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).
[2] *Greater Sage-Grouse (Centrocercus urophasianus) Conservation Objections: Final Report*, U.S. Fish and Wildlife Service (Feb. 2013).

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.

Prepared by Wildlife Science International, Inc.

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 (UFWS), 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 were 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.

Attachment B

A Review of Scientific Research Efforts Undertaken Since Adoption of the 2015 GRSG LUPAs With Respect to the GRSG and its Habitat, and Conformity of Federal Land Management Approaches and State GRSG Conservation Plans with Findings from That Research, and;

Examination of Scientific Research Efforts for Conformity to DQA Including but not Limited to General Public Availability of Data and Code.

Prepared by Wildlife Science International, Inc.

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.

Attachment C

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.

Prepared by Wildlife Science International, Inc.

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.

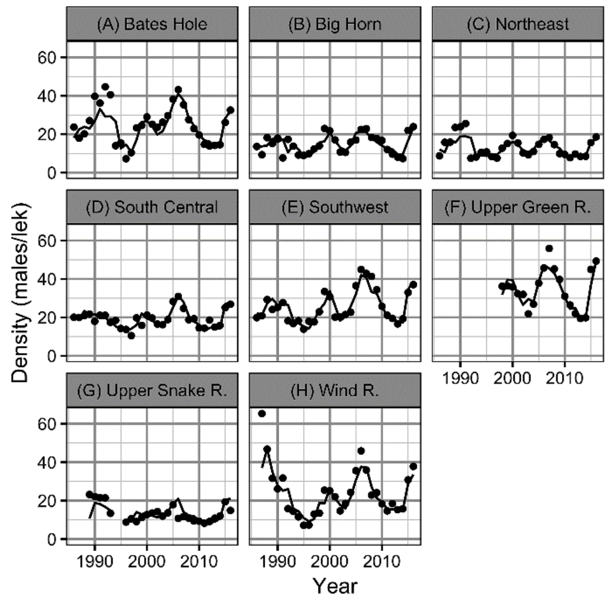
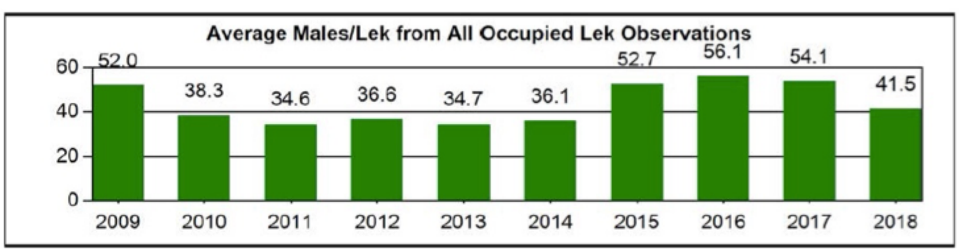


Figure 1. Examples of synchronous greater sage-grouse population fluctuations in Wyoming (from Ramey at al. (2018).

Upper Green River Basin Working Group (Pinedale Planning Area)



Expect a low ebb in 2020, due to a negative PDO ➔

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.

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Attachment D

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

Prepared by Wildlife Science International, Inc.

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).

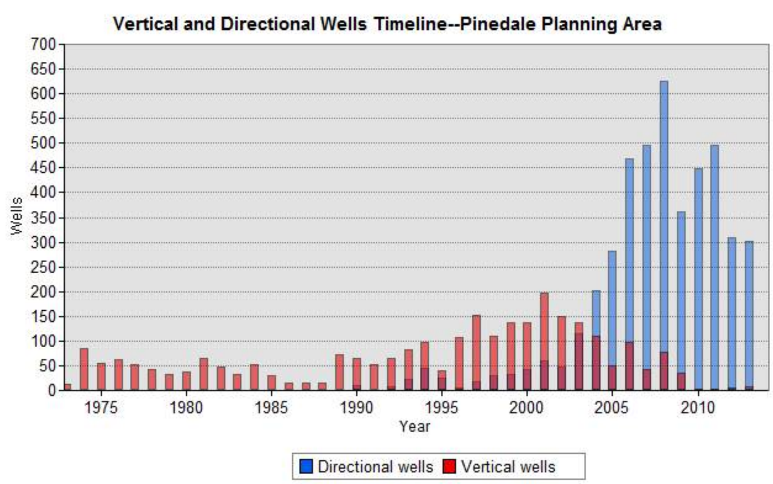

Figure 1. Annual number of vertical and directional wells drilled by the oil and gas industry in the Pinedale Planning Area from 1973 to 2012. The annual number of traditional vertical bore wells is indicated in red, and directional wells (including horizontal wells) are indicated in blue. The transition from predominantly vertical wells to directional wells took place in 2004. As of 2010, virtually all new wells drilled in the Pinedale Planning Area are directional wells.

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 approximatly 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).

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Attachment E

Suggested Parameters and Methods For Determining the Effects of Human Activities and Land Management Plans on Greater Sage-Grouse Population Dynamics

Prepared by Wildlife Science International, Inc.

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.

