relied on unpublished data and speculation, and employed suspect testing equipment under unrealistic conditions. Conservation measures based upon “professional judgment” and flawed studies do not constitute the best available science, and BLM should not have relied upon these studies or the NTT Report in the 2015 LUPAs.

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\(^1\) *Report on National Greater Sage-Grouse Conservation Measures Produced by the BLM Sage-Grouse National Technical Team*, Bureau of Land Management (Dec. 2011).

Finally, the NTT Report failed to cite or include numerous scientific papers and reports on oil and natural gas operations and mitigation measures that were available at the time the report was created. For example, the NTT Report failed to cite a 2011 paper (which was made available to the NTT authors) that discusses the inadequacy of the research relied upon by the NTT Report in light of new technologies and mitigation measures designed to enhance efficiency and reduce environmental impacts.

The COT Report likewise fails to utilize the best available science, and the BLM and other agencies inappropriately relied upon it in the 2015 LUPAs. The COT Report provides no original data or quantitative analyses, and therefore its validity as a scientific document hinges on the quality of the data it employs and the literature it cites. The COT Report contains serious methodological biases and mathematical errors, and the report’s data and modeling programs are not public and thus neither verifiable nor reproducible.

Finally, the COT Report provides a table assigning various rankings to GrSG threats, but gives no indication that any quantitative, verifiable methodology was used in assigning these ranks. Absent a quantifiable methodology, these rankings are subjective and rather than relying upon any conservation measures derived from these rankings.

As noted in the materials the Trades submit with this letter, the science that has been published since 2015 is extensive and collectively supersedes the NTT and COT reports. This science makes use of improved methodologies, such as: refined technology for estimating sage grouse seasonal habitat, models that incorporate climate variables to predict population trends, and cause-and-effect mechanisms that drive predation or disturbance (Attachment C). Additionally, several recent papers document how new oil and natural gas technologies (i.e. directional drilling) and environmental regulations (i.e. Wyoming’s Core Areas) have measurably reduced impacts to the GrSG (Attachment D).

In a similar manner, more recent genetic studies with large sample sizes and data from GPS tagged birds reveal that sage grouse disperse over much greater distances than previously thought, refuting previous assumptions central to the NTT and COT reports that sage grouse dispersal was limited. These same data also refute the assumptions behind the extinction predictions by Garton et al. (2011) that were central to the COT report and the 2010 "Warranted but Precluded" ESA-listing decision. Finally, this new body of science provides extensive documentation of refined mitigation measures and habitat restoration that reduce impacts to GrSG. This dramatically improved body of research is more precise and reliable than the studies previously relied upon in the NTT and COT Reports, and other reports relied upon in the development of the 2015 LUPAs.

Furthermore, as the information we’re submitting with this letter will describe in more detail, various advancements in operational efficiency, with secondary benefits to sage grouse, have also been implemented in exploration and production operations carried out within the GrSG range, both as voluntary efforts and as measures undertaken in compliance with regulatory requirements. These improvements in operational efficiency translate into reduced drilling and completion times, reductions in operational footprints, reduced noise and truck traffic, and therefore, reduced disturbance to sage grouse and other species. Virtually all of these innovations came after the primary and most influential studies on which the NTT and COT Reports rely were conducted (i.e. after 2006).

The Pinedale Planning area is an area in which a significant population of the GrSG occurs as well as a region within which periods of noteworthy oil and natural gas resource development have taken place
during the past 100 years. Therefore, we think it is particularly important to note that another difference between past and current oil and natural gas development, particularly in the Pinedale Planning Area, has been the implementation of extensive mitigation measures designed to reduce overall impacts to sage grouse and enhance their habitat. Pinedale was the subject of many of the reports upon which the findings and conclusions of the NTT and COT Reports were based. These factors demonstrate the importance of BLM’s management of these lands and lands elsewhere in the range of the GrSG being informed by the best available science (Attachment E).

Finally, we suggest BLM provide further support for decisions made in the 2019 plan amendments regarding the following subjects, each of which were identified in the district court’s order as being insufficiently justified:

- Elimination of Sagebrush Focal Areas (SFAs), and adequate protection of the COT report’s Priority Areas for Conservation (PAC), including connectivity areas between PACs
- Reduction/elimination/waiver of buffers
- Changes to hard and soft triggers
- Elimination of Compensatory Mitigation

We support the changes BLM made to those provisions, but it is imperative to emphasize those decisions were made consistent with the best available science, as discussed in the attachments to this letter. By clarifying that these changes are supported by the science, BLM will place the 2019 plans on firmer legal ground.

The Trades support a finding that BLM has achieved its goals of improved conservation of the Greater Sage-Grouse and its habitat while meeting its legal obligations. BLM’s 2019 management plans are legally defensible and scientifically sound, and we urge BLM to expeditiously finalize this supplemental review with the additions discussed above. Please do not hesitate to contact us with any questions.

Sincerely,

Tripp Parks
Vice President of Government Affairs
Western Energy Alliance

Richard Ranger
Senior Policy Advisor
American Petroleum Institute
Attachment A

A critical consideration of the NTT and COT reports and their applicability to land management in the GRSG range and to state management plans for the GRSG; and

A critical examination of scientific research efforts undertaken prior to 2015 and the validity of assumptions in this research regarding technologies, industry practices, and efficacy of conservation efforts on behalf of the species or its habitat.


in collaboration with Holsinger Law LLC and Maxwell Natural Resources Consulting

The NTT Report

In 2011, the Bureau of Land Management (BLM) formed the National Technical Team (NTT) to develop a report outlining new or revised regulatory mechanisms to protect and conserve the greater sage-grouse (GRSG) and its habitat on BLM-administered lands. Members of the NTT included resource specialists and scientists from BLM, state wildlife agencies, the U.S. Fish & Wildlife Service (USFWS), Natural Resources Conservation Service (NRCS), and U.S. Geological Survey (USGS). BLM incorporated select regulatory mechanisms from the NTT report into 98 land use plans (LUPs) for greater sage-grouse across 11 western states in 2015. According to the NTT, the report “provides the latest science and best biological judgment to assist in making management decisions.” In reality, the NTT report represents a partial presentation of scientific information to justify a narrow range of preferred conservation measures and policies.

The NTT report relied substantially on a highly influential series of scientific and policy papers on GRSG released initially as near-final drafts in 2009 and officially published in 2011 by the Cooper Ornithological Society as a monograph in the journal, *Studies in Avian Biology* (hereafter, the “Monograph”). The Monograph was central to development of the NTT report, the USFWS’s 2010 *Warranted but Precluded* Endangered Species Act (ESA)-listing decision, as well as subsequent Conservation Objectives Team (COT) and Buffer reports (discussed below), and directly or indirectly, the BLM and USFS land use plans.

A critical examination of the scientific basis (data, methods, results, and conclusions) of each paper in the Monograph as well as in the NTT report was subsequently undertaken. In 2012, a concise, independent peer review of the Monograph was produced by Wildlife Science International, Inc. at the request of the American Petroleum Institute (API). That review, *A Comprehensive Review of Greater Sage-Grouse: Ecology and Conservation of a Landscape Species and its Habitats, and Additional Papers of Relevance*, provided the scientific basis for Data Quality Act challenges on the Monograph prepared by Holsinger Law, LLC on behalf of a broad coalition of industry, agriculture and local governments (Coalition).
In 2013, a critical examination of the scientific basis of the NTT report was produced by Wildlife Science International, Inc. at the request of the Coalition. That review, *Review of Data Quality Issues in, A Report on National Greater Sage-Grouse Conservation Measures, Produced by the BLM Sage-Grouse National Technical Team (NTT)* provided the initial scientific basis for Data Quality Act (DQA) challenges to the NTT report (prepared by Holsinger Law).

**The COT Report**

In 2013, the COT Report was prepared by representatives from the USFWS and State agencies in an effort to develop range-wide conservation objectives for the greater sage-grouse, and to inform USFWS’ upcoming (2015) ESA listing decision. There were no original data or quantitative analyses used in developing the report, nor was there a comprehensive and unbiased review of *all* of the available scientific literature about conservation of the species. Instead, the COT Report provided a limited and selective review of the scientific literature and unpublished reports on GRSG as a basis for its objectives and proposed actions. As a result, outdated information and beliefs were perpetuated in the COT Report. In 2013, a critical examination of the scientific issues with the COT report was produced by Wildlife Science International, Inc. at the request of the Coalition. That report, *Data Quality Issues in the U.S. Fish & Wildlife Service’s Greater Sage-grouse (Centrocercus urophasianus) Conservation Objectives: Final Report* provided the initial scientific basis of the DQA challenge to the COT report.

While the COT Report was intended only to serve as a guidance document to federal agencies, states, and others, it has played a substantial role in the development of the 2015 BLM and USFS land use plan amendments. And like the 2011 NTT report, this report also figured prominently in Judge Windmill’s October 16, 2019 preliminary injunction that enjoined the BLM from implementing the 2019 BLM Sage-Grouse Plan Amendments for Idaho, Wyoming, Colorado, Utah, Nevada/Northeastern California, and Oregon.

**The Buffer Report**

In 2014, the USGS produced a report titled *Conservation Buffer Distance Estimates for Greater Sage-Grouse—A Review* (Manier et al. 2014) a/k/a (the Buffer Report). The stated purpose of the report was to "provide a convenient reference for land managers and others who are working to develop biologically relevant and socioeconomically practical buffer distances around sage-grouse habitats." In reality, the report was a brief but influential literature review that "interpreted" the scientific literature in order to produce recommended buffer distances from various human activities or development. The Coalition filed a DQA Challenge against the Buffer Report as well.

**The Data Quality Act Challenges**

In the years leading up to the preparation of the 2015 GRSG LUP amendments, there was disproportionate scientific influence by a small number of sage grouse specialist-advocates that had a disproportionate influence on formulating federal policy on GRSG. This included their overlapping participation in preparation of the USGS Monograph, the NTT Report, the COT Report, and the Buffer Report. Many of the same studies were repeatedly cited in each of these documents, and their findings repurposed in support of a preferred management decision.
The DQA requires federal agencies to ensure and maximize the quality, objectivity, utility, and integrity of information disseminated. Independent peer reviewers have found these influential reports to be inaccurate, unreliable, and biased. Specifically, the Monograph and reports were developed with unsound research methods resulting in a partial and biased presentation of information. They contain substantial omissions, technical errors (including one glaring mathematical error in a critical formula used to estimate population persistence in the Monograph), misleading use of authority (i.e. treating the authors' opinions as if they were legitimate scientific results) and failing to acknowledge studies that did not support their narratives. As a result, preparation of the Monograph and NTT, COT, and Buffer reports led to conjectural conclusions that are not scientifically supported.

In 2015, the Coalition retained Holsinger Law and submitted separate Challenges for Correction of Information against the USGS Monograph, BLM’s NTT Report, the USFWS COT Report, and the USGS Buffer Report, pursuant to the Federal Information Quality Act (Data Quality Act or DQA), various federal guidelines, and presidential and secretarial orders for ensuring the quality of scientific information used by federal agencies. While the outcome of the DQA challenges was disappointing—it was hardly surprising. In fact, the proponents used the DQA challenges as a way to document these significant issues for the record. The agencies failed to adequately address these issues and issued only a four-page response to all of these significant issues and a two-page response to subsequent appeals. In subsequent National Environmental Policy Act (NEPA) documents on the 2015 LUPs, the agencies hardly recognized the existence of the challenges, let alone addressed their merits. Despite the well-documented issues in the DQA challenges, the Monograph and NTT, COT, and Buffer reports remained unaltered and substantially influenced the 2015 LUPs. Despite repeated inquiries and requests, this DOI has failed to recognize the scientific shortcomings documented in detail in the challenges. As a result, bad science in the NTT, COT and Buffer Reports played a seminal role in Judge Windmill’s 2019 decision to issue a preliminary injunction that enjoined the BLM from implementing the updated 2019 GRSG Plan Amendments.

**Potential Path Forward**

The disappointing outcomes described in the preceding paragraph beg the following question: What would be the most effective strategy to ensure that an effort to revise and update LUPs are not again influenced by misguided information and recommendations of the Monograph and NTT, COT, and Buffer reports? With over 150 scientific papers and reports produced on greater sage-grouse biology and conservation since 2014, a straightforward solution would be to either file new DQA challenges, describing why the Monograph and reports are outdated and superseded by new research, or work with the BLM to help them reach the same conclusion and revise its contested RMPs accordingly.

In looking at our compilation of research since 2014, most of it was initiated during a new era of enhanced voluntary conservation efforts, more stringent state and federal regulatory requirements, the adoption of new technologies and practices by the oil and gas industry (that are less harmful to sage grouse), higher quality data and improved statistics. For the oil and gas industry, the most significant period when these changes being implemented was around 2005, as a result of increased awareness of the need for sage grouse conservation, along with a rapid increase in technological development and innovation in the oil and gas industry (i.e. directional drilling, 3D subsurface mapping,
liquid gathering systems, and other innovations). Additionally, we have observed a maturing of the scientific investigations over the past decade, with more investigators seeking to understand the specific cause and effect mechanisms behind sage grouse behaviors and population responses, something that was largely ignored previously in the Monograph, and NTT, COT, and Buffer reports and the scientific research cited in them.
We produced a concise annotated bibliography of scientific research of significance on greater sage-grouse published since 2015, drawing upon of two USGS annotated bibliographies (Carter et al. 2015; and Arkle et al. forthcoming) as well as PubMed and Google Scholar searches. While the USGS annotated bibliographies saved search time, we found their summaries generally inadequate for our purpose. Therefore, we downloaded and read each paper (or abstract if the paper was behind pay-per-view firewall). This allowed us to produce our own summaries that more tailored to the issues of interest.

For ease of use, we produced our annotated bibliography as a spreadsheet (Attachment F). This spreadsheet lists: the lead author, citation, implications, whether it supersedes the NTT or COT reports, the primary issue addressed, the significance of the findings, and additional comments. We have also flagged papers for additional review because of their potential to be highly influential during the upcoming USFWS status review and land use plan revisions.

After reviewing these papers, several key observations emerge:

1) The science that has been published since 2015 is extensive and collectively supersedes the NTT and COT reports. Importantly, improved methodologies such as: refined technology to estimating GRSG seasonal habitat, models that incorporate climate variables to predict population trends, and cause and effect mechanisms that drive predation or disturbance. Additionally, several recent papers document how new oil and gas technologies (i.e. directional drilling) and environmental regulations (i.e. Wyoming's Core Areas) have measurably reduced impacts to GRSG.

Similarly, genetic studies with large sample sizes and data from GPS tagged birds reveal that GRSG disperse over much greater distances than previously thought, refuting previous assumptions central to the NTT and COT reports that GRSG dispersal was limited. These same data also refute the assumptions behind the extinction predictions by Garton et al. (2011) that were central to the COT report and the 2010 "Warranted but Precluded" ESA-listing decision.

And finally, this new body of science provides extensive documentation of refined mitigation measures and habitat restoration that reduce impacts to GRSG. This dramatically improved body of research is more precise and reliable than the studies previously relied upon in the NTT, COT, Buffer Report, and land use plans.
2) We expect that anthropogenic climate change will be cited in the upcoming USFWS status review as a serious threat to sage grouse. That assessment is based on multiple papers that make long-range projections regarding the future of GRSG habitat, forward in time to 2050, 2070, and 2100. The weakness of these papers however, is three-fold. First, these papers base their long-range predictions on downscaled general circulation models (IPCC or similar) and rely on linking outputs of several models, thus multiplying uncertainty. Second, we found that at least two of these papers utilize the "unlikely high-risk future" scenarios of the IPCC Representative Concentration Pathway RCP8.5. A recent January 29, 2020 paper in the journal Nature pointed out the fallacy of basing predictions on such worst-case scenarios as they are highly unlikely to come true (https://www.nature.com/articles/d41586-020-00177-3). And third, such long-range predictions are inherently untestable as hypotheses because: a) their predictions extend far enough into the future that they exceed a typical human career span (i.e. 30 years), thus it is highly unlikely that they will ever be tested, and b) because of the fast pace of climate science, no one bothers to testing the validity of such predictions at shorter intervals in the first place. This general lack of potential falsifiability puts many climate science predictions outside the realm of empirical, testable science.

3) Although numerous papers point to a stable or not-so troubling GRSG declines to a stable equilibrium, there are a handful of authors who consistent seem to find severe, ongoing declines in the same data sets. It would be worthwhile reviewing these papers in detail to understand why this is the case. These reviews should be completed before the USFWS status review gets underway.

4) Outside of what we have described above, there are no other obvious issues that we have found during this initial review that would appear to require a Data Quality Act challenge. However, that could change as more in-depth reviews are performed, new scientific papers and reports are published, and new agency actions or litigation undertaken.
Importance of Incorporating Data on Regional Climatic Variation and Greater Sage-Grouse Population Fluctuations into Conservation Efforts and Future Land Use Plans Within the Species Range.


It is well documented in the scientific literature that annual fluctuations in sea surface temperatures in the North Pacific Ocean drive multi-year variation in temperature and precipitation patterns in western North America. The Pacific Decadal Oscillation (PDO) is an index of the sea surface temperature variation in the North Pacific Ocean that has a significant influence on temperature and precipitation patterns (http://research.jisao.washington.edu/pdo/PDO.latest). This regional climatic variation (i.e. periodic fluctuations in large-scale weather patterns) in turn affect marine and terrestrial plant and animal population cycles, and contributes to phenomena such as summer heat and fire frequency in the western USA. Large-scale climate indices, such as the PDO, often outperform local temperature and precipitation data in predicting population dynamics and ecological processes (Stenseth et al. 2002; Hallett et al. 2004).

Multiple authors have reported that greater sage-grouse populations experience cyclic fluctuations, and that these population dynamics are linked to patterns of temperature and precipitation, or the PDO, which affect reproduction and survival (Blomberg et al., 2012, 2014, 2017; Green, Aldridge & O’Donnell, 2016; Coates et al., 2016; Gibson et al., 2017; Ramey et al. 2018). This relationship between climatic variation on population dynamics of greater sage-grouse is not surprising as there is a long and ecologically important history of studies examining the influence of climatic variation on the population dynamics of other tetraonids, including black grouse, ptarmigans, and prairie chickens. Those papers include: Moran (1952, 1954); Ranta, Lindstrom & Linden (1995); Lindström et al. (1996); Cattadori, Haydon & Hudson (2005); Ludwig et al. (2006); Kvasnes et al. (2010); Selås et al. (2011); Viterbi et al. (2015); Ross et al. (2016); Hagen et al. (2017).

Significance

The significance of these findings to the conservation of sage grouse, and to future land use plans in particular, are threefold:

1) State and federal agencies need to account for the predictable responses to periodic regional climatic fluctuations when managing sage grouse in Wyoming and elsewhere in the western USA in an adaptive management framework. This is especially important as the current USFS and BLM Land Use Plans for greater-sage grouse make no mention of this obviously important demographic phenomenon.

2) Policies based on population "triggers" (i.e. additional restrictions and conservation measures that are implemented when a population dips to a certain level) are flawed unless the effects of the PDO are taken into account so that natural fluctuations are not misinterpreted. Such triggers should be defined as the percent divergence from the expected carrying capacity, with the carrying capacity tracking the regional climate. Several of the current triggers will be tripped during the course of natural population fluctuations.
3) The current pattern of the PDO indicates that sage grouse populations will be at a temporary low ebb in 2020 when the US Fish and Wildlife Service conducts a status review and reconsiders an Endangered Species Act "threatened" listing.

Figure 1. Examples of synchronous greater sage-grouse population fluctuations in Wyoming (from Ramey et al. (2018)).

Figure 2. Example of GRSG cyclic population fluctuations in the Upper Green River Working Group in Wyoming (figure from Wyoming Game and Fish). Note the expected low ebb in the population in 2020.

**Chronology of recent research on regional climate variation and greater sage-grouse population trends**

Collectively, this literature (briefly summarized below) underscores the importance of ensuring that the
BLM's and USFS's adaptive management of sage grouse populations take into account the effects of regional climatic variation, as indexed by the PDO (or other measures as regionally appropriate), so that natural population fluctuations are not misinterpreted and conservation efforts misdirected.

Neilson et al. (2005) were the first to hypothesize that inter-annual and inter-decadal climate variability of El Niño-La Niña (ENSO) and the Pacific Decadal Oscillation (PDO) affect sagebrush ecosystem dynamics in the Great Basin, with the PDO being the primary driver of wet-dry cycles.

Fedy and Doherty (2011) reported on the synchrony between population cycles of Wyoming cottontail rabbits (Sylvilagus spp.) and greater sage-grouse, and hypothesized "a broad-scale causal influence" of weather cycles affecting these species.

Blomberg et al. (2012) reported that as much as 75% of the annual variance in greater sage-grouse population size in their study area over 12 years could be accounted for with annual variation in precipitation variables. The authors concluded that, "These results are consistent with bottom-up regulation of sage-grouse populations, where abundance is determined in large part by climate-driven variation in resource availability."

Guttery et al. (2013) reported that large-scale climatic variability in Utah and Idaho plays a primary role in determining greater sage-grouse reproductive success and that temperature and precipitation variables were found to have significant effects on chick survival. They concluded that, "An understanding of large-scale population drivers is essential for effective wildlife conservation planning and provides a baseline for developing meaningful hypotheses about specific local factors affecting populations at smaller spatial and temporal scales."

Coates et al. (2016 and 2017) demonstrated the importance of modeling climatically driven population cycles of sage grouse in Nevada and eastern California to understand "the difference between when populations are responding naturally to weather related patterns, compared to experiencing more localized- and habitat-based declines."

Ramey et al. (2018) reported that regional climatic variation, as indexed by the Pacific Decadal Oscillation (PDO), was an important positive predictor of density changes at both the local and population level, particularly in the most recent part of the time series when lek count data were of higher quality.

Literature Cited


Summary of Improvements in Oil and Gas Technology and Best Practices That Have Reduced Overall Impacts to Greater Sage-Grouse in the Pinedale Planning Area of Wyoming


The adverse effects of oil and gas development on greater sage-grouse in the western USA and Canada has been described in an extensive body of scientific literature. Virtually all of these analyses rely on a central simplifying assumption: impacts from current operations will be the same as those in the past. It has been assumed that all oil and gas wells and infrastructure will have the same level of disturbance to sage grouse regardless of when it was developed, as if nothing has changed from the 1980s to the present with oil and gas technology, industry best practices, or regulations.

While such assumptions simplify data analysis and modeling, it is worthwhile questioning whether these assumptions accurately represent current impacts, given advances in technology, more efficient industry practices, and more stringent environmental regulations. This is particularly relevant when the data sets used in analyses span decades and are used to make predictions far into the future. It becomes even more important when subsequent recommendations and regulations are based on those studies (i.e. the National Technical Team Report (NTT 2011) and the 2015 Bureau of Land Management and U.S. Forest Service greater sage-grouse Land Use Plans).

The aim of this briefing paper is to inform the public and decision makers of the most significant changes in the evolution of oil and gas technology and practices over the past three decades, and why these matter in the evaluation of impacts to greater sage-grouse populations.

Oil and gas development in western North America has had a long history. Here we focus on its more recent history in the BLM's Pinedale Planning Area in the Upper Green River Basin of northwestern Wyoming. The Pinedale area has experienced ongoing oil and gas development since its first well was drilled in 1912. It also continues to have a thriving sage grouse population that fluctuates in number, like other sage grouse populations, due to natural causes (Ramey et al. 2018).

BLM's Pinedale Planning Area is where advances in technology, industry practices, environmental regulations, and conservation efforts are well documented. As such, it serves as a laboratory to illustrate how oil and gas technology has evolved since the 1980s and early 1990s when there was little environmental oversight and technology was relatively primitive compared to today's. We further highlight major changes that began in the mid-1990s and have accelerated since the mid-2000s, with dramatic improvements in drilling, completion, and production technologies, that reduced the duration of potentially disruptive activities and surface disturbance. Since 2005, these technological improvements, coupled with more conservation-minded regulatory oversight and voluntary conservation efforts, represent a dramatically different era compared to that which came before.