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Attachment F	Author	Year	Title	Implications: Modified from USGS Annotated Bibliographies (2018, 2019) or from each paper	Supersedes NTT	Supersedes COT	Issue	Significance	Comment
Oil and Gas (includes WY Core Areas)									
	Fedy et al.	2015	The influence of mitigation on sage-grouse habitat selection within an energy development field: PLoS ONE, v. 10, no. 4, article e0121603, 19 p., https://doi.org/10.1371/journal.pone.0121603	Mitigation efforts appeared to improve GRSG nesting habitat, but additional studies linking habitat changes to actual species fitness are needed to determine ultimate consequences of mitigation for GRSG populations.			Oil & Gas	Updated practices reduce impacts; habitat behavioral, or population effects; mitigation, WY Core Areas	
	Fedy et al.	2015	Large-scale control site selection for population monitoring—An example assessing sage-grouse trends: Wildlife Society Bulletin, v. 39, no. 4, p. 700–712	The authors demonstrated that GIS-based, large-scale control site selection can be used successfully for wildlife impact monitoring, and identified 129 control sites for the current study. Both control sites and affected sites in the Atlantic Rim Project Area (natural gas development) had similar trends and change-points in the cyclic trends of GRSG populations, suggesting they were tracking statewide trends and were not fundamentally different. No significant differences in population trends were observed between control and treatment sites.	X	X	Technique refinement; esimating population trends and impacts; oil and gas	Significant in that that area affected by natural gas development tracked population trends in control site.	
	Holloran et al.	2015	Winter 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.	Effects of gas development on GRSG can be reduced by minimizing well densities and adopting methods that reduce anthropogenic activities, such as the use of wells that are connected to liquid gathering systems. Effects of anthropogenic activity may have a time lag because GRSG avoidance of drilling rigs often continued at wells equipped with liquid gathering systems, but the lag time at those wells was not as long as the lag time documented at conventional wells.			Oil & Gas mitigation	Updated practices (liquid gathering systems) reduce impacts	
	Kirol et al.	2015	Mitigation effectiveness for improving nesting success of greater sage-grouse influenced by energy development: Wildlife Biology, v. 21, no. 2, p. 98–109.	Onsite mitigation of natural gas development improves nest success. Minimizing reservoirs appears to be the most effective mitigation measure because of reduced risk to West Nile virus and nest predators associated with water, including raccoons and skunks.	X	X	Oil & Gas mitigation	Updated practices and onsite mitigation improved nest success	
	Kirol et al.	2015	Identifying greater sage-grouse source and sink habitats for conservation planning in an energy development landscape: Ecological Applications, v. 25, no. 4, p. 968–990.	Authors created Source-sink maps to evaluate effects of Atlantic Rim Project Area (ARPA), a developing coalbed natural gas field in south-central Wyoming. Source-sink maps from this study can inform future siting of energy infrastructure and potential mitigation actions. Maintenance of source habitat in proximity to energy developments may improve colonization of reclaimed sites following energy extraction. Methods to develop these maps are applicable to other species of concern.	X	X	Techinque refinement; mapping and quantifyin oil and gas demographic effects	Prioritization of management. Likely a highly influential paper.	Additional review suggested.
	Rice et al.	2016	Seasonal habitat use by greater sage-grouse (Centrocercus urophasianus) on a landscape with low density oil and gas development: PLoS ONE, v. 11, no. 10, article e0165399, 20 p.,	The authors concluded that studies of behavior prior to development occurring, such as this one, can provide resource managers with information that can be valuable when trying to site development to minimize effects on GRSG and their habitat, managing GRSG populations, and quantifying potential effects of development on GRSG populations. Conflicting findings regarding the effect of roads on breeding habitat when evaluated at local and landscape scales indicated that the spatial scale of analysis can have important and sometimes contradictory effects on model results; these findings also suggested that energy development in North Park may not currently be at a level that is affecting GRSG populations significantly.	X	X	Technique refinement; Oil and gas impact mapping	Potential effect of updated O&G practices & reduced impacts	Caveat: Potentially small sample size limits resolution or oil and gas impacts are less than expected.
	Christiansen et al.	2017	Wyoming sage-grouse working groups—Lessons learned: Human-Wildlife Interactions, v. 11, no. 3, p. 274–286.	This paper describes the history of Wyoming's local sage-grouse working groups, their role in Core Area planning, and discusses the effectiveness of local and statewide conservation efforts.	X	X	Wyoming Core Area concept; Oil and gas development	Working group program history and effectiveness	Important background
	Gamo and Beck	2017	Effectiveness of Wyoming's sage-grouse core areas— Influences on energy development and male lek attendance: Environmental Management, v. 59, no. 2, p. 189–203.	The authors sought to evaluate energy development and compare GRSG lek attendance in Core and non-Core Areas to inform assessment of the executive order's short-term effectiveness. : Results provide support for the Core Area designations effectively tempering development and contributing to population stability statewide and in MZ II. Despite implementation of the 2008 Executive Order for Sage-Grouse, GRSG populations in MZ I [Powder River Basin] appear vulnerable to further decline. Mitigation and changes in development rate may improve population numbers.			Oil and gas; CorWyoming e Area	"…results provide support for the effectiveness of Core Areas in maintaining sage-grouse populations in Wyoming, but also indicate the need for increased conservation actions to improve sage-grouse population response in (MZ) I."	MZ I includes most if not all the Powder River Basin, which is not a good example of the Core Area Strategy, as much of the development occurred prior to its implementation.
	Garman	2017	A 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., https://doi.org/10.1007/s10666-017-9559-1.	"To evaluate the conservation potential of this [new] technology, I developed an energy footprint model that simulates well, pad, and road patterns for oil and gas recovery options that vary in well types (vertical and directional) and number of wells per pad and use simulation results to quantify physical and wildlife-habitat impacts. I applied the model to assess tradeoffs among 10 conventional and directional-drilling scenarios in a natural gas field in southwestern Wyoming. Scenarios spanned a gradient in the number of vertical and directional wells, and in number of pads (2000 to 250), but all extracted the same amount of gas over a 15-year period. Reducing pad numbers with directional-drilling technology reduced surface disturbance area and impacts on spatially extensive habitats (48–96% of study area) such as sagebrush-obligate songbird habitat, elk winter range, and sagebrush core area."	X	x	Oil and gas impact modeling	New Oil and gas technology and improved practices reduce impacts compared to past; WY Core Areas	A significant contribution deserving more attention.
	Green et al.	2017	Investigating impacts of oil and gas development on greater sage-grouse: Journal of Wildlife Management, v. 81, no. 1, p. 46– 57.	The authors compiled data on GRSG lek counts, well density, and the disturbance area of well pads across Wyoming for each year from 1980 to 2008. They analyzed these data, along with estimates of sagebrush cover and seasonal precipitation, at five spatial scales. Study results provide "further support for a negative effect of oil and gas developments on GRSG populations", and declines may become evident 1–4 years after development. Current regulations in Core Areas could limit GRSG losses from energy developments, but they may not promote GRSG recovery.			Oil and gas impacts; Wyoming Core Area	Another paper with Aldridge finding substantial current impacts contrary to others. Why does a paper published in 2017 only use data up to 2008?	Caveat: Likely biased results due to use of old data (1980s and data collected prior to extensive mitigation and regulation. Only used seasonal precipitation which is a poor predictor of regional climate variation.

	Edmunds et al.	2017	Greater sage-grouse population trends across Wyoming: Journal of Wildlife Management, 16 p., https://doi.org/10.1002/jwmg.21386.	Using data from Wyoming, the authors examined population trends at different spatial scales. While this is a refinement that could allow managers to focus efforts 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 Ramey 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 an erratum because of a coding error that led to overestimates of population declines and misintepretation of λ as a fixed term.	X	X	Population trends	Potential Improved methodology, however, estimated declines do not seem to match current observations. Cyclical population fluctuations noted.	Caveat: Conclusions do not appear match revised results. (See review of paper, erratum, and supplemental materials). None the less, likely to be cited as evidence of population declines in WY due to Oil and gas.
	Juliusson and Doherty	2017	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. 98–111.	Modeled two oil and gas build-out scenarios based on to evaluate riskexposure of GRSG to oil and gas development, which is not uniform across MZs I and II. Bureau of Land Management land-use plans and the State of Wyoming Core Area Strategy vary in management actions, but they may similarly reduce risks to GRSG populations and breeding habitats, and were used to constrain build-out scenarios, as compared to Copeland et al.(2009, 2013) randomforests approach. Visualization tools enabled spatial assessment of locations where potential exposure risk is elevated across the management zones.	X	X	Technique refinement; oil and gas development scenarios	Likely highly influential paper used to predict oil an dgas effects on GRSG.	Additional review suggested.
	Spence et al.	2017	Probability of lek collapse is lower inside sage-grouse core areas—Effectiveness of conservation policy for a landscape species: PLoS ONE, v. 12, no. 11, article e0185885, 15 p.	The proportion of the male population within core areas and the observed decreased probability of lek collapse within core areas suggest that the core area policy is providing broad protection for GRSG in Wyoming. However, limitations on development near core areas may be needed to more effectively protect GRSG populations within core areas. From the authors, "Collectively, these data suggest that the Wyoming Core Area Strategy has benefited sagegrouse and sage-grouse habitat conservation; however, additional guidelines limiting development densities adjacent to Core Areas may be necessary to effectively protect Core Area populations."			Mitigation; Wyoming Core Areas	Another validation of the Core Area concept	
	Ramey et al.	2018	Local and population-level responses of greater sage-grouse to oil and gas development and climatic variation in Wyoming: PEERJ, v. 2018, no. 6, p. e5417, https://doi.org/10.7717/peerj.5417.	Hierarchical models were used to estimate the effects of the areal disturbance due to well pads as well as climatic variation on individual lek counts and Greater sage-grouse populations (management units) over 32 years. Modeling revealed that oil and gas had a strong negative effect on local-scale lek attendance within a 3.2 km radius around a well. Oil and gas was a weak predictor of population-scale changes, but appeared consistent with local-scale responses. The PDO was found to be a strong predictor of long-term population density fluctuations at local and population scales.	x	x	Climate (regional climatic variation); population fluctuations; oil & gas	PDO was the major driver of population trends rather than oil and gas development	Wildlife agencies need to account for the effects of regional climatic variation when managing sage-grouse populations
	Heinrichs et al.	2019	Influences of potential oil and gas development and future climate on sage-grouse declines and redistribution: Ecological Applications, v. 0, no. 0, article e01912, 16 p, https://doi.org/10.1002/eap.1912.	The authors modeled for low, medium, and high oil and gas development for the years 2012-2062, 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 recalculated habitat selection maps to dynamically modify future habitat quantity, quality, and configuration. .... The inclusion of movement and demographic responses to oil and gas infrastructure resulted in substantive 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."			Oil and gas impact modeling; climate change	Likely to be cited as evidence against oil and gas despite improved technology, practices, and regulations.	Caveat: mixed older error prone data with newer, higher quality data (1980-2008) such that impacts potentially overestimated. Unknown why data to 2018 was not used.
Wind Turbines and Transmission Lines									
	LeBeau et al.	2017	Greater sage-grouse habitat selection, survival, and wind energy infrastructure: Journal of Wildlife Management, v. 81, no. 4, p. 690–711.	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 suggest a lagged population-level response. GRSG survival did not appear to be negatively affected by the facility.	X	X	Wind energy; GRSG habitat use and survivorship	Apparent lag effect of wind energy infrastructure.	
	Kohl et al.	2019	The effects of electric power lines on the breeding ecology of greater sage-grouse: Plos One, v. 14, no. 1, p. E0209968., https://doi.org/10.1371/journal.pone.0209968	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.			Mitigation	Transmission lines	
	LeBeau et al.	2019	Greater Sage-grouse habitat function relative to 230-kV transmission lines: The Journal of Wildlife Management, p. 1-14.	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 3.1 km from occupied leks if possible.			Mitigation	Transmission lines	
Mining									
	Petersen et al.	2016	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.	The authors conclude that surface coal mining and associated mitigation did not cause a decline in the existing GRSG population at the Alton/Sink Valley area of southwest 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.	X	X	Coal mining; mitigation	Lack of avoidance is notable, the question is why?	

	Pratt and Beck	2019	Greater sage-grouse response to bentonite mining: The Journal of Wildlife Management, v. 84, no. 4, p. 866-879	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 propmotion of sagebrush regeneration is important for restoring GRSG habitat.			bentonite mining impacts	Reclaimed mines not utilized by GRSG due to slow regeneration.	
Grazing									
	Monroe et al.	2017	Patterns in greater sage-grouse population dynamics correspond with public grazing records at broad scales: Ecological Applications, v. 27, no. 4, p. 1096–1107,	High levels of grazing in this study represent intensities near maximum allowable 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.	X	X	Technique refinement; grazing management	Prioritization of management actions to improve grazing in GRSG habitat.	New geo spatial data from used public land records.
	Smith et al.	2018	Effects of livestock grazing on nesting sage-grouse in central Montana: Journal of Wildlife Management, v. 82, no. 7, p. 1503-1515.	Female sage grouse selected nest sites based on sagebrush cover and distance from roads, and nest failure was driven by precipitation. Data regarding livestock was inconclusive. The authors suggest that conservation of shrub cover and preventing additional habitat fragmentation by roads would benefit GRSG nesting habitat and nest success.			Roads; livestock grazing	Seasonal effects of weather on nest success; roads fragment habitat.	
	Cutting et al.	2019	Maladaptive nest-site selection by a sagebrush dependent species in a grazing-modified landscape: Journal of Environmental Management, v. 236, no. Epub 2019, p. 622-630	These findings suggest that certain sagebrush habitats may function as ecological traps, whereas others may be undervalued, especially in an actively grazed setting. 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 >100 m away from nearest fence. Timing of graze could best achieve herbaceous requirements for successful nesting. Fence modifications along with prioritization of sagebrush type are discussed."			Grazing; mitigation	Recommendations to avoid ecological traps in areas subject to grazing	
	Runge et al.	2019	Unintended habitat loss on private land from grazing restrictions on public rangelands: Journal of Applied Ecology, v. 56, no. 1, p. 52-62.	Restricting grazing on public lands could result in increased GRSG habitat loss on private land over the next 30 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.	X	X	Grazing management		Unintended consequences
	Taylor et al.	2019	Economic impact of sage grouse management on livestock grazing in the Western United States: Western Economics Forum, v. 17, no. 1, p. 98-114.	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		
Predation									
	Howe and Coates	2015	Observations of territorial breeding common ravens caching eggs of greater sage-grouse: Journal of Fish and Wildlife Management, v. 6, no. 1, p. 187–190.	Ravens can significantly influence reproductive success of GRSG at local scales, but population-level effects remain unclear. Breeding ravens may target GRSG nests more than nonbreeders. Declines of GRSG may be compounded by anthropogenic activities that have improved nesting habitat for ravens in sagebrush ecosystems.	X	X	predation; mitigation (Technique refinement)	Predator management and mitigation	Examined cause and effect mechanisms behind predation
	Coates et al.	2016	Landscape characteristics and livestock presence influence common ravens—Relevance to greater sage-grouse conservation: Ecosphere, v. 7, no. 2, article e01203, 20 p., https://doi.org/10.1002/ecs2.1203. Background: Over the last four decades,	"Ravens are known to depredate GRSG nests, and results demonstrated a positive association between raven occurrence and leks. The strongest association was between raven occurrence and the presence of cattle, apparently because of the food and water subsidies associated with cattle. Importantly, cattle showed stronger support for raven occurrence than anthropogenic resource subsidies. The authors suggest that reducing anthropogenic subsidies is likely to be most effective in reducing raven densities over the long term and that limiting livestock grazing near leks during nesting and brood rearing may reduce GRSG exposure to ravens and increase GRSG reproduction."	X	X	Predation mitigation; reducing GRSG nest and brood predation by ravens	Anthropogenic subsidies; Ravens	Important as it examined cause and effect mechanisms.
	Dinkins et al.	2016	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 results 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, long-term 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 and thus locating and predating GRSG in wetter years.	X	X	Predation; Potetial mitigation (Technique refinement)	Recommendations for more effective predator management; Mesopredator release after coyote removal	Also, noted increased coyote predation on GRSG in wet years (like due to smell) - good investigation of cause and effect mechanisms.
	Peebles et al.	2016	Effectiveness of the toxicant DRC-1339 in reducing populations of common ravens in Wyoming: Wildlife Society Bulletin, v. 40, no. 2, p. 281– 287.	Results indicated that raven populations near GRSG nests can be reduced through DRC-1339 poisoning. However, populations quickly recovered to pretreatment levels, suggesting that annual treatment may be needed. The authors also suggested limiting anthropogenic sources of food for ravens and frequently removing roadkill.	X	X	Predation (Technique refinement)	Prioritization of management actions; raven management using DRC-1339 avicide	

	Walker et al.	2016	Mapping and prioritizing seasonal habitats for greater sage-grouse in Northwestern Colorado: Journal of Wildlife Management, v. 80, 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 100 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	Imporved habitat mapping for enhancement (i.e. pinion-juniper removal) and mitigation.	
	Conover and Roberts	2017	Predators, predator removal, and sage-grouse—A review: Journal of Wildlife Management, v. 81, no. 1, p. 7–15.	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.
	Peebles et al.	2017	Adult sage-grouse numbers rise following raven removal or an increase in precipitation: Wildlife Society Bulletin, v. 41, no. 3, p. 471–478.	Annual 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 forb and insect abundance. The authors suggest that raven removal may be most beneficial where subsidized 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 thatwhen used in conjunction managers 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 10 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 line 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
	Harju 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 e02348, 16 p, https://doi.org/10.1002/ecs2.2348.	Lethal control of ravens at primary subsidies likely does not impact breeding ravens, who tend to utilize these sources less and pose a greater threat to GRSG through nest depredation. Inducing nest failure may cause ravens to change their space use 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 succeptible to lethal control.
	Kirol et al.	2018	Using DNA from hairs left at depredated greater sage-grouse nests to detect mammalian 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 predators that influence GRSG nest productivity. It can also help to identify exotic predators that benefit from human subsidies and habitat modification. This methods could be expanded to include other forms of DNA (e.g. feathers or saliva) for greater inference.	X	X	Predation (Technique refinement)	Potential method for 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)	Prioritization of management; improved methodolgy for more 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 over emphasized in evaluating habitat quality.	
	Dudko et al.	2019	Movements of female sage grouse centrocercus urophasianus during incubation recess: IBIS, v. 161, no. 1, p. 222-229.	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 recesses may expose GRSG to predation by ravens. Striking vertical structures during these flights, which typically occur during low light conditions, may be a mortality risk.			Predation risk; Potential mitigation	Ravens	Provides a behavioral mechanism for susceptibility to raven predation, and therefore informs better predator control methods.
	Kammerle and Storch	2019	Predation, predator control and grouse populations: a review: Wildlife Biology, article wlb.00464, 12 p., https://doi.org/10.2981/wlb.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 grouse predation 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. 1495-1507.	The authors suggest that individual-based resource selection function models(RSF) 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 duplicative of other methods to delineate winter habitat.	
Climate (long range preditions)									