Two evolving technologies that have reduced surface disturbance and impacts of oil and gas development to sage grouse are 3D seismic surveys and directional drilling.
3D seismic surveys

The rapid evolution of 3D seismic survey technology and its widespread adoption in the mid-1990s was arguably the most significant change to how oil and gas exploration and development occurred in sage grouse habitat (Gray et al. 2002; Chopra and Marfurt 2005). While this technology resulted in the discovery and development of new oil and gas fields, it also led to far more efficient and concentrated development of those resources than was previously possible.

Consequently, the previous practice of grading access roads and drilling numerous exploratory "wildcat wells" across the landscape became obsolete by the late 1990s. With concentrated development possible directly over the most concentrated resources, planned oil and gas development was possible along with large, planned conservation set-asides for sage grouse and other species. In the Pinedale Planning Area, this led to large no surface occupancy areas being set aside by the BLM for sage grouse and other species. To visualize one-hundred years of change in surface development in the Pinedale Planning Area, from the era of wildcat well exploration and development to 3D seismic exploration and development (post 1995), please click on the following animation link.

Directional Drilling

The most environmentally-significant of these new technologies has been improvements to and widespread adoption of directional drilling (Arthur and Cornue 2010; BLM 2006a; Ramey, Brown, and Blackgoat 2011; Seto 2011; Applegate and Owens 2014). Directional drilling involves drilling multiple wells (up to 50 presently) that angle away from a centralized well pad and single rig to tap oil and gas deposits a mile or more away and thousands of feet below the surface (https://www.rigzone.com/training/insight.asp?insight_id=295). This is a far more efficient, economical, and less environmentally impactful method than drilling many vertical wells to tap the same resource, because operators can access subsurface resources over a broad area from a single pad. (Directional wells that start vertically and make a 90-degree turn to traverse laterally to access in horizontal strata are known as horizontal wells.) Formerly, many closely-spaced vertical wells on separate pads were required to tap the same resource, which resulted in extensive surface disturbance, such as that seen in aerial photographs of the Jonah Field in Wyoming in the early 2000s. The Jonah Field underwent extensive vertical drilling in the 1990s before the widespread adoption of directional drilling and more stringent regulations on well pad spacing.

While many directional wells currently traverse laterally a distance of less than two miles, the most recent records for lateral distance is 6.1 miles in the USA and 6.8 miles in Qatar (https://www.drillingcontractor.org/corva-helps-break-north-american-drilling-record-for-longest-lateral-with-32468-ft-well-53647; https://www.guinnessworldrecords.com/world-records/longest-drilled-oil-well/). These records illustrate that under ideal conditions a single well pad has the potential to access oil and gas resources in a subsurface area of over 19 square miles (12,265 acres) with minimal surface disturbance.

Data from the Pinedale Planning Area shows that the transition from predominantly vertical wells to directional wells occurred around 2004 (Figure 1). This represented a major shift in drilling efficiency and subsequently less surface disturbance. Directional wells now account for virtually all of the wells drilled in the Pinedale Planning Area and those planned for the Normally Pressurized Lance Field.
More recently, advances in computational geoscience coupled with down-hole, near-the-drill-bit gamma ray, resistivity, and navigational sensors, allow real-time, high resolution 3D visualization of subsurface features in rocks surrounding the bore as drilling proceeds. This technology, coupled with the advent of rotary steerable system drill bits (first introduced on the Pinedale Anticline in 2008) dramatically decreases drilling time (Okafor et al. 2009). This combination of technologies, along with more recent advances in dynamic point-the-bit rotary steerable systems and analytical software has ushered in a new era of "geosteering" which has further increased the efficiency of tapping subsurface resources (Zhang et al. 2019). In simple terms, higher drilling efficiency translates into less surface disturbance and activity above ground, both of which can affect sage grouse.

Directional drilling of multiple wells from the same well pad has also led to a new type of operational efficiency, one that was not possible during the single-well-per-pad-era: the co-location of supporting infrastructure for completion and production activities being simultaneously carried out on different wells drilled from the same well pad. This translates into reduced surface disturbance, equipment moving on and off site, and manpower required. For example, drilling rig moves that used to take 150 or more truck trips to move between pads, are now accomplished by skidding the rig a few feet to a nearby location on the same pad (Kreckel, 2011).

Advances in technology allow shorter drilling and completion times, reducing potential disturbance to sage grouse

More efficient technology has also resulted in shorter drilling and well completion times. While the averages we report show marked improvement (from spudding to completion), it should be noted that these completion times also include periods of inactivity at a well site due to interruptions from logistical and seasonal constraints. Therefore, actual drill and completion times (not including inactive periods), may provide a more accurate portrayal of the duration of potentially disturbing activities to...
sage grouse. For example, companies reported that drilling a well on the Pinedale Anticline (with an average depth of 13,000 feet) took an average of 65 days in 2002 and this decreased to 35 days by 2006 (OGJ 2007). By 2011 this had improved further, to an average of 14 days of drilling to depth, and in 2013, QEP Resources reported that they had achieved a well to depth time of 9.3 days, a new record (QEP 2013). Similar improvements in drilling and completion efficiency have been reported elsewhere (DTC Energy Group 2013).

Overall, uninterrupted completion times have dropped from six months to as few as 2 to 3 days in 2013 (AECOM 2013). Currently (as of January 2020), the average well depth on the Pinedale Anticline is 13,700 feet and drilling from spud to total depth takes an average of 8 days (range 6 to 10 days). Completions take approximately 3 days for two wells which are done in pairs for greater efficiency (data from Ultra Resources, Inc.).

Collectively, these data illustrate that much has changed in drilling and completion technology over the 18 years from 2002 to 2020, resulting in reduced industrial activity and subsequent potential disturbance to sage grouse.

Closed-loop drilling fluid systems and field-level liquid gathering systems

Beginning in the early 2000s closed-loop drilling fluid systems began to replace open reserve pits adjacent to wells being drilled. Closed-loop drilling fluid systems are a best management practice that has emerged as a more environmentally responsible and economically viable alternative to open reserve pits and evaporation ponds that require frequent truck trips, can trap sage grouse and other birds, and represent a potential source of groundwater pollution (US Environmental Protection Agency 2019). Closed-loop systems separate drilling fluid from drill cuttings and other solids, which are dewatered for solid waste disposal in landfills. Water is then recycled back into the drilling process, minimizing fresh water use and making solid waste easier to dispose of (Colorado School of Mines. 2009; Pei et al. 2011). While an increasing number of companies have adopted closed loop drilling systems and on-site water purification systems to recycle produced water (Colorado Department of Natural Resources 2019, as cited in U.S. Environmental Protection Agency 2019), some have gone further and implemented a comprehensive, field-level liquid gathering systems (LGS) and water purification facilities.

The most notable of these liquid gathering and water purification facilities went online on the Pinedale Anticline in 2012 and was designed to eliminate 165,000 truck trips per year (BLM 2005). A study conducted over two winters reported that the LGS system reduced overall human activity at LGS-equipped well pads, as compared to conventional well pads, by at least a factor of two and thereby reduced avoidance by sage grouse (Holloran et al. 2015). That study concluded that "implementing efforts to decrease anthropogenic activity levels associated with infrastructure of natural gas fields during both drilling and production phases of development (i.e. using LGS) may also help reduce effects of the infrastructure on wintering sage-grouse." A similar LGS and water purification system is also planned for the Normally Pressurized Lance Field for the same reasons.

Other changes in oil and gas operational efficiency

Other advancements in operational efficiency, with secondary benefits to sage grouse, have also been
implemented in the Pinedale Planning Area, both as voluntary and regulatory efforts. The most significant of these to sage grouse have included:

- Installation of remote telemetry systems to monitor wells and condensate tanks (initiated in 2008 and completed in 2012; BLM 2008a,b).

- Electrification of the Pinedale Anticline (BLM 2012), allowing equipment to be powered with electricity rather than internal combustion generators and motors. While this change was originally intended to reduce high levels of ozone accumulation in the Pinedale Planning Area, it has the secondary benefit of reducing engine noise and truck traffic (needed to refuel and maintain internal combustion engines).

- Required use of EPA compliant Tier II diesel engines on drill rigs, with phase out into more efficient Tier III and IV designs, all of which reduce noise (and pollutants) compared to non-compliant engines in use prior to 2006.

Collectively, these improvements in efficiency translate into reduced drilling and completion times, reduced noise and truck traffic, and therefore, reduced disturbance to sage grouse and other species. Virtually all of the innovations listed above came after the primary and most influential studies were conducted at Pinedale (i.e. after 2006).

Admittedly, the development of more efficient oil and gas development and production technology is often driven by economic considerations, however the benefits to the environment are obvious: reduced drilling and completion time which translates into less noise, less traffic, and less overall disturbance to wildlife.

Mitigation measures

Another difference between past and current oil and gas development, particularly in the Pinedale Planning Area, has been the implementation of extensive mitigation measures designed to reduce overall impacts to sage grouse and enhance their habitat. Mitigation measures became notable with development of the Pinedale Anticline starting in 2000 (BLM 2000, 2008a) followed by the Jonah Drilling Infill Project (BLM 2006b) and culminating in the Pinedale Resource Management Plan Record of Decision (BLM 2008b). These measures have resulted in 183,608 ha of sage grouse habitat in the Pinedale Planning Area set aside by the BLM as unavailable to oil and gas development (BLM 2008b).

Also, seasonal restrictions were placed on an additional 122,126 ha to safeguard sage grouse winter concentration areas and nesting habitat, and no surface occupancy stipulations were placed on any new development. Additionally, required mitigation funds (BLM 2006b) have funded habitat improvement projects, offsite mitigation, and contributed to the purchase 34,772 ha of conservation easements in the Pinedale Planning Area through 2012. And finally, Executive Orders issued by the Governor of Wyoming, beginning with Core Population Area designation and protection in 2008, and subsequently updated multiple times (State of Wyoming 2019), limit surface disturbance to an average of 5% in core areas statewide (or an average of 1 well pad per square mile).
Literature Cited


BLM. 2000. Record of Decision for the Pinedale Anticline Oil & Gas Exploration and Development Project.

BLM 2005. Finding of No Significant Impact (FONSI) and Decision Record (DR) for Questar year-round drilling proposal – condensate pipeline modification (QYDP-CPM) EA #WY-100-EA05-283.


Central Question

What are appropriate methods and parameters for analysis to determine the local and population-level effects of human activities on greater sage-grouse at three different scales: 1) a local project (i.e. <100ha in size), 2) a major field with continuing operation (or a new development such as Naturally Pressurized Lance field (50,000-100,000ha)), or 3) land management plans on GRSG populations (i.e. spanning 3-5 working groups). How should such parameters models vary with the scale of a project or planning effort in determining its consequences?

Methods

In essence, the local and population-level effects should be quantified by the relative change in abundance of sage grouse after controlling for intrinsic factors such as density-dependence and extrinsic factors such as climatic variation (Coates et al. 2018; Ramey et al. 2018). As described below, these methods include analysis of lek counts based on stage-based population dynamic models.

The sage grouse abundance should be based on lek counts (Walsh et al. 2004) as this data is relatively inexpensive and non-intrusive to collect, has been collected historically via ground-based visual surveys for several decades in many areas and provides an index of population abundance (Monroe et al. 2016). In particular, the counts of male sage grouse should be corrected for sightability (Fremgen et al. 2016; Coates et al. 2019), seasonality (Wann et al. 2019) and where possible time of day to provide an estimate of the absolute male attendance at each lek in each year. Lek counts from ground based visual surveys can be supplemented by more extensive aerial infrared surveys (Gillette et al. 2013), provided they are also corrected for sightability (Coates et al. 2019).