	Creutzburg et al.	2015	Climate change and land management impact rangeland condition and sage-grouse habitat in southeastern Oregon: AIMS Environmental Science, v. 2, no. 2, p. 203–236.	This paper, "evaluated varying scenarios of future climate and management and their implications for rangeland condition and habitat quality, ... simulations indicate that climate change may have both positive and negative implications for maintaining sage-grouse habitat."	X	X	Climate (long range predictions)	Potential changes to habitat are posiive and negative for GRSG	"Linking multiple models creates greater complexity and creates new opportunities for error." In this case, four models with unknown error.
	Homer et al.	2015	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. 55, p. 131–145.	Predicted losses of GRSG habitat to 2050 based on two extreme scenario, downscaled IPCC general circulation models.			Climate (long range predictions)	Questionable long-range predictions	Caveats: Old error-prone data mixed with new data (1984-2011); Predictions rely on two highest anthrogenic radiative forcing models
	Balzotti et al.	2016	Beyond the single species climate envelope—A multifaceted approach to mapping climate change vulnerability: Ecosphere, v. 7, no. 9, article e01444, 23 p., https://doi.org/10.1002/ecs2.1444.	Long-range predictions of habitat changes in Nevada and Utah (to 2070) were based on machine-learning software utilizing regional predictions derived from previously published, downscaled global general circulation models and data from 1961–90 "normal period."			Climate (long range predictions)	Long-term predictions on habitat or population trends	Caveat: Long range predictions to 2070. Predictions untestable.
	Boyte et al.	2016	Boyte, S.P., Wylie, B.K., and Major, D.J., 2016, Cheatgrass percent cover change—Comparing recent estimates to climate change–driven predictions in the northern Great Basin: Rangeland Ecology and Management, v. 69, no. 4, p. 265–279.	Identified areas where cheatgrass was likely to change and projected the potential future magnitude of change for years 2050 and 2070. Climate projections were based on scenarios from the Intergovernmental Panel on Climate Change (IPCC) for 2050 and 2070.			Climate (long range predictions)	Evaluated potential cheatgrass spread inl future	Caveat: Climate projections based on scenarios derived from IPCC general circulation models
	Palmquist et al.	2016	Mid-latitude shrub steppe plant communities—Climate change consequences for soil water resources: Ecology, v. 97, no. 9, p. 2342–2354	Long-range predictions (to 2100) based on global circulation models (GCM), representative concentration pathways (RCPs), and process-based soil water model. Longer, drier summers will likely have a negative effect on sagebrush regeneration and seedling survival and may result in changes to plant functional group composition within current GRSG habitats. Oucome depends on GCM chosen.			Climate (long range predictions)	Questionable very long-range predictions	Caveats: Predictions based on down-scaled general circulation models and outputs of multiple linked models.
	Palmquist et al.	2016	Spatial and ecological variation in dryland ecohydrological responses to climate change— Implications for management: Ecosphere, v. 7, no. 11, article e01590, 20 p.,	Long-range predictions (2050) based on GCM and RCPs. Predict drier summer conditions in higher elevation areas could lead to increased suitability for big sagebrush, whereas mid to lower elevation sites could become less suitable for big sagebrush and consequently GRSG. This information could help prioritize areas for conservation of shrub steppe ecosystems into the future (but they do not say how).			Climate (long range predictions)	Questionable long-range predictions based on most extreme warming scenario (i.e. 5°C by 2100).	Caveat: Predictions based on most extreme scenario RCP8.5 (i.e. unlikely high-risk future) and outputs of multiple linked models.
				Regional climatic variation and weather					
	Caudill et al.	2016	Factors affecting seasonal movements of juvenile greater sage-grouse—A reconceptualized nest survival model: The Condor, v. 118, no. 1, p. 139–147.	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 its 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.	X	X	Seasonal climate and juvenile GRSG migration; Technique refinement: hunting season	Measurable effects of weather on seasonal movements and habitat use; prioritization of management	
	Gibson et al.	2017	Weather, habitat composition, and female behavior interact to modify offspring survival in greater sagegrouse: Ecological Applications, v. 27, no. 1, p. 168–181.	The authors evaluated relations between (1) weather and brood survival, (2) drought and breeding site 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 highelevation sites.	X		Climate (local/seasonal and regional drought)	Local/seasonal effects of weather and drought on vital rates, nesting behavior, and population	GRSG exihibit behavioral response to drought although prolonged drought can be deleterious.
	Coates et al	2018	The relative importance of intrinsic and extrinsic drivers to population growth vary among local populations of greater sage-grouse: an integrated population modeling approach: AUK, v. 135, no. 2, p. 240-261.	Using integrated population modeling allowed the authors to disentangle the effects of precipitation variability on GRSG populations at the DPS level from those at the sub-population level. This information will help resource managers understand how growth rates in the Bi-State DPS can appear stable, while at the same time, certain sub-populations may decline due to extrinsic factors such as drought, unless management actions are taken.	X	X	Technique refinement; population trends	Measurable local, seasonal effects of precipitation variability on population dynamics.	
	Mathews et al.	2018	An integrated population model for greater sage-grouse (Centrocercus urophasianus) in the bi-state distinct population segment, california and nevada, 2003-17: US Geological Survey Open-File Report 2018-1177, 89 p., https://doi.org/10.3133/ofr20181177.	Results suggested that GRSG use increased following pinyon-juniper conifer removal treatments. Modeling showed annual variations in subpopulations, with an overall 2 percent decline in the Bi-State population from 2003 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.			Climate (regional variation and drought); Habitat restoration; Translocation	Population trends in response to drought, Positive resposnse to habitat restoration)	Increased GRSG use after tree removal, drought causes population declines. Mixed results for translocated broods.
	Ramey et al	2018	Local and population-level responses of greater sage-grouse to oil and gas development and climatic variation in Wyoming: PEERJ, v. 2018, no. 6, p. e5417, https://doi.org/10.7717/peerj.5417.	Hierarchical models were used to estimate the effects of the areal disturbance due to well pads as well as climatic variation on individual lek counts and Greater sage-grouse populations (management units) over 32 years. Modeling revealed that oil and gas had a strong negative effect on local-scale lek attendance within a 3.2 km radius around a well. Oil and gas was a weak predictor of population-scale changes, but appeared consistent with local-scale responses. The PDO was found to be a strong predictor of long-term population density fluctuations at local and population scales.	X	X	Climate (regional climatic variation); population fluctuations; oil & gas	PDO was the major driver of population trends rather than oil and gas development	Wildlife agencies need to account for the effects of regional climatic variation when managing sage-grouse populations.
				Population Connectivity					
	Crist et al	2015	Range-wide network of priority areas for greater sage-grouse—A design for conserving connected distributions or isolating individual zoos?: U.S. Geological Survey Open-File Report 2015–1158, 34 p.	Used graph theory a to analyze connectivity between identified priority areas and potential isolation of some areas or populations. "Similar information was later addressed by Crist and others (2017), also summarized in this report."			Connectivity	Long distance movements & population connectivity	Caveat: used graphy theory in GIS analysis, a poor substitute for actual dispersal data.
	Davis et al.	2015	Genetic structure of greater sage-grouse (*Centrocercus urophasianus*) in a declining, peripheral population: The Condor, v. 117, no. 4, p. 530–544.	The study assessed genetic diversity within and between lek sites, spatial 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 are a single genetic population with evidence of gene flow between the leks, despite the fact that leks there are farther apart than those elsewhere across the GRSG range. Individuals at leks were largely unrelated to each other, and females had higher gene flow and greater dispersal distances than males.		x	Connectivity; dispersal	Greater dispersal and genetic connectivity than expected	Movements inferred from population genetic data; Dispersal is critical factor to maintain genetically viable grouse populations

	Cross et al	2016	Hierarchical population structure in greater sage-grouse provides insight into management boundary delineation: Conservation Genetics, v. 17, no. 6, p. 1417–1433.	This study sought to quantify dispersal of males and females among leks, some over long distances using genetic data from 3,244 genetic samples from 763 leks. There were 80 were 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 genetic linkages among distant populations formerly though to be isolated.	X	X	Connectivity; (Technique refinement)	Long distance GRSG movements & population connectivity; Habitat mapping	Data-driven estimates of dispersal and lek-switching
	Crist et al	2017	Range-wide connectivity of priority areas for greater sage-grouse—Implications for long-term conservation from graph theory: The Condor, v. 119, no. 1, p. 44–57.	Published version of Crist et al. 2015, used circuit theory and network analyses 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.			Connectivity	Long distance movements & Population connectivity	Caveat: sage grouse do not behave like electrical currents
	Fedy et al.	2017	Integration of genetic and demographic data to assess population risk in a continuously distributed species: Conservation Genetics, v. 18, no. 1, p. 89–104	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 if 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 trend estimation.	x	X	Connectivity/population management units); Climate (regional variation);	Method for prioritization and tailoring of management based on genetic clusters. Notes need for accounting for cyclic nature of population fluctuations.	Clearly an alternative to the one-size-fits-all approach of NTT.
	Cross et al	2018	The genetic network of greater sage-grouse: range-wide identification of keystone hubs of connectivity: Ecology and Evolution, v. 8, no. 11, p. 5394-5412.	Maintaining hubs and keystone nodes is important for GRSG connectivity, gene flow, and resilience. The loss of these habitats or populations could reduce gene flow and diversity disproportionately across the species' range.			Connectivity; Conservation priorities	Long distance movements & Population connectivity;	Data-driven estimates of population connectivity.
	Ramey et al.	2018	Local and population-level responses of greater sage-grouse to oil and gas development and climatic variation in Wyoming: PEERJ, v. 2018, no. 6, p. e5417, https://doi.org/10.7717/peerj.5417.	Hierarchical models were used to estimate the effects of the areal disturbance due to well pads as well as climatic variation on individual lek counts and Greater sage-grouse populations (management units) over 32 years. Modeling revealed that oil and gas had a strong negative effect on local-scale lek attendance within a 3.2 km radius around a well. Oil and gas was a weak predictor of population-scale changes, but appeared consistent with local-scale responses. The PDO was found to be a strong predictor of long-term population density fluctuations at local and population scales.	X	X	Climate (regional climatic variation); population fluctuations; oil & gas	PDO was the major driver of population trends rather than oil and gas development	Wildlife agencies need to account for the effects of regional climatic variation when managing sage-grouse populations.
	Row et al.	2018	Quantifying functional connectivity: the role of breeding habitat, abundance, and landscape features on range-wide gene flow in sage-grouse: Evolutionary Applications, v. 11, no. 8, p. 1305-1321.	Compared estimated connectivity (from resistance models) and genetic differentiation (from microsatellite genotypes from 6,844 GRSG) within five long-established Sage Grouse Management Zones (MZ) I-V. "It was clear from our cross-validation that the predictive ability of our resistance models varied with the levels of genetic differentiation and among management zone s. ... Without our cross-validation to provide an estimate of predictive ability, conservation initiatives could direct actions that will not have the desired improvement on connectivity." Also found that individuals are willing to travel through undesirable habitat if lek attendence is low.	X	X	Connectivity; Mitigation (Technique refinement)	Identification and prioritization of movement corridors. Cross-validation needed before applying resistance models.	Important paper, additional review suggested.
	Oh et al.	2019	Conservation genomics in the sagebrush sea: Population divergence, demographic history, and local adaptation in sage-grouse (Centrocercus spp.): Genome Biology and Evolution, v. 11, no. 7, p. 2023-2034., https://doi.org/10.1093/gbe/evz112	The Washington population's genetic dissimilarity potentially makes it important as a "reservoir" for improving genetic diversity of other populations via translocation. The authors suggested that special protections for this population may therefore be warranted" "highly differentiated populations like the Washington greater sage-grouse may warrant recognition and protection as a genetically distinct conservation unit. "However, possible adaptation to local sagebrush varieties may complicate translocation of individuals between populations.			Connectivity; Mitigation; potential identification of genetic reservoirs	Also, suggests need for a new Washington DPS.	Caveat: Extensive use of adjectives to describe results rather than comparative statistics to other studies or genetic markers. Possible that genetic differeniation may be due to bottleneck(s) and recent isolation rather than isolation or adaptation (needs testing).
Translocation and Captive Breeding for GRSG Restoration									
	Thompson et al.	2015	Captive rearing sagegrouse for augmentation of surrogate wild broods—Evidence for success: Journal of Wildlife Management, v. 79, no. 6, p. 998–1013.	Egg collection and hatching, rearing, and adoption of captive-raised chicks into wild broods is feasible.	X	X	Captive rearing GRSG; itigation	Another paper showing population augmentation is feasible	
	Gruber-Hadden et al.	2016	Population vital rates of resident and translocated female greater sage-grouse: Journal of Wildlife Management, v. 80, no. 4, p. 753–760.	Retention of translocated GRSG within the targeted release site was 82 percent. There was not 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 resolving issues that have imperiled the resident population.	X	X	Mitigation	Translocation	Small sample size, more data needed
	Apa, et al.	2017	Apa, A.D., Thompson, T.R., and Reese, K.P., 2017, Juvenile greater sage-grouse survival, movements, and recruitment in Colorado: Journal of Wildlife Management, v. 81, no. 4, p. 652–668.	Experimentally introduced domestically-hatched chicks into existing wild broods. Was deemed successful because survival rates of these birds were comparable to wild-hatched birds.	x	x	mitigation; translocation	Translocation successful; reintroduction and augmentation are viable techniques	Successful experimental reintroduction technique.
	Duvuvuei et al.	2017	Contribution of translocated greater sage-grouse to population vital rates: Journal of Wildlife Management, v. 81, no. 6, p. 1033–1041.	Translocating adult females may maximize translocation success overall, as adults are more likely than juveniles to raise a brood in the first year. Authors recommend continuing monitoring for multiple years following translocations. They suggest that factors causing declines in the focal GRSG population be mitigated prior to receiving translocated females.	X	X	Mitigation	Translocation/population augmentation	One of several recent studies that have shown translocation is a useful tool for GRSG conservation.
	Ebenhoch et al.	2019	Effects of post-release movements on survival of translocated sage-grouse: The Journal of Wildlife Management, v. 83, no. 6, p. 1314-1326.	Newly translocated GRSG had smaller home ranges and traveled longer daily distances than either resident or previously translocated birds, but distances moved between seasonal centers did not differ among the three groups. Annual survival was not significantly lower in newly translocated birds; males and birds that moved greater daily distances had greater mortality risk. Newly translocated birds initiated nests less often than other groups, but nest initiation date and nest survival did not vary with residency status. Nest success was higher when nests were initiated later in the nesting season. Resident GRSG nested farther from active leks than translocated birds.	X	X	Technique improvement; Mitigation	Translocation of GRSG is a potential tool for augmenting declining populations or reestablishing ones that have been extripated.	It has long been argued that translocation is unsuccessful despite data to the contrary (Strawberry Hill). This information also suggests that survival of translocated birds does not differ from resident birds