The change in abundance due to human activity should be quantified in terms of the change in male lek attendance relative to what the attendance would have been in the absence of the activity. In order to estimate this term it is not enough to simply compare the lek attendance before the activity to the lek attendance after the activity. This is because lek attendance in sage grouse like other tetraonids (Kvasnes et al. 2010) undergoes large oscillations driven by density-dependence (i.e. population density feedbacks affect population growth rate) and regional climatic variation (i.e. inter-annual and multi-decadal variation in large-scale regional weather patterns) (Ramey et al. 2018). In other words, we must be able to account for these two naturally interacting processes in any analysis of human influences. Without accounting for these, the result could be an activity with a negative impact appearing neutral or even beneficial if it was undertaken while the population was recovering from lowered densities due to suboptimal climatic conditions. Likewise, a downturn may be entirely due to natural processes, rather than the activity in question (e.g. a low ebb in the Wyoming sage grouse can be expected as part of a population cycle, based almost entirely on the natural processes).
In addition to accounting for temporal dependencies due to population fluctuations, the statistical models also need to account for spatial dependencies in the response of individual leks. In particular the effect of an activity is expected to decay by distance while reductions at one lek could lead to decreases or increases at neighbouring leks depending on whether depensation (i.e. decrease in local population density or number due to the loss of breeding adults) or compensation (i.e. displacement of breeding sage grouse to nearby, undisturbed leks) is occurring. The extent to which these mechanisms are operating and how best to model them remains an open question. However, this is an important question to answer because it is central to quantifying the extent to which a locally-observed decrease in sage grouse density in a project area may, or may not be, contributing to an overall decrease in the carrying capacity of the larger, surrounding population, or the cumulative effects of multiple projects and activities on a population. In other words, the question of "how much is too much" development, relative to a desirable population threshold.

Depending on the scale, the most promising method(s) include statistical analyses that can either use other leks that are outside the zone of influence as controls and/or explicitly model density-dependence, climatic variation and other extrinsic factors (Ramey et al. 2018). Ideally they would do both. The resultant effect size should be expressed as the estimated n-fold change due to the activity with 95% confidence/credible intervals (Bradford et al. 2005). As described below, explicit models should be stage-based population dynamics models.

The biggest limitation of a statistical approach is the uncertainty in the effect of an individual project. At more local scales, this uncertainty can be substantially reduced by including data from other similar projects in the analyses while allowing for inter-project variation in the response (LaMontagne et al. 2002) through a random effect (Kéry 2010). Large-scale projects such as land-management plans may have to be broken into a series of smaller activities in order to estimate the effect with sufficient certainty for it to be useful in decision-making. The models should strive to analyse all available lek count data including historical counts using stage-based population dynamic models (Kery and Schaub 2011; McCaffery and Lukacs 2016). The advantages of stage-based population dynamic models are that multiple sources of information for different life-stages and sexes including prior information from previous analysis can be readily incorporated while lags are readily accounted for thus providing tighter linkages between population drivers and lek counts. However, computational memory and/or run-time requirements may necessitate the fitting of simpler models to reduced datasets if they cannot be overcome through the use of supercomputers.

**Literature Cited**


<table>
<thead>
<tr>
<th>Author et al.</th>
<th>Year</th>
<th>Title</th>
<th>Implications: Modified from USGS Annotated Bibliography (2018, 2019) or from each paper</th>
<th>Supercedes NVT</th>
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<th>Significance</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fedy et al.</td>
<td>2015</td>
<td>The influence of mitigation on sage-grouse habitat selection within an energy development field: Plut ONE, v. 10, no. 4, article e0121603, 19 p., <a href="https://doi.org/10.1371/journal.pone.0121603">https://doi.org/10.1371/journal.pone.0121603</a></td>
<td>Oil &amp; Gas (includes WY Core Areas)</td>
<td>Oil &amp; Gas</td>
<td>Oil &amp; Gas mitigation</td>
<td>Updated practices reduce impacts; habitat behavioral, or population effects; mitigation, WY Core Areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fedy et al.</td>
<td>2015</td>
<td>Large-scale control site selection for population monitoring—An example assessing sage-grouse trends. Wildlife Society Bulletin, v. 39, no. 4, p. 700–712</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Updated practices liquid gathering systems reduce impacts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holloran et al.</td>
<td>2015</td>
<td>Freeier habitat use of greater sage-grouse relative to activity levels at natural gas well pads. Journal of Wildlife Management, v. 79, no. 4, p. 630–640.</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Updated practices and onsite mitigation improved nest success</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kirol et al.</td>
<td>2015</td>
<td>Mitigation effectiveness for improving nesting success of greater sage-grouse influenced by energy development. Wildlife Biology, v. 21, no. 2, p. 98–109.</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Updated practices and onsite mitigation improved nest success</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kirol et al.</td>
<td>2015</td>
<td>Identifying greater sage-grouse source and sink habitats for conservation: energy development landscape: Ecological Applications, v. 25, no. 4, p. 968–980.</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Oil &amp; Gas mitigation</td>
<td>Updated practices and onsite mitigation improved nest success</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Krill et al.</td>
<td>2018</td>
<td>Seasonal habitat use by greater sage-grouse (Centrocercus urophasianus) on a landscape with low density oil and gas development: Plut ONE, v. 11, no. 10, article e015599, 20 p.</td>
<td>Oil &amp; Gas and ConWyoming e Area</td>
<td>Oil &amp; Gas and ConWyoming e Area</td>
<td>Oil &amp; Gas and ConWyoming e Area</td>
<td>Potential effect of updated O&amp;G practices &amp; reduced impacts</td>
<td>Caveat: Potentially small effect on oil and gas impacts are less than expected</td>
<td></td>
</tr>
<tr>
<td>Christiana et al.</td>
<td>2017</td>
<td>Wyoming sage-grouse working groups—Lessons learned: Human-Wilson interactions. v. 11, no. 3, p. 274–286.</td>
<td>Wyoming Core Area concept; Oil and gas development</td>
<td>Wyoming Core Area concept; Oil and gas development</td>
<td>Wyoming Core Area concept; Oil and gas development</td>
<td>Working group program history and effectiveness</td>
<td>Important background</td>
<td></td>
</tr>
<tr>
<td>Gamon and Beck</td>
<td>2017</td>
<td>Effectiveness of Wyoming’s sage-grouse core areas—Influences on energy development and male lek attendance: Environmental Management, v. 59, no. 2, p. 189–205.</td>
<td>Oil and gas and ConWyoming e Area</td>
<td>Oil and gas and ConWyoming e Area</td>
<td>Oil and gas and ConWyoming e Area</td>
<td>, results provide support for the effectiveness of Core Areas in maintaining sage-grouse populations in Wyoming, but also identifies increased conservation strategies to improve sage-grouse population response in (MZ) I.“</td>
<td>Caveat: Potentially small effect on oil and gas impacts are less than expected.</td>
<td></td>
</tr>
<tr>
<td>Gamon</td>
<td>2017</td>
<td>An simulation framework for assessing physical and wildlife impacts of oil and gas development scenarios in Southwestern Wyoming: Environmental Modeling and Assessment, v. 23, no. 1, p. 39–56., <a href="https://doi.org/10.1007/s10666-017-9559-9">https://doi.org/10.1007/s10666-017-9559-9</a></td>
<td>Oil and gas impact modeling</td>
<td>Oil and gas impact modeling</td>
<td>Oil and gas impact modeling</td>
<td>New Oil and gas technology and improved practices reduce impacts compared to past; WY Core Areas</td>
<td>A significant contribution deserving more attention.</td>
<td></td>
</tr>
<tr>
<td>Green et al.</td>
<td>2017</td>
<td>Investigating impacts of oil and gas development on greater sage-grouse: Journal of Wildlife Management, v. 81, no. 4, p. 48–57.</td>
<td>Oil and gas impacts; Wyoming Core Area</td>
<td>Oil and gas impacts; Wyoming Core Area</td>
<td>Oil and gas impacts; Wyoming Core Area</td>
<td>Another paper with Aldridge finding substantial current impacts contrary to others. Why does a paper published in 2017 only use data up to 2009?</td>
<td>Caveat: Likely least results due to use of old data (1990s) and use of extensive mitigation and regulation. Only used seasonal data on sagebrush core sites as a poorer predictor of regional climate variation.</td>
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<td>Authors</td>
<td>Year</td>
<td>Title</td>
<td>Abstract</td>
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<td>X</td>
<td>Population trends</td>
<td>Potential Improved methodology, however, estimated declines do not seem to match current observations. Cyclical population fluctuations noted.</td>
<td>Caveat: Conclusions do not appear match revised results. See review of paper, erratum, and supplemental materials).</td>
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</tr>
<tr>
<td>Edmunds et al.</td>
<td>2017</td>
<td>Oil and gas development exposure and conservation scenarios for greater sage-grouse—Combining spatially explicit modeling with GIS visualization provides critical information for management decisions: Applied Geography, v. 80, p. 30-111.</td>
<td>Using data from Wyoming, the authors examined population trends at different spatial scales. While this is a refinement that could allow managers to focus on small-scale populations, that are influencing large-scale trends, allowing for more efficient use of resources and for testing of management effectiveness (similar to Ely et al. 2018), however, regional climate variation is only accounted for using a trend internal covariate). Additionally, it is significant that this paper had to issue a retraction of a coding error that led to overestimates of population declines and misrepresentation of a as a flat trend.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Jakusson and Oelhert</td>
<td>2017</td>
<td>Oil and gas development exposure and conservation scenarios for greater sage-grouse—Combining spatially explicit modeling with GIS visualization provides critical information for management decisions: Applied Geography, v. 80, p. 30-111.</td>
<td>The proportion of the male population within core areas and the observed decreased probability oflek collapse within core areas suggest that the core area policy is providing broader protection for GRSG in Wyoming. However, limitations on development near core areas may need to be more effectively protect GRSG populations within core areas. From the authors, “Collectively, these data suggest that the Wyoming Core Area Strategy has benefited sage-grouse and sage-grouse habitat conservation; however, additional guidelines limiting development densities adjacent to Core Areas may be necessary to effectively protect Core Area populations.”</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Spence et al.</td>
<td>2017</td>
<td>Probability oflek collapse is a lower inside sage-grouse core areas—Effectiveness of conservation policy for a landscape species: PLoS ONE, v. 12, no. 11, article e0185851, 15 p.</td>
<td>The authors modeled for low, medium, and high oil and gas development for the years 2012-2022, and climate changes to 2050 in southwest Wyoming. Authors state “we projected oil and gas development footprints and climate induced vegetation changes 50-years into the future. Using a time-series of planned oil and gas development and predicted climate-induced changes in vegetation, we calculated habitat selection maps to dynamically model future habitat, quality, and configuration. The inclusion of movement and demographic responses to oil and gas infrastructure resulted in substantial changes in distribution and abundance when cumulated over several decades and throughout the regional population. When combined, additive development and climate-induced vegetation changes reduced abundance by up to half of the original size.” “Our findings contribute to the growing number of studies suggesting oil and gas development has negative impacts on sage-grouse populations and suggest that current regulations may only be sufficient for limiting population declines but not for reversing these trends.”</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramey et al.</td>
<td>2018</td>
<td>Local and population-level responses of greater sage-grouse to oil and gas development and climatic variation in Wyoming: PSEER, v. 2018, 6, p. x5147, <a href="https://doi.org/10.7737/pwem.5147">https://doi.org/10.7737/pwem.5147</a>.</td>
<td>The authors proposed 2.3 km buffer zones around active leks as a best management practice for new transmission lines. Maintenance management for distribution lines, and colocation with other GRSG infrastructure resulted in substantive changes in GRSG habitat and demographics and that transmission lines likely highly influential paper used to predict oil and gas effects on GRSG.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Heinrichs et al.</td>
<td>2019</td>
<td>Influences of potential oil and gas development and future climate on sage-grouse declines and redistribution: Ecological Applications, v. 9, no. 2, 10.1002/eca.21912, 16 p, <a href="https://doi.org/10.1002/eca.21912">https://doi.org/10.1002/eca.21912</a>.</td>
<td>The authors conclude that surface coal mining and habitat conservation, in association with the mine: Human-Wildlife Interactions, v. 10, no. 2, p. 205–216. The authors conclude that surface coal mining and associated mitigation did not cause a decline in the existing GRSG population at the Altin/Sitek Valley area of southwestern Utah. Habitat fidelity and acclimation to a long history of anthropogenic activities may have affected GRSG behavior in this region. GRSG at this location did not avoid mining activities as other GRSG populations have been observed to do elsewhere in the range.</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lefebvre et al.</td>
<td>2017</td>
<td>Greater sage-grouse habitat selection, survival, and wind energy infrastructure: Journal of Wildlife Management, v. 81, no. 3, p. 680-711.</td>
<td>GRSG appeared to select nest sites without regard to wind energy infrastructure but avoided such infrastructure during brood rearing and summer. Stronger effects of disturbance associated with wind energy on brood-rearing habitat selection in the later time period suggested a lagged population-level response. GRSG survival did not appear to be negatively affected by the facility.</td>
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<td></td>
<td>Wind energy; GRSG habitat use and survivorship</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kohl et al.</td>
<td>2019</td>
<td>The effects of power lines on the breeding ecology of greater sage-grouse: PLoS ONE, v. 14, no. 3, e2009988, <a href="https://doi.org/10.1371/journal.pone.2009988">https://doi.org/10.1371/journal.pone.2009988</a>.</td>
<td>The authors proposed 2.3 km buffer zones around active leks as a best management practice for new transmission line construction. They also proposed site-specific management for distribution lines, and colocation with existing disturbances for all new power lines. Maintenance of sagebrush cover around power lines may improve GRSG habitat suitability, despite the presence of human disturbance.</td>
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<td>Wind energy; GRSG habitat use and survivorship</td>
<td>Mitigation Transmission lines</td>
<td>Mitigation Transmission lines</td>
</tr>
<tr>
<td>Lefebvre et al.</td>
<td>2019</td>
<td>Greater Sage-grouse habitat function relative to 230-kV transmission lines: The Journal of Wildlife Management, p. 1-14.</td>
<td>The authors suggest that future transmission line placement decisions should consider potential negative effects on GRSG habitat and demographics and that transmission lines should be located in areas of lower GRSG habitat suitability and greater than 3.5 km from occupied leks if possible.</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Peterson et al.</td>
<td>2016</td>
<td>Response of greater sage-grouse to surface coal mining and habitat conservation in association with the mine: Human-Wildlife Interactions, v. 10, no. 2, p. 205–216.</td>
<td>The authors conclude that surface coal mining and associated mitigation did not cause a decline in the existing GRSG population at the Altin/Sitek Valley area of southwestern Utah. Habitat fidelity and acclimation to a long history of anthropogenic activities may have affected GRSG behavior in this region. GRSG at this location did not avoid mining activities as other GRSG populations have been observed to do elsewhere in the range.</td>
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<td>Coal mining; mitigation</td>
<td>Lack of avoidance is noteworthy—what is it?</td>
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</table>
Observations of territorial breeding common ravens: The Journal of Wildlife Management, v. 84, n. 4, p. 866-879