	Heinrichs et al.	2019	Optimizing the use of endangered species in multi-population collection, 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									
	Cade	2015	Cade, B.S., 2015, Model averaging and muddled multimodel inferences: Ecology, v. 96, no. 9, p. 2370–2382.	Identified three flawed practices associated with model averaging coefficients when making multimodel inferences in analyses of ecological data. Illustrated issues with highly influential paper by Rice et al. 2013 (DOI: 10.1002/jwmg.496) that modeled GRSG habitat in Colorado.			Technique refinement	Habitat mapping: refutes the habitat mapping conclusions of Rice et al. (2013) in CO	Describes a fundemental statistical issue with use of model selection
	Coates et al.	2016	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 remarkably 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 mapping	Improved methodolgy	
	Coates et al.	2016	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 2016–1080, 160 p., https://doi.org/10.3133/ofr20161080.	"This report provides an updated process for mapping relative habitat suitability and management categories for sage-grouse in Nevada and northeastern California (Coates and others, 2014, 2016)." Must significantly, the authors describe refined methods for habitat mapping including adding VHF and GPS telemetry locations, integrating high resolution vegetation maps with 1–2 meter resolution, modeling seasonal habitat suitability (spring, summer, winter) "that corresponded to critical life history periods for sage-grouse (breeding, brood-rearing, over-wintering)," account for differences in habitat availability between more mesic sagebrush steppe communities and drier Great Basin sagebrush, and indicies of sage-grouse abundance and human footprints.	X	X	Technique refiniement; habitat suitability mapping	Integrated multiple data sets to produce high resolution maps of habitat suitability.	
	Dahlgren et al.	2016	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, summer, and winter habitats. They collected telemetry data on adult GRSG nesting, brooding, and nonbreeding locations throughout the state. They recorded nest success and brooding, live chick, lek, and nonbreeding adult locations for resident and translocated GRSG and evaluated sagebrush habitat extents and vegetation cover types. Seasonal movements of Utah GRSG were generally lower than reported rangewide. Priority Areas for Conservation captured 85 percent of seasonal locations from radio-marked birds.			Connectivity	Long distance movements, movement between leks, seasonal movements	
	Maestas et al.	2016	Tapping 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; soils mapping	Prioritization of management actions: wildlife and invasive species	Tool that ws not available previously.
	Pennington et al.	2016	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 biologists regarding the importance of forbs for GRGS, 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 eat 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 details for most species were lacking. Filling this knowledge gap could facilitate forecasting climate change effects on forbs in sagebrush ecosystems.	X	X	Technique refinement; GRSG diet	Literature review of forb use by GRSG	Indirectly suggests that previous studies on forb use and the resulting management is not well suported.
	Dinkins et al.	2017	Quantifying overlap and fitness consequences of migration strategy with seasonal habitat use and a conservation policy: Ecosphere, v. 8, no. 11, article e01991, 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. Winter habitats were used by migratory and nonmigratory females, and migratory and nonmigratory 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-water equivalent positively influenced adult female survival during the breeding season, but winter weather did not affect survival.			GRSG winter habitat; Core Area use	Suggest that additional protections needed for some winter GRSG habitat.	
	Burkhalter et al.	2018	Landscape-scale habitat assessment for an imperiled avian 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 (86%) exhibited landscape conditions conducive to supporting medium or large 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 eastern 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 projections 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; Wyoming Core Areas	Improved habitat suitability mapping; supports Core Area concept.	Conclusions surprising considering authors.

	Luna et al.	2018	Common native forbs of the northern great basin important for greater sage-grouse: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-387, 76 p.	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 horsebrush are the most important plants for both food and cover.	X	X	Technique refinement	Improved habitat & vegetation mapping	Tool that was not available previously. Useful at local scales.
	Coates et al.	2019	Spatially explicit models of seasonal habitat for greater sage-grouse at broad spatial scales: Informing areas for management in Nevada and northeastern California. *Ecol Evol*. 2019 Nov 25;10(1):104-118. doi: 10.1002/ece3.5842. PMID: 31993115; PMCID: PMC6972839.	An updated version of 2016 report: Spatially explicit modeling of annual and seasonal habitat for greater sage-grouse (Centrocercus urophasianus) in Nevada and northeastern California	X	X	Technique refinement	Significant improvement in habitat and vegetation mapping	
	Bates and Davies	2019	Characteristics of intact Wyoming big sagebrush associations in southeastern Oregon: Rangeland Ecology & Management, v. 72, no. 1, p. 36-46.	These findings could be used to help develop and implement management guidelines and actions aimed at preserving or restoring intact Wyoming big sagebrush communities.	X	X	Technique refinement; habitat mapping	Habitat & vegetation mapping	
	Henderson et al.	2019	Vegetation mapping to support greater sage-grouse habitat monitoring and management—Multi- or univariate approach? Ecosphere, vol. 10, no. 8, p. 1-22., https://doi.org/10.1002/ecs2.2838.	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.	X	X	Technique refinmement; habitat mapping	Habitat & vegetation mapping	Minor Improvement paper. Important for local conservation efforts.
	Pratt et al.	2019	Prioritizing seasonal habitats for comprehensive conservation of a partially migratory species: Global Ecology and Conservation, v. 17, e00594, p. 1-11., https://doi.org/10.1016/j.gecco.2019.e00594.	Conservation approaches like Wyoming's Core Areas Strategy that prioritize breeding habitat appear to be effective as a first step. However, various GRSG populations may partly 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.			Technique refinement: habitat mapping	Method for refining at a local scale	
Improved Estimation of Population Abundance and Trends									
	Gibson et al.	2015	Observer effects strongly influence estimates of daily nest survival probability but do not substantially increase rates of nest failure in greater sage-grouse: The Auk, v. 132, no. 2, p. 397–407	Observer-induced nest abandonment can decrease estimates of daily nest survival. The authors recommend assessing the potential costs and benefits of nest surveys on sensitive populations and incorporating bias corrections into estimates of nest survival.	X		Technique refinement; nest survival studies	Researchers can have deleterious effect on parameter they are studying.	Raises concern that some previous studies may have biased results.
	Dahlgren et al.	2016	Evaluating vital rate contributions to greater sage-grouse population dynamics to inform conservation: Ecosphere, v. 7, no. 3, article e01249, 15 p.,	Lek counts reliably 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 nest survival is highly variable and more affected by natural environmental variation.	X	X	Technique refinement; Lek count and telemetry studies	Improved methodology for populaion management	
	Fregman et al.	2016	Male greater sage-grouse detectability on leks: Journal of Wildlife Management, v. 80, no. 2, p. 266–274.	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.	X	X	Technique improvement; lek counts	Sightability estimates are key to estimating population density or abundance from count data.	Improves lek counting, outdates previous methods and anything that relied on previous standards
	Gibson et al.	2016	Evaluating vegetation effects on animal demographics—The role of plant phenology and sampling bias: Ecology and Evolution, v. 6, no. 11, p. 3621–3631.	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 date corrections between hatching and nest-fate measurement.	X		Technique refinement; nesting studies		
	McCaffery et al.	2016	Improved analysis of lek count data using N-mixture models: Journal of Wildlife Management, v. 80, no. 6, p. 1011–1021	The authors found that N-mixture models produced more accurate 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	X	X	Technique refinement; population trend estimates	Highly significant paper on estimating population trend estimates than traditional methods from lek count data.	Additional review suggested.
	McCaffery and Lukacs	2016	A generalized integrated population model to estimate greater sage-grouse population dynamics: Ecosphere, v. 7, no. 11, article e01585, 14 p.,	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 sizes, sex-specific survival rates by life stage, and the proportion of leks surveyed annually in a given area.	X	X	Technique refinement: Improved analysis of lek count data using N-mixture models	Highly significant paper for future estimating of population trends and abundance	Additional review suggested
	Caudill et al.	2017	Individual heterogeneity and effects of harvest on greater sage-grouse populations: Journal of Wildlife Management, v. 81, no. 5, p. 754–765.	"Using the revised formulae, the authors demonstrated that effects of selective harvest on grouse tend to 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."			Technique refinement; Hunting	Mitigating potential population-level effect of hunting	Example of effective application of determing cause and effect mechanisms for effective mitigation.
	Clawson et al.	2017	Performing statistical population reconstruction using program PopRecon 2.0: Wildlife Society Bulletin, v. 41, no. 3, p. 581–589.	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, "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."	X	X	Technique refinement; population trend reconstruction	Found population trends to be cyclical (similar to papers on influence of regional climate/weather patterns).	
	Forby et al.	2017	Emerging technology to measure habitat quality and behavior of grouse—Examples from studies of greater sage-grouse: Wildlife Biology, article wlb.00238, 10 p., https://doi.org/10.2981/wlb.00238	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 target data collection and use	X		Potential technique refinements	Showcasing of various potential Improvements in methodology via UAVs, spectral imaging, robotic animals and biotelemetry systems.	Caveat: Except for spectral imaging of vegetation, seems like high tech methods in search of a question.

	Fregman et al.	2017	Male greater sage-grouse movements among leks: Journal of Wildlife Management, v. 81, no. 3, p. 498–508.	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 lek counts, reducing the ability of lek count data to accurately depict GRSG population abundance or trends. Lek 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 GRSG move to higher elevations as snowpack melts. Conducting lek counts during peak attendance and avoiding counts during days with precipitation, particularly at higher elevations, is recommended.	X	X	Technique improvement; lek counts	Timing of lek counts is important to maximizing sighting of males at leks.	
	Fregman et al.	2017	Necklace-style radio-transmitters are associated with changes in display vocalizations of male greater sage-grouse: Wildlife Biology, article wlb.00236, 8 p., https://doi.org/10.2981/wlb.00236.	Vocalizations made by males with necklace-style radio transmitters fell outside the normal range of vocalizations produced by males throughout the range of GRSG, suggesting that radio collars may impair their ability to produce normal vocalizations. The use of necklace-style collars that sit on the necks of GRSG are not recommended for use in behavioral studies of GRSG. Alternative attachment methods should be developed and tested.	X		Technique refinement	Necklace-style transmitters alter behavior.	Raises concern that previous studies that used this and other outdated technology may have biased results.
	Hagen et al.	2018	Estimating sex-ratio, survival, and harvest susceptibility in greater sage-grouse: making the most of hunter harvests: Wildlife Biology, article wlb.00362, 7 p., https://doi.org/10.2981/wlb.00362.	The authors suggest that demographics of harvested populations can be modeled for GRSG or other game birds using a mark-recovery approach of harvested individuals.	X	X	Technique refinement; population estimation	Hunter harvested sage grouse are an important source of data on suvivorship.	Caveat: requires hunting
	Shyvers et al.	2018	Dual-frame lek surveys for estimating greater sage-grouse populations: Journal of Wildlife Management, v. 82, no. 8, p. 1689-1700.	Study in northwestern Colorado. Authors report that, "We estimated 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 analyses and management efforts."	X	X	Technique refinement; lek counts	Important for estimating population denity and trends in low density populations.	Data used by CPW and BLM for RMP development for NW Colorado is obviously biased.
	Coates et al.	2019	Estimating sightability of Greater Sage-grouse at leks using an aerial infrared system and N-mixture models. Wildlife Biology, 2019: wlb.00552, p. 1-11.	The authors suggest that ground-basd lek surveys are likely to result in population estimates about 14% lower than true values, especially in areas with high sagebrush cover. Using aerial integrated infrared imaging system surveys resulted in greater sightability rates, however using repeated morning ground-based surveys or generalized correction values provided by the authors could improve GRSG population estimates derived from ground-based lek counts.	X	X	Technique refinement; lek counts	New method for estimating lek attendance and therefore, population trends.	
	Fregmen et al.	2019	Weather conditions and date influence male sage grouse attendance rates at leks: IBIS, v. 161, no. 1, p. 35-49.	Considering potential biases of attendance, detection can improve the performance of lek counts as indices of population abundance. Attendance here was strongly influenced by precipitation, consistent with other studies and supporting lek-count protocols that discourage counts during rain. Slight negative effects of wind observed here also support avoiding counts during high winds.	X	X	Technique refinement; lek counts	Don't count sage grouse in the rain.	
	Monroe et al.	2019	The importance of simulation assumptions when evaluating detectability in population models: Ecosphere, v. 10, no. 7, p. 1-17., https://doi.org/10.1002/ecs2.2791.	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 GRSG populations with N-mixture 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 GRSG populations across their range.	X	X	Technique refinement; estimating abundance and population trend	Simulations used to evaluate proposed analytical approach which performed favorably	
	O'Donnell et al.	2019	Designing multi-scale hierarchical monitoring frameworks for wildlife to support management: a sage-grouse case study: Ecosphere, v. 10, no. 9, p. 1-34.	The ability to cluster GRSG leks into nested, biologically meaningful lek clusters may aid researchers and managers in producing population trend estimates at different spatial scales and help them determine drives of trends across scales. This information will be important for developing effective management actions.	X	X	Technique refinement; population trends	Additional research required for evaluation for implementation	
	Severson et al.	2019	Global positioning system tracking devices can decrease Greater Sage-grouse survival: The Condor, v. 121, p. 1-15.	The authors reported, "We found lower survival for GPS marked compared to VHF-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. Differences in survival could be attributed to features associated with GPS devices, including greater weight, position of attachment (e.g., rump-mount harness), and a semi-reflective solar panel."	X	X	Technique refinement; GPS tagging	GPS tagged individual had decreased survival compared to older VHF rtechnology. Studies using GPS tags assume no cost to survival or fitness, an assumption obviously violated.	Consistent with other studies. Previos studies using GPS may have biased results.
	Wann et al.	2019	Assessing lek attendance of male greater sage-grouse using fine-resolution gps data—implications for population monitoring of lek mating grouse: Population Ecology, v. 61, no. 2, p. 183-197., https://doi.org/10.1002/1438-390X.1019.	Lek-switching occurred at a higher rate than previously thought. Therefore, the authors recommended that surveys of leks within 4 km of each other should be conducted on the same morning to reduce the chance of double counting males. Date-corrected daily lek counts using attendance probability can reliably estimate population sizes, allowing more leks to be monitored less frequently.	X	X	Technique refinement; lek counts	Potentially resolves issue with males moving beween multiple leks by counting simultaneously.	
Improved Prioritization of GRSG Management									
	Dahlgren et al.	2015	Greater sage-grouse and range management—Insights from a 25-year case study in Utah and Wyoming: Rangeland Ecology and Management, v. 68, no. 5, p. 375–382.	This retrospective analysis used 25 years of data across three large landscapes in northern Utah and southwestern Wyoming to assess sage-grouse population change and corresponding land management differences and sagebrush treatments (prescribed fire, chemical treatment, and grazing) in a case study design to test hypotheses and make recommendations based on research.	X	X	Technique refinement; habitat and population management	Long-term research used to inform effective habitat and population management.	