High levels of grazing in this study represent intensities near maximum allowed levels defined by the Bureau of Land Management. Study findings did not suggest that reducing these grazing levels would benefit GRSG populations, but rather that grazing may have both positive and negative effects on GRSG, depending on timing and intensity. Study results suggest that broad-scale analyses are important to capture the range of responses that wildlife can have to land-use and livestock management. These findings could also help guide sustainable livestock management decisions, such as delaying high-level grazing until after peak vegetation productivity, in similar habitats.

Coates et al.

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Runge et al.

Restricting grazing on public lands could result in increased GRSG-habitat loss on private land over the next 10 years. It is important to consider the connections between public land policy and private land use change. Policies that balance the need to conserve habitat on public lands with economic needs of ranchers are promising.

Taylor et al.

Reducing or eliminating livestock grazing on federally protected lands recognized as GRSG habitat would create negative economic impacts on both a ranch-scale and regional scale, and may create increased economic burdens for rural communities in western states. Grazing mitigation; Recommendations to landowners about areas subject to grazing

References

Pratt and Beck

Grazing

Monroe et al.

Coating 2017

Peebles et al.

Dinkins et al.

Howe and Coates 2015

Runge et al.

Peebles et al.

Fence modifications along with prioritization of sagebrush regeneration of sagebrush cover, so intense promotion of sagebrush regeneration is important for restoring GRSG habitat. Additional fencing in these locations may lower GRSG nest survival rates. Author highlights, " Nest survival in preferred sagebrush type was one-fourth the rate in type avoided. Nest survival was four times higher when placed 128 m away from nearest fence. Timing of grazing could best achieve herbaceous requirements for successful nesting. Fence modifications along with prioritization of sagebrush type are discussed."

Cuting et al.

Ravens can significantly influence reproductive success of GRSG at local scales, but population-level effects remain unclear. Breeding ravens may control GRSG nests more than nonbreeders. Declines of GRSG may be compounded by anthropogenic activities that have improved nesting habitat for ravens in sagebrush ecosystems.

Runge et al.

Taylor et al.

Economic impact of sage grouse management on livestock grazing in the Western United States: Western Economics Applications, v. 27, no. 4, p. 622-630

Effects of livestock grazing on nesting sage-grouse in central Montana: Journal of Wildlife Management, v. 82, n. 7, p. 1501-1515

Effects of common raven and coyote removal and temporal variation on climate on greater sage-grouse nesting success: Biological Conservation, v. 202, p. 50-58

The authors asked whether (1) changes in raven density and coyote abundance following removal efforts affected GRSG nest success and (2) weather conditions influenced these effects for coyotes. Management of breeding and transient ravens may be a viable mitigation action in areas with high raven densities because it can reduce raven abundance and may increase GRSG nest success. However, large-scale solutions, such as reducing supplemental food sources and perch structures, are necessary. Coyote removal likely results in lowered GRSG nest success because of the potential expansion of mesopredators (for example, badgers, skunks, and raccoons), which do better at smelling prey but may be less evident, especially in an actively grazed setting.

Howe and Coates 2015

Grazing

Dinkeys et al.

Pratt and Beck

In general, the adverse effects of bentonite mining on GRSG appear to be consistent with those of energy development. A greater proportion of the Bighorn Basin GRSG population is affected by mining during the winter season than at other times of the year. Therefore, prioritization of winter habitat may be a key management strategy there. Further, reclaimed mines remain unsuitable for GRSG due to slow regeneration of sagebrush cover, so intense propagation of sagebrush regeneration is important for restoring GRSG habitat.

Dinkeys et al.

High levels of grazing in this study represent intensities near maximum allowed levels defined by the Bureau of Land Management. Study findings did not suggest that reducing these grazing levels would benefit GRSG populations, but rather that grazing may have both positive and negative effects on GRSG, depending on timing and intensity. Study results suggest that broad-scale analyses are important to capture the range of responses that wildlife can have to land-use and livestock management. These findings could also help guide sustainable livestock management decisions, such as delaying high-level grazing until after peak vegetation productivity, in similar habitats.

Dinkeys et al.

The authors suggest that reducing anthropogenic subsidies may be a viable mitigation action in areas with high raven densities because it can reduce raven abundance and may increase GRSG nest success. However, large-scale solutions, such as reducing supplemental food sources and perch structures, are necessary. Coyote removal likely results in lowered GRSG nest success because of the potential expansion of mesopredators (for example, badgers, skunks, and raccoons), which do better at smelling prey but may be less evident, especially in an actively grazed setting.

Dinkeys et al.

Grazing

Grazing; mitigation; Predator management and mitigation

Pratt and Beck

Ravens can significantly influence reproductive success of GRSG at local scales, but population-level effects remain unclear. Breeding ravens may control GRSG nests more than nonbreeders. Declines of GRSG may be compounded by anthropogenic activities that have improved nesting habitat for ravens in sagebrush ecosystems.

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The authors suggest that reducing anthropogenic subsidies may be a viable mitigation action in areas with high raven densities because it can reduce raven abundance and may increase GRSG nest success. However, large-scale solutions, such as reducing supplemental food sources and perch structures, are necessary. Coyote removal likely results in lowered GRSG nest success because of the potential expansion of mesopredators (for example, badgers, skunks, and raccoons), which do better at smelling prey but may be less evident, especially in an actively grazed setting.
| Walker et al. (2018) | Mapping and prioritizing seasonal habitats for greater sage-grouse in Northwestern Colorado: Journal of Wildlife Management, v. 81, no. 1, p. 63–77. | Study in Northwestern Colorado: GRSG generally selected for vegetation characteristics at small spatial scales (100–400 m); terrain roughness was also a strong negative predictor at 500 m in all seasons. A mosaic of habitats with sagebrush are important in multiple seasons, and actions that increase sagebrush within 400 m and reduce forest within 100–400 m may be most beneficial. Topics: broad-scale habitat characteristics, new geospatial data, effect distances or spatial scale, behavior or demographics, habitat selection, site-scale habitat characteristics. | X | X | Technique refinement; habitat mapping | Improved habitat mapping for enhancement (i.e., junior upland removal) and mitigation. |
| Conover and Roberts (2017) | Predators, predator removal, and sage-grouse—A review: Journal of Wildlife Management, v. 81, no. 7, p. 21–35. | This was a literature review of past studies of varying quality, methods, and conclusions. The authors concluded that predation is not a likely factor in rangewide GRSG trends, with the exception of ravens in recent years. | Predation | Literature review | Caveat: literature review of papers looking at different predator species and using different methods. |
| Pessl et al. (2017) | Adult sage-grouse numbers re occurrence following removal and an increase in precipitation: Wildlife Society Bulletin, v. 45, no. 3, p. 473–478. | Actual removal of ravens was effective at reducing raven densities at a landscape scale over a multiyear period. Removal of ravens was associated with larger numbers of GRSG the following year, as was cool, wet weather. The increase in GRSG abundance may have been due to decreased nest predation, increased habitat availability, or increased forbs and visit abundance. The authors suggest that raven removal may be most beneficial where subsampled raven densities are high and GRSG populations are small. | X | X | Predation; mitigation (technique refinement) | Prioritization of management; Predator control | Makes a connection between weather conditions and predator control, suggesting that raven removal can increase GRSG survival. |
| Gibson et al. (2018) | Effects of power lines on habitat use and demography of greater sage-grouse (Centrocercus urophasianus): Wildlife Monographs, v. 200, no. 1, p. 1–41. | There was support for GRSG avoidance of power lines to 30 km, for decreased demographic rates to 12.5 km, and for decreased population growth to 5 km. Multiple effects of transmission lines varied with raven abundance, which increased near the transmission lines in this study. Some effects were small, highlighting the importance of long-term (10-20 year) studies of impact assessment. Transmission line effects on GRSG may be mitigated by decreasing raven numbers near the line, but the effectiveness of previous predator control and perch deterrent efforts have been inconclusive. Co-locating, burying, or routing lines outside of GRSG habitat may be options. | X | X | Transmission lines; associated predation; mitigation | Potential mitigation of raven predation near transmission lines. | Negative effects can be potentially mitigated. |
| Haras et al. (2018) | Common raven movement and space use: Influence of anthropogenic subsidies within greater sage-grouse nesting habitat: Ecosphere, v. 9, no. 7, article e02548, 16 p, https://doi.org/10.1002/ecs2.2548. | Lethal control of ravens at primary subsidies likely does not impact breeding ravens, who tend to utilize these resources and pose a greater threat to GRSG through nest predation. Reducing nest failure may cause ravens to change their space and movement patterns to a wider-ranging nonbreeding pattern, which would likely, and leave them more vulnerable to lethal control at primary subsidies. | X | X | Predation; mitigation (technique refinement) | Ravens | Potential method to disrupt raven behavior making them more susceptible to lethal control. |
| Kind et al. (2018) | Using DNA from horns left at depredated greater sage-grouse nests to detect mammal nest predators: Wildlife Society Bulletin, v. 42, no. 1, p. 160–165. | This study presents a novel, noninvasive, and cost-effective survey method that minimizes collection bias and can be used at larger spatial scales to gain insight on mammalian predations that influence GRSG nest productivity. It can also help to identify exotic predators that benefit from human subsidies and habitat modification. These methods could be expanded to include other forms of DNA (e.g., feathers or saliva) for greater inference. | X | X | Predation; mitigation (technique refinement) | Identifying mammalian predators of GRSG nests. | Comment: Trail cameras at nests would provide data with shorter turn-around time. |
| O’Neil et al. (2018) | Broad-scale occurrence of a subsidized avian predator—reducing impacts of ravens on sage-grouse and other sensitive prey: Journal of Applied Ecology, v. 55, no. 6, p. 2641–2652., https://doi.org/10.1111/1365-2664.13249. | The authors proposed that their anthropogenic influence index can be used to identify priority areas where ravens are more likely to affect GRSG. It can also be used to target where management of anthropogenic features can help reduce raven expansion. Finally, they argued that their methods can be applied to the management of other generalist predators. | X | X | Predation (technique refinement) | Potential method for identifying mammalian predators of GRSG nests. | Potential method for effective predator management. |
| Smith et al. (2018) | Phenology largely explains taller grass at successful nests in greater sage-grouse: Ecology and Evolution, v. 8, p. 356–364 | The available evidence for a causal relation between grass height and nest success was weak, although grass height remained positively correlated with nest survival in the Powder River Basin of Wyoming after correction. Variations in results suggested that taller grass may be beneficial to nest survival in some circumstances (such as where shrub cover is low), but this explanation was not supported by the data analyzed here. Nest site selection or other life stages (for example, brood survival) may be affected by the structure of grasses. The authors suggested that findings from previous studies may have led to an overemphasis of the role of grass height in GRSG nesting habitat quality. | X | X | Technique refinement; habitat quality mapping | Grass height is overemphasized; evaluating habitat quality. |
| Dubbs et al. (2019) | Movements of female sage grouse during pre-nest time: Diffusion versus random walk with limited resources: IBIS, v. 161, no. 1, p. 122–229. | Data suggest that a larger area around nests than previously thought may be important for nesting success, which is an important consideration in determining minimum patch sizes needed for nesting and appropriate spatial scales for evaluating nesting habitat. The flights associated with nestless may expose GRSG to predators by ravens. Striking vertical structures during these flights, which typically occur during low light conditions, may be a mortality risk. Well-designed predator control programs are likely to cause short-term benefits to various grouse species. However, more research is needed, particularly on how the competitive interactions of predator species influence ground predator risk and whether removing certain predator species may have unintended cascading effects. | Predation risk; Potential mitigation | Ravens | Provides a behavioral mechanism for susceptibility to raven predation, and therefore informs better predator control methods. |
| Kammermeier and Stinch (2019) | Predator, predation and grouse populations: a review: Wildlife Biology, article wbi.00464, 12 p., https://doi.org/10.2981/wbi.00464. | Well-designed predator control programs are likely to cause short-term benefits to various grouse species. However, more research is needed, particularly on how the competitive interactions of predator species influence ground predator risk and whether removing certain predator species may have unintended cascading effects. | X | X | Predation; mitigation (technique refinement) | Predator management | Looked at cause and effect mechanisms behind unintended consequences. |
| Smith et al. (2019) | Approaches to delineate Greater Sage-Grouse winter concentration areas: The Journal of Wildlife Management, v. 83, no. 7, p. 1409-1507. | The authors suggest that individual-based resource selection function models (RSSF) can be useful when data on flock sizes are not available in winter concentration areas. They also suggest that their survey and modeling approach was constructive for identifying habitat selection and determining whether currently protected areas are adequate for all seasons of use by GRSG. They conclude that an important amount of GRSG winter habitat might not be adequately protected by Core Areas in Wyoming (although this conclusion is not well justified). | Potential technique refinement | This is a duplicative of GRSG's needs to delineate winter habitat. | Climate long range predictions.

Homer et al. 2016
Forecasting sagebrush-ecosystem components and greater sage-grouse habitat for 2050—Learning from past climate patterns and LandSat imagery to predict the future. Ecological Indicators, v. 50, p. 112–145.

Balatti et al. 2016

Boyle et al. 2016

Patnaik et al. 2016
Mid-latitude shrub-steppe plant communities—Climate change consequences for soil water resources: Ecology, v. 97, no. 5, p. 2342–2354.

Caudill et al. 2016

Gibson et al. 2017

Cayleff et al. 2016

Cates et al. 2018

Mathews et al. 2018

Rumney et al. 2018

Critt et al. 2015

Davis et al. 2015
The study assessed genetic diversity within and between leks sites, spacial genetic structure, within-lek relatedness, and dispersal patterns. The GRSG surveyed had genetic diversity similar to less isolated populations in the center of the range. GRSG in northeastern California is a single genetic population with evidence of gene flow between the leks, despite the fact that all leks were far apart. Other than all other regions across the GRSG range. Individuals at leks were largely unrelated to each other, and females had higher gene flow and greater dispersal distance than males.

Increased GRSG use after tree removal, drought causes population decline. Mixed results for translocated broods.

Results suggested that precipitation, rather than snow accumulation or depth, was the primary driver of juvenile migration. Movement from late fall habitats to winter habitats was variable, indicating that the effects of harvest may vary with harvest timing and in relation to seasonal movements. Changes in climate may negatively affect GRSG if the onset of winter conditions is delayed, affecting the movement of juveniles to winter habitat. The model application presented here may be used to develop a better understanding of relations between environmental factors and GRSG behavior.

The authors evaluated relations between (1) weather and brood survival, (2) drought and brood size selection, and (3) shifts in breeding site selection and brood survival of GRSG. Chick survival was negatively related to drought severity. Nest sites at low elevations may contribute little to reproduction in drought years and extended droughts may be detrimental to GRSG populations that cannot access high elevation sites.

Results suggested that GRSG experience following crop-year Juniper conferion removal treatments. Modeling showed varied survival variations in subpopulations, with an overall 2 percent decline in the Bi-State population from 2005 to 2017. The overall decline in the Bi-State population was likely a result of drought events, subpopulations that are stable or increasing are insulated from drought due to water availability.

PDP was the major driver of population trends rather than oil and gas development and climate change. Caveats: Predictions based on Bi-State population modeling and subpopulations of multiple linked models.

Modeling showed presence of significant habitat within the area despite declining population trends.

Population Connectivity

Critt et al. 2015

The study assessed genetic diversity within and between leks sites, spacial genetic structure, within-lek relatedness, and dispersal patterns. The GRSG surveyed had genetic diversity similar to less isolated populations in the center of the range. GRSG in northeastern California is a single genetic population with evidence of gene flow between the leks, despite the fact that all leks were far apart. Other than all other regions across the GRSG range. Individuals at leks were largely unrelated to each other, and females had higher gene flow and greater dispersal distance than males.

Wildlife agencies need to account for the effects of regional climate variation when managing sage-grouse populations.

Caveats: Climate projections based on scenarios derived from IPCC general circulation models.
This study sought to quantify dispersal of males and females among sites, some over long distances using genetic data from 3,244 genetic samples from 763 leks. There were 80 recaptures. "Of the recaptures, half were at the same lek in a different year, and half were at a different lek in the same year or a different year. " And, "Two recaptured males were detected at three different leks, visiting leks 14 to 90 kilometers apart in the same year. " Such long-distance dispersal, even by a few males can provide gene linkages among distant populations formerly thought to be isolated.

By combining genetic and demographic information, authors identified four genetic clusters in different regions of Wyoming with different population trends and lek activity. Management plans can be tailored to the needs of distinct clusters that have different population trajectories, particularly as threats and effects vary regionally. Wyoming clusters could be managed as three units (two northern, one southern). Future studies should address the cyclic nature of GRSG populations in need estimation.

Egg collection and hatching, rearing, and adoption of captive-rased chicks into wild broods is feasible.

Retention of translocated GRSG within the targeted release site was 82 percent. There was no statistical support for a difference between resident and translocated birds for female, nest, and chick survival. Nest initiation rates and clutch sizes were generally higher for residents compared to translocated GRSG. Nest success was positively related to grass height. Successful translocations will depend on finding sites that have met the resident population

Egg collection and hatching, rearing, and adoption of captive-rased chicks into wild broods is feasible.

Experimental translocations of 100 female birds were conducted across the state with some success. However, long-term survival and reproduction of these birds remain to be determined.

Data-driven estimates of dispersal and lek-switching

Published version of Crist et al. 2015, used circuit theory and network analysis to analyze connectivity between identified priority areas and potential isolation of some areas or populations. Based on priority areas from each state. Did not use actual genetic data or lek data for analysis.

Clearly an alternative to the one-size-fits-all approach of NIT.

Data-driven estimates of population connectivity

Mitigation (Technique refinement)

Connectivity; Long distance movements & Population connectivity

Published version of Crist et al. 2015, used circuit theory and network analysis to analyze connectivity between identified priority areas and potential isolation of some areas or populations. Based on priority areas from each state. Did not use actual genetic data or lek data for analysis.

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Mitigation (Technique refinement)

Connectivity; Long distance movements & Population connectivity
| 2019 | Heinrichs et al. | Optimizing the use of endangered species in multi-population collections, captive breeding and release programs: Global Ecology and Conservation, v. 17, article e00558, 12 p., https://doi.org/10.1016/j.gecco.2019.e00558. | Modeled tradeoffs of releasing captive bred birds to augment populations. Reported, "Releases into small and rapidly declining populations provided the greatest near-term reductions in extinction risk, but improvements were short-term. Yet releases into larger and more stable populations resulted in longer lasting conservation benefits than in more vulnerable populations but required greater initial release effort. Systematic modeling approaches that evaluate a spectrum of trade-offs and quantify conservation risks and benefits can help direct the expectations and effort invested in captive breeding and release programs." | X | X | Technique refinement; captive breeding and release | Captive breeding and release is a potentially effective tool to bolster wild populations. |

### Improved Habitat Mapping and Assessment

| 2016 | Coates et al. | Integrating spatially explicit indices of abundance and habitat quality—An applied example for greater sage-grouse management: Journal of Applied Ecology, v. 53, no. 1, p. 83-95. | This paper appears remarkable similar but condensed version of the previous report: "Spatially explicit modeling of annual and seasonal habitat for greater sage-grouse (Centrocercus urophasianus) in Nevada and northeastern California—An updated decision-support tool for management." | X | X | Technique refinement; habitat suitability mapping | Improved methodology |
| 2016 | Coates et al. | Spatially explicit modeling of annual and seasonal habitat for greater sage-grouse (Centrocercus urophasianus) in Nevada and northeastern California—An updated decision-support tool for management: U.S. Geological Survey Open-File Report 2016-1061, 14 p., https://doi.org/10.3133/ofr20161061. | The authors investigated whether Utah’s priority areas include breeding, wintering, and winter habitats. They collected telemetry data on adult GRSG nesting, breeding, and nonbreeding locations throughout the state. They recorded nest success and breeding, low chick, and nonbreeding adult locations for resident and translocated GRSG. They used satellite data to evaluate sagebrush habitat extent and vegetation cover type. Seasonal movements of Utah GRSG were generally greater than reported rangewide. Priority Areas for Conservation captured 85 percent of seasonal locations from radio-marked birds. | X | X | Technique refinement; habitat suitability mapping | Long distance movements, movement between leks, seasonal movements |
| 2016 | Dahlgren et al. | Seasonal movements of greater sage-grouse populations in Utah—Implications for species conservation: Wildlife Society Bulletin, v. 40, no. 2, p. 288-299. | The authors investigated whether Utah’s priority areas include breeding, wintering, and winter habitats. They collected telemetry data on adult GRSG nesting, breeding, and nonbreeding locations throughout the state. They recorded nest success and breeding, low chick, and nonbreeding adult locations for resident and translocated GRSG. | X | X | Technique refinement; habitat suitability mapping | Long distance movements, movement between leks, seasonal movements |
| 2016 | Mestas et al. | Mapping soil survey information for rapid assessment of sagebrush ecosystem resilience and resistance: Rangelands, v. 38, no. 3, p. 120-128. | Soil survey information is valuable for putting resistance and resilience concepts into practice in sagebrush ecosystems. Regional datasets have been provided for large-scale applications, and a soils report tool is now available to support site-scale planning. Combining soils data with information on biotic factors, such as vegetation, provides a powerful framework for managing fire and invasive species risks. | X | X | Technique refinement; prioritization of management actions | Tool that we not available previously |
| 2016 | Perrington et al. | Sagebrush, greater sage-grouse, and the occurrence and importance of forbs: Western North American Naturalist, v. 76, no. 3, p. 298-312. | The authors concluded that wide agreement exists among ecologists regarding the importance of forbs for GRSG, but information on forb distribution and relations to climate is limited. Habitat descriptions that lump all herbaceous species (grasses and forbs), or simply recognize that GRSG forbs do not provide sufficient information for management of GRSG-preferred forbs. Different forb species respond differently to grazing, invaders, chemical treatments, and climate, but data for most species were lacking. Filling this knowledge gap could facilitate forecasting climate change effects on forbs in sagebrush ecosystems. | X | X | Technique refinement; diet | Literature review of diet use by GRSG |
| 2017 | Orńskis et al. | Quantifying overlap and fitness consequences of migration strategy with seasonal habitat use and a conservation policy: Ecospheres, v. 8, no. 11, article 01391, 14 p., https://doi.org/10.1002/ecs2.1991. | Habitats protected by Wyoming’s Core Areas overlapped GRSG winter habitats less than other seasonal habitats. Western habitats were used by migratory and nommigratory females, and migratory and nommigratory birds had similar nest and brood success on average. Winter survival rates were higher than those in other seasons. Nest success and brood survival did not differ between areas inside compared to outside Core Areas. Temperature negatively and snow depth positively influenced adult female survival during the breeding season, but winter weather did not affect survival. | X | X | Technique refinement; habitat assessment, Core Area use | Suggest that additional protections needed for some winter GRSG habitat |
| 2018 | Burkhardt et al. | Landscape-scale habitat assessment for an imported alien species: Animal Conservation, v. 21, no. 3, p. 241-251. | By assessing relative changes in abundance over time, our models indicated that most of the habitat within core areas (88%) exhibited landscape conditions conducive to supporting medium or larger greater sage-grouse populations that were stable or increasing through time. Larger populations were associated with larger, more centrally located core areas. Conversely, core areas supporting relatively small or declining populations were located along range margins in the western portion of the state. The landscape-scale habitat relationships we developed can be used in combination with local-scale assessments to generate a more complete picture of greater sage-grouse habitat suitability."..."Our predictions of landscape-level habitat suitability align with management approaches being implemented through the greater sage-grouse Core Area Protection policy that focus on conserving landscapes, establishing direct conservation relevance to assessments at this scale." | X | X | Technique refinement; habitat assessment, Core Area use | Improved habitat suitability mapping; supports Core Area concept. |