	Doherty et al.	2016	Importance of regional variation in conservation planning-A rangewide example of greater sage-grouse: Ecosphere, v. 7, no.10, article e01462, 27 p.	Improved spatial population models show overlap of habitats, populations, conservation actions, and threats. Threats to, or conservation actions in, these hotspots could affect a large proportion of GRSG populations. Thresholds in vegetation cover types, disturbance, and other factors varied spatially, so results from one location may not extrapolate to other locations. GRSG in MZ VI (Columbia Basin) and MZ I (Northern Great Plains) appeared to diverge in functional habitat selection from other MZs. The authors emphasize the large spatial scale of this analysis and that on-the-ground management actions may need to be informed by analyses at smaller spatial scales.	X	X	Technique refinement; Conservation planning	Management prioritization, improved methodology	Underscores the fact that a one-size fits all approach is inappropriate.
	Chambers et al.	2016	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: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-356, 143 p.,	"This [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 nonnative 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, and land use and development threats, such as oil and gas development and cropland conversion, to develop effective management strategies." "Areas for targeted management are assessed by overlaying matrix components with Greater sage-grouse Priority Areas for Conservation and Gunnison sage-grouse critical habitat and linkages, breeding bird concentration areas, and specific habitat threats. Decision tools are discussed for determining the suitability of target areas for management and the most appropriate management actions."	X	X	Technique refinement; Conservation management	Prioritization of management; Provides a holistic approach to managing threats, conservation, and restortation.	Caveat: long-term projections based on untestable Global Circulation Models
	Chambers et al.	2017	Science framework for conservation and restoration of the sagebrush biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions. Part 1. Science basis and applications: Geno. Tech. Rep. RMRS-GTR-360. Fort Collins, CO: U.S Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 213.	This comprehensive report provides the scientific basis and applications for the DOI's Conservation and Restoration Strategy for sagebrush ecosystems. As such, it is a highly influential document. The 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 nonnative plants), (2) the capacity of an area to support target species and/or resources, and (3) the predominant threats."	X	X	Comprehensive conservation strategy.	Likely highly influential document.	Additional review suggested.
	Chambers et al.	2017	Using resilience and resistance concepts to manage persistent threats to sagebrush ecosystems and greater sage-grouse: Rangeland Ecology and Management, v. 70, no. 2, p. 149–164.	From the paper's conclusions: "We successfully operationalized resilience and resistance concepts in a risk-based framework to help managers reduce persistent threats to a species of high concern in one of the largest terrestrial ecosystems in North America. By linking our understanding of sagebrush ecosystem resilience to disturbance and resistance to invasive annual grasses to sage-grouse distribution and habitat requirements, we provided a means for decision makers to strategically allocate resources and triage complex problems. This approach offers an innovative decision support system to address the needs of at-risk species in the context of dynamic and adaptive ecosystems. We believe this approach is applicable to species conservation in other largely intact ecosystems with persistent, ecosystem-based threats such as invasive species and altered disturbance regimes."	X	X	Technique refinement; identification of threats; conservation triage	Improved methodology and prioritization of management	Utilize an operational definition of resistance and resilience.
	Coates et al.	2017	Hierarchical population monitoring of greater sage-grouse (Centrocercus urophasianus) in Nevada and California—Identifying populations for management at the appropriate spatial scale: U.S. Geological Survey Open-File Report 2017–1089, 49 p., https://doi.org/10.3133/ofr20171089.	The authors, describe a novel monitoring framework and "early warning system" for estimating annual rates of population change for GRSG within a Bayesian hierarchical and spatially nested structure. This approach "allows for separation of population trends occurring as a result of local and more manageable stressors, relative to those occurring at broader scales" (i.e. broad-scale wildfire and region-wide drought). "Built-in spatial and temporal thresholds help guard against implementing unnecessary management action for populations that falsely signal a warning."	X	X	Technique refinement; mitigation; population dynamics	New method for population and subpopulation management.	Significant improvement over LUP "triggers"
	Carlisle et al.	2018	Identifying holes in the greater sage-grouse conservation umbrella: Journal of Wildlife Management, v. 82, no. 5, p. 948-957.	The authors conclude that species with small distributions or those with habitat requirements that are only partly similar to those of GRSG will receive relatively fewer conservation benefits from GRSG as an umbrella species. These species may need seperate protections established for their conservation. The authors further suggest that applying the umbrella species concept to GRSG and sagebrush habitats requires attention to details regarding the umbrella species, habitat reserves created to benefit the species, and the degree of habitat similarity shared with co-occurring species.	X	X	Technique refinement; GRSG as a conservation "umbrella species"	Prioritization of management actions; unintended consequences	The NTT, COT, and LUPs completely fail to take into account other species and can have negative impacts on other species at a local level. The one-size fits all, single species managemnt approach has proven adverse effects to other species.
	Hanser et al.	2018	Greater sage-grouse science (2015-17)–synthesis and potential management implications: U.S. Geological Survey, Open-File Report 2018-1017, 46 p., https://doi.org/10.3133/ofr20181017.	This is a USGS synthesis of papers from the USGS annotated bibliography on GRSG literature by Carter et al. (2018) covering topics: The six primary topics were: Multiscale habitat suitability and mapping tools; Discrete anthropogenic activities; Diffuse activities; Fire and invasive species; Restoration effectiveness; Population estimation and genetics.	X	X	Literature review 2015-2018	Likely influential in USFWS 2020 status review.	USGS literature review. Potentially influential, additional review recommended.
	Crist et al.	2019	Science framework for conservation and restoration of the sagebrush biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions. Part 2. Management applications. Gen. Tech. Rep. RMRS-GTR-389. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 237 p.	The strategic, long-term, multiscale approaches described in this report, as well as associated tools, will aid resource managers in implementing on-the-ground management actions in the sagebrush biome.	X	X	Technique refinement	Prioritization of management. Likely highly influential.	Additional review suggested.
				Habitat Improvement					

	Lockyer et al.	2015	Nest-site selection and reproductive success of greater sage-grouse in a fire-affected habitat of northwestern Nevada: Journal of Wildlife Management, v. 79, no. 5, p. 785–797,	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 >40 percent shrub cover within 0.8 ha of nest sites. Cheatgrass control may also improve nest success. GRSG may benefit from postfire restoration that recovers shrubs and perennial grasses.	X	X	Technique refinement; habitat management	Prioritization of management	
	Pyke et al.	2015	Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 1. Concepts for understanding and applying restoration: U.S. Geological Survey Circular 1416, 44 p.	This report will help resource managers make decisions about where and how to conduct restoration treatments in former sagebrush ecosystems for the benefit of sagebrushobligate species like GRSG. Topics: broad-scale habitat characteristics, fire or fuel breaks, habitat restoration or reclamation, nonnative invasive plants.	X	X	Technique refinement	Prioritization of management	
	Pyke et al.	2015	Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 2. Landscape level restoration decisions: U.S. Geological Survey Circular 1418, 21 p	This report and the decision tool that it describes will help resource managers make decisions for prioritizing landscapes for restoration work. Once priority landscapes are determined, managers can move to selecting sites for restoration and use Part 3 in the handbook series.	X	X	Technique refinement	Prioritization of management	
	Baxter et al.	2017	Baxter, J.J., Baxter, R.J., Dahlgren, D.K., and Larsen, R.T., 2017, Resource selection by greater sage-grouse reveals preference for mechanically-altered habitats: Rangeland Ecology and Management, v. 70, no. 4, p. 493–503.	Dense patches of sagebrush were mechanically treated annually by using either a chain harrow or brushhog mower in treatment sites. An increase in forb cover after treatment was expected but not observed, potentially because of lower annual precipitation levels after treatment, competition with grasses, or a lag effect of treatment. A significant increase in use of habitat in and near (within 90 meters) treated mountain big sagebrush sites by brooding GRSG suggests that such treatments may be beneficial to GRSG.			Technique refinement	Habitat restoration	Habitat improvement but Survival and recruitment were not assessed
	Pyke et al.	2017	Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 3 . Site level restoration decisions: U.S. Geological Survey Circular 1426, 62 p	This report and the tool it describes will help resource managers make decisions that should enhance their success in restoring sagebrush ecosystems and thus GRSG habitat at an individual site.	X	X	Technique refinement	Prioritization of management	
	Smith and Beck	2017	Sagebrush treatments influence annual population change for greater sage-grouse: Restoration Ecology, Early View article posted September 15, 2017, 9 p.,	The authors state, "With the exception of chemical treatments exhibiting a positive association with sage-grouse population change 11 years after implementation, population response to treatments was either neutral or negative for at least 11 years following treatments. Our work supports a growing body of research advocating against treating big sagebrush habitats for sage-grouse, particularly in Wyoming big sagebrush (A. t. wyomingensis)."			Mitigation; sagebrush treatments	Argues against big sagebrush treatments	
	Carlisle et al.	2018	Nontarget effects on songbirds from habitat manipulation for greater sage-grouse: implications for the umbrella species concept: Condor, v. 120, no. 2, p. 439-455.	The authors suggest that sagebrush mowing treatments intended to benefit GRSG, an ostensive umbrella species at a broad spatial scale, could have negative effects on co-occurring species at more localized scales, especially if mowing treatments are widespread.	X	X	Technique refinement	Prioritization of management actions; Unintended consequences	The NTT, COT, and LUPs completely fail to take into account other species and can have negative impacts on other species at a local level. The one-size fits all, single species managemnt approach has proven adverse effects to other species.
	Gustafson et al.	2018	Using object-based image analysis to conduct high-resolution conifer extraction at regional spatial scales: International Journal of Applied Earth Observation and Geoinformation, v. 73, p. 148 – 155.	The maps produced can help to inform land managers on where to target pinyon-juniper treatment in order to aid sagebrush restoration and GRSG conservation.	X	X	Technique refinement; habitat mapping; Pinion-juniper treatment	Habitat mapping; habitat restoration	Potential technique for offset mitigation.
	Ricca et al.	2018	A conservation planning tool for greater sage-grouse using indices of species distribution, resilience, and resistance: Ecological Applications, v. 28, no. 4, p. 878-896.	The CPT could help resource managers evaluate potential costs and benefits of treatments in particular locations in order to facilitate restoration prioritization decisions across landscapes used by GRSG.	X	X	Technique refinement; habitat restoration	Prioritization of management; new planning tool	An improved planning tool. Also undermines the argument that habitats cannot be restored by recognizing the BLM prioritization process for restoring lands needs improvement. This tool can help with that.
	Davee et al.	2019	Using beaver dam analogues for fish and wildlife recovery on public and private rangelands in Eastern Oregon: Research Paper PNW