### References

- Heinrichs et al. 2018
- Cade et al. 2015
- Coates et al. 2016
- Dahlgren et al. 2016
- Mestas et al. 2016
- Perrington et al. 2016
- Orńskis et al. 2017
- Burkhardt et al. 2018
<table>
<thead>
<tr>
<th>Author et al.</th>
<th>Year</th>
<th>Title</th>
<th>Abstract</th>
<th>Technique</th>
<th>Population size estimation</th>
<th>Habitat &amp; vegetation mapping</th>
<th>Tool that was not available previously.</th>
<th>Useful at local scales.</th>
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</thead>
<tbody>
<tr>
<td>Luna et al.</td>
<td>2018</td>
<td>Common native forbs of the northern great basin are important for greater sage-grouse</td>
<td>The top three most important plant species for GRSG are sage shrubs, other desert shrubs, and dandelion-like flowers with milky sap. Sagebrush, rabbitbrush, and horehound are the most important plants for both food and cover.</td>
<td>Technique refinement</td>
<td>Improved habitat &amp; vegetation mapping</td>
<td>Tool that was not available previously.</td>
<td>Useful at local scales.</td>
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<tr>
<td>Costas et al.</td>
<td>2019</td>
<td>Spatiotemporal models of seasonal habitat for greater sage-grouse at broad spatial scales: informing areas for management in Nevada and northeastern California</td>
<td>An updated version of 2016 report: Spatiotemporal modeling of annual and seasonal habitat for greater sage-grouse (Centrocercus urophasianus) in Nevada and northeastern California</td>
<td>Technique refinement</td>
<td>Significant improvement in habitat and vegetation mapping</td>
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<tr>
<td>Bures and Davies</td>
<td>2016</td>
<td>Characteristics of intact Wyoming big sagebrush associations in southeastern Oregon: Rangeland Ecology &amp; Management, v. 72, no. 1, p. 36-46.</td>
<td>These findings could be used to help develop and implement management guidelines and actions aimed at preserving or restoring intact Wyoming big sagebrush communities.</td>
<td>Technique refinement</td>
<td>Habitat &amp; vegetation mapping</td>
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<tr>
<td>Henderson et al.</td>
<td>2016</td>
<td>Vegetation mapping to support greater sage-grouse habitat monitoring and management—Multivariate or univariate approach?</td>
<td>The multivariate modeling approach was better for describing the multiple dimensions of vegetation that describe GRSG habitat than the univariate approach. Therefore, the authors argued that the multivariate approach can better inform GRSG habitat management decisions at mid and broad scales.</td>
<td>Technique refinement</td>
<td>Habitat &amp; vegetation mapping</td>
<td>Minor improvement paper. Important for local conservation efforts.</td>
<td></td>
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<tr>
<td>Pratt et al.</td>
<td>2019</td>
<td>Prioritizing seasonal habitats for comprehensive conservation of a partially migratory species: Global Ecology and Conservation, v. 17, e00956, p. 1-11.</td>
<td>Global map analysis of the Wyoming Core Areas Strategy that prioritizes breeding habitat appears to be effective as a first step. However, various GRSG populations may partially require additional conservation of different seasonal habitats. Local information on behavior and habitat should be used to determine these specific habitat requirements and how to manage them.</td>
<td>Technique refinement; habitat mapping</td>
<td>Method for refining at a local scale</td>
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<td>Gibson et al.</td>
<td>2015</td>
<td>Improved estimation of population abundance and trends: N-mixture models for data collection and use</td>
<td>Observers noted that abandonment can decrease estimates of daily nest survival. The authors recommended assessing the potential costs and benefits of nest surveys on sensitive populations and incorporating bias corrections into estimates of nest survival.</td>
<td>Technique refinement; nest survival studies</td>
<td>Researchers can have deleterious effect on parameter they are estimating.</td>
<td>Relates concern that some previous studies may have biased results.</td>
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<tr>
<td>Dahlgren et al.</td>
<td>2018</td>
<td>Evaluating vital rate contributions to greater sage-grouse population dynamics to inform conservation</td>
<td>Life table analysis revealed estimate changes in GRSG populations, and telemetry studies are useful for demographic monitoring. In combination, these two methods can be used to measure life-cycle dynamics. Results suggest that GRSG females can exploit varying environmental conditions and may respond to management actions, whereas survival is highly variable and more affected by natural environmental variation.</td>
<td>Technique refinement; life table and telemetry studies</td>
<td>Improved methodology for population management</td>
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<td>Fregman et al.</td>
<td>2018</td>
<td>Mark greater sage-grouse detectability on basis: Journal of Wildlife Management, v. 82, no. 3, p. 266-274.</td>
<td>Conducting sightability surveys to establish correction factors is recommended to avoid underestimation of regional GRSG abundance, particularly if vegetation and snow cover vary among leks.</td>
<td>Technique refinement: lek counts</td>
<td>Sighting estimates are key to estimating population density or abundance based on lek count data</td>
<td>Improves lek counting, facilitates previous methods and anything that relied on previous standards.</td>
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<tr>
<td>Gibson et al.</td>
<td>2018</td>
<td>Evaluating vegetation effects on animal demographies—The role of plant phenology and sampling bias: Ecology and Evolution, v. 8, no. 11, p. 3621-3633.</td>
<td>Statistical artifacts can confound interpretations of the importance of vegetation to GRSG nest survival. Researchers should consider the confounding effects of plant phenology when planning animal demography studies. The authors provide techniques for data corrections between hatching and nest failure dates.</td>
<td>Technique refinement; nesting studies</td>
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<td>McCaffrey et al.</td>
<td>2018</td>
<td>Improved analysis of lek count data using N-mixture models: Journal of Wildlife Management, v. 82, no. 6, p. 2011-2021</td>
<td>The authors found that N-mixture models produced more robust population trend estimates than naive lek count data, largely because they corrected for substantial year-to-year variability in detection probability. Using naive lek count data may result in inaccurate and misleading estimates of GRSG population size and trend when compared to results obtained by using an N-mixture modeling approach that can better account for variable detection probability and missing data. The authors provide suggestions for lek monitoring designs that can be analyzed using N-mixture models.</td>
<td>Technique refinement; population trend estimates</td>
<td>Highly significant paper on estimating population trend estimates than traditional methods from lek count data.</td>
<td>Additional review suggested.</td>
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<td>McCaffrey and Lukacs</td>
<td>2018</td>
<td>A generalized integrated population model to estimate greater sage-grouse population dynamics: Ecology, v. 7, no. 11, article e01985, p. 14</td>
<td>Integrated population models: improved estimates of annual GRSG population dynamics by smoothing variability attributable to sampling noise. The authors conclude that their integrated population model framework could provide robust assessments of population size and trend. Information on mechanisms underlying observed trends, and a unified tool for use by GRSG biologists studying various populations throughout the range of the species. The authors suggest that future field sampling efforts should seek improved information on sex and age ratios, female population size, sex-specific survival rates by file stage, and the proportion of leks surveyed annually in a given area.</td>
<td>Technique refinement; improved analysis of lek count data using N-mixture models</td>
<td>Highly significant paper on estimating population trends and abundance</td>
<td>Additional review suggested.</td>
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<td>Caudill et al.</td>
<td>2017</td>
<td>Individual heterogeneity and effects of harvest on greater sage-grouse populations: Journal of Wildlife Management, v. 81, no. 4, p. 754-765.</td>
<td>Using the revised formulas, the authors demonstrated that effects of selective harvest on grise be depensatory (adult mortality contributes to reduced productivity and/or survivorship in the population) when robust individuals are more susceptible to harvest, and some level of compensation is likely when frail individuals are more susceptible to harvest.</td>
<td>Technique refinement; Hunting</td>
<td>Mitigating potential population-level effect of hunting</td>
<td>Example of effective application of determining cause and effect mechanism for effective mitigation.</td>
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<td>Clawson et al.</td>
<td>2017</td>
<td>Performing statistical population reconstruction using program PopRecon 2.0: Wildlife Society Bulletin, v. 43, no. 3, p. 381-389.</td>
<td>Introduced a population estimation program PopRecon 2.0 that used GRSG hunt harvest data from Oregon to reconstruct population dynamics. Most significantly, the study found that, &quot;Population estimates for the eastern Oregon populations were variable, demonstrating cyclical population dynamics and high variability in recruitment and comparable to estimates from other research.&quot;</td>
<td>Technique refinement; population trend reconstruction</td>
<td>Found population trends to be cyclical (similar to papers on influence of regional climate/weather patterns).</td>
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<td>Forby et al.</td>
<td>2017</td>
<td>Emerging technology to measure habitat quality and behavior of grouse—Examples from studies of greater sage-grouse: Wildlife Biology, article 00238, 10 p., <a href="https://doi.org/10.2981/awb.00238">https://doi.org/10.2981/awb.00238</a></td>
<td>Significant changes in our understanding of GRSG ecology may arise from new technologies, but they will require scientific testing, calibration, and communication between managers and scientists to overcome challenges and large data collection and use</td>
<td>Potential techniques</td>
<td>Showcasing of various potential improvements in methodology via UAV’s, spectral imaging, robots, animals and biotelemetry systems.</td>
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Necklace-style radio-transmitters are associated with changes in display vocalizations of male greater sage-grouse: Fregman et al. 2017

Vocalizations made by males with necklace-style radio transmitters fall outside the normal range of vocalizations produced by males throughout the range of GSGS, suggesting that radio collars may impair their ability to produce normal vocalizations. The use of necklace-style collars that sit on the necks of GSGS are not recommended for use in behavioral studies of GSGS. Alternative attachment methods should be developed and tested.

The authors suggest that demographics of harvested populations can be modeled for GSGS or other game birds using a mark-recapture approach of harvested individuals. https://doi.org/10.1002/1438-390X.1019.

The authors suggest that ground-based lek surveys are likely to result in population estimates about 14% lower than true values, especially in areas with high sagebrush cover. Using aerial infrared imaging system surveys resulted in greater sighting rates, however using repeated morning ground-based surveys or generalized correction values provided by the authors could improve GSGS population estimates derived from ground-based lek counts.

The authors reported, “We found lower survival for GPS-marked birds with considerable variation among sex and age classes. Differences in survival could be attributed to features associated with GPS devices, including greater weight, position of attachment (e.g., rump-mounted harness), and a semi-reflective solar panel.”

The reported frequency of crossing between leks is higher than in previous estimates. As such, movements between leks may explain a substantial amount of variability in annual kill counts, reducing the ability of kill count data to accurately depict GSGS population abundance or trends. Leks counts done earlier in the spring are less likely than those done later (at peak attendance) to reflect population abundance, particularly in areas where male GSGS move to higher elevations as snow packs melt. Conducting kill counts during peak attendance and avoiding counts during days with precipitation, particularly at higher elevations, is recommended.

The importance of simulation assumptions when evaluating detectability in population models: Monroe et al. 2019

The authors reported, “We found lower survival for GPS-marked sage-grouse across most sex, age, and seasonal comparisons. Estimates of annual survival for GPS-marked sage-grouse were 0.55–0.86 times that of VHF-marked birds with considerable variation among sex and age classes.”

Weather conditions and data influence male sage-grouse attendance rates at leks (BJS, v. 161, no. 1, p. 35-49. X X

Considering potential issues of attendance, detection can improve the performance of kill counts as indices of population abundance. Attendance here was strongly influenced by precipitation, consistent with other studies and supporting kill-count protocols that discourage counts during rain. Slight negative effects of sand observed here also support avoiding counts during winds.

At higher elevations as snowpack melts. Conducting lek counts during peak attendance and avoiding counts during days with precipitation, particularly at higher elevations, is recommended.

The authors report that annual lek surveys captured an average of 45–74% of active leks and 43–78% of lekking males each year. Our results suggest that many active leks remain unknown and annual counts fail to account for a substantial, but variable, proportion of the number of active leks and lekking males in the population in any given year. Managers need to recognize this potential source of bias in lek-count data and, if possible, account for it in trend analysis and management efforts.

Using simulation scenarios with systematic trends in detectability may be more informative for evaluating population models than scenarios that assume detectability is constant or random. With finite monitoring resources available, using auxiliary data on lek attendance to model GSGS populations with lek-based models may allow more leks to be studied less intensively. However, additional investigation is needed to evaluate the extent to which auxiliary data are appropriate for different GSGS populations across their range.

The ability to cluster GSGS leks into nested, biologically meaningful lek clusters may aid researchers and managers in producing population trend estimates of different spatial scales and help them determine drives of trends across scales. This information will be important for developing effective management actions.

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<th>Notes</th>
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<tr>
<td>Chambers et al.</td>
<td>2018</td>
<td>Using resilience and resistance concepts to manage threats to sagebrush ecosystems, Gunnison sage-grouse, and greater sage-grouse in their eastern range—A strategic multi-scale approach</td>
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### Habitat Improvement

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<tr>
<th>Technique refinement; Conservation management</th>
<th>Prioritization of management actions; unintended consequences</th>
<th>New method for population and subpopulation management.</th>
<th>Likely highly influential document.</th>
<th>Utilize an operational definition of resistance and resilience.</th>
<th>Significant improvement over LUP “triggers”</th>
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**Notes:**
- The [USDA] report provides a strategic approach developed by a Western Association of Fish and Wildlife Agencies interagency working group for conservation of sagebrush ecosystems. Greater sage-grouse, and Gunnison sage-grouse. It uses information on (1) factors that influence sagebrush ecosystem resilience to disturbance and resistance to normative invasive annual grasses and (2) distribution and relative abundance of sage-grouse populations to address persistent ecosystem threats, such as invasive annual grasses and wildfire. It uses a hierarchical and spatially nested structure. This Science Framework is intended to help prioritize areas for management and determine the most appropriate management strategies. The Science Framework is based on: (1) the likely response of an area to disturbance or stress due to threats and/or management actions (i.e., resilience to disturbance and resistance to invasion by native plants); (2) the capacity of an area to support target species and/or resources, and (3) the cumulative effects of threats to a species of high concern in one of the largest intact ecosystems in North America. By linking our understanding of sagebrush ecosystem resilience to disturbance and resistance to invasive annual grasses and wildfire, and habitat requirements, we provided a means for decision makers to strategically allocate resources and trage complex problems. This approach offers an innovative decision-support system to address the needs of an risk species in the context of dynamic and adaptive ecosystems. We believe this approach is applicable to target species conservation in other larger intact ecosystems with persistent, ecosystem-based threats such as invasive species and altered disturbance regimes.

**References:**
- Chambers et al. 2018
- Coates et al. 2017
- Crist et al. 2019
Habitat management for all shrub species, rather than just sagebrush, may confer the greatest benefits to GRSG. Reproductive success of GRSG may be improved by maintaining perennial grasses and >100 parent shrubs cover within 0.8 ha of nest sites. Cooperative management may also improve nest success, GRSG may benefit from postfire restoration that removes shrubs and perennial grasses.

This report will help resource managers make decisions about where and how to conduct restoration treatments in former sagebrush ecosystems for the benefit of sagebrush-obligate species like GRSG. Topics: broad-scale habitat characteristics, fire or fuel breaks, habitat restoration andenalization, noxious invasive plant species

Habitat restoration

The authors conclude that GRSG are negatively affected by pinyon-juniper. From the authors: “Collectively, these results provide clear evidence that local sagebrush distributions and demographic rates are influenced by pinyon-juniper, especially in habitats with higher primary productivity but relatively low and seemingly benign tree cover. Such areas may function as ecological traps that convey attractive resources but adversely affect population vital rates. To increase sagebrush survival, our model predictions support reducing actual pinyon-juniper cover as low as 1.5%, which is lower than the published target of 4.0%.”

Mitigation-Restoration of Habitat - Pinyon-Juniper removal

Management actions can have a dual purpose.

Technique refinement; pinyon-juniper removal

Management can be refined; new planning tool

An improved planning tool. Also undermines the argument that habitats cannot be restored by recognizing the one-size fits all, single species management approach has proven adverse effects to other species.

Technique refinement; habitat restoration

Mitigation; sagebrush treatments

Argus against big sagebrush treatments

The CPT could help resource managers evaluate potential costs and benefits of treatments in various localities in order to facilitate restoration prioritization decisions across ecosystems used by GRSG.

Expands mesic areas making them more resilient (potentially useful for drought/climate mitigation and/or conservation efforts).

Technique refinement; habitat mapping; Pinyon-Juniper treatment

Habitat mapping; habitat restoration

Potential technique for offset mitigation.
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<tr>
<th>Authors</th>
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<td>Reinhardt et al.</td>
<td>2017</td>
<td>Next-generation restoration for sage-grouse: A framework for visualizing local confiner cuts within a landscape context</td>
<td>Ecosphere, v. 8, no. 7, article e018888, 18 p</td>
<td>The authors conclude that the optimization framework and models used in this study illustrate an approach, increasingly available to land managers, which can augment or complement standard expert-based approaches to planning and prioritization. Such approaches could reduce planning and implementation time for landscape-scale confiner removal treatments.</td>
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<td>Davis and Ecology and Evolution, DOI: 10.1002/ece3.5432.</td>
<td>2019</td>
<td>Long-term evaluation of sagebrush restoration after juniper control and herbaceous vegetation trade-offs</td>
<td>Range Ecol &amp; Management, v. 72, no. 2, p. 260-265.</td>
<td>Following juniper control in dense stands that lack sagebrush, mountain big sagebrush re-establishment is likely to be accelerated by seeding, whereas herbaceous vegetation cover may be reduced.</td>
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<td>Coates et al.</td>
<td>2018</td>
<td>Case study—Short-term response of greater sage-grouse to wildfire in mountain big sagebrush communities</td>
<td>Wildlife Society Bulletin, v. 39, no. 1, p. 129-137.</td>
<td>The authors sought to identify the short-term (&lt;11 year) response of GRSG nesting and brood-nesting habitats to wildfire. In mountain big sagebrush communities where sagebrush is abundant, the understory is composed of adequate native perennial grasses and forbs, and invasive annual grasses are limited, prescribed burning may be a useful tool for improving GRSG habitat.</td>
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<td>Elsworth et al.</td>
<td>2016</td>
<td>Ecosystem resilience is evident 17 years after fire in Wyoming big sagebrush ecosystems</td>
<td>Ecosphere, v. 7, no. 12, article e015108, 12 p</td>
<td><a href="https://doi.org/10.1002/ecs2.1618">https://doi.org/10.1002/ecs2.1618</a>.</td>
<td>Results demonstrate post-fire resilience of the sere Wyoming big sagebrush system, possibly because of its high quality and presence of unburned patches within the fire perimeter. The conditions are representative of sere: Wyoming big sagebrush communities prior to the invasion of cheatgrass, where there were islands of sagebrush left after fire which helps the system recover from fire and provide habitat for GRSG. Controlled burning of some sagebrush systems that are in good condition and dominated by native may have benefits for ecosystem heterogeneity and herbaceous cover. Authors conclude, “Our results illustrate that management of all habitat components, including natural disturbance and a mosaic of successional stages, is important for persistent resilience and that suppression of all fires in the sagebrush steppe may create long-term losses of heterogeneity in good condition Wyoming big sagebrush ecosystems.”</td>
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<td>Foster et al.</td>
<td>2018</td>
<td>Potential effects of GPS transmitters on greater sage-grouse survival in a post-fire landscape</td>
<td>Wildlife Biology, v. 2018, no. 1, p. 260-265.</td>
<td>Survival rates measured in this post-fire study were much lower than observed in other studies in the Great Basin, though they did eventually increase to comparable levels (after the conclusion of this study). If the slightly lower survival rates of birds with GPS versus VHF devices observed in this study are confirmed (5% lower survival), they are of concern because of the increasing use of GPS units and the potential for effects of this magnitude to affect population growth rates. Findings from this study were limited by small sample sizes.</td>
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<td>Stenvodden et al.</td>
<td>2019</td>
<td>The ecological importance of unburned islands as refugia for the persistence of wildlife species in fire-prone ecosystems</td>
<td>Ecology and Evolution, DOI: 10.1002/ece3.5432.</td>
<td>Population dynamics of birds located within fire perimeters are negatively impacted. Unburned islands play an important role as refugia, and maintaining unburned vegetation may be vital for the survival of GRSG populations after a wildfire event. The recovery of natural vegetation postfire may also benefit GRSG populations.</td>
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**Mitigation—Wildfire**

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**Other Mitigation**

- Supports the reality that historical habitat was not a vast sagebrush sea, but rather an ecosystem made up of sagebrush islands. Supports the reality that historical habitat was not a vast sagebrush sea, but rather an ecosystem made up of sagebrush islands. Auditors appropriately recognize that the GPS may have biased the conclusions. Auditors appropriately recognize that the GPS may have biased the conclusions. Suggest additional review due to significance as a mitigation measure. Suggest additional review due to significance as a mitigation measure.

- Mitigation—Wildfire

- Other Mitigation
| Blomberg et al. | 2015 | Blomberg, E.J., 2015, The influence of harvest timing on greater sage-grouse survival—A cautionary perspective: Journal of Wildlife Management, v. 79, no. 5, p. 695–703. | The author concluded that timing of mortality, coupled with potential effects indicated by compensatory and additive mortality models, suggests that moving harvest to later in the year will not benefit GRSG populations and may have unintended negative consequences. | Technique refinement: reducing population effects but shifting hunting season | Applies only to where GRSG are hunted |
| Wing and Meaner | 2016 | Impact of sagebrush nutrients and monoterpenes on greater sage-grouse vital rates: Human-Wildlife Interactions, v. 10, no. 2, p. 237–248. | Study results confirmed the importance of black sagebrush as pre-nesting season forage and suggested that any forage selection related to monoterpenes may reflect some aspect of an individual monoterpenes rather than the total concentration of all monoterpenes. Study results should be interpreted cautiously because of the small sample size, single year, and single study site. | X | X | black sagebrush; GRSG forage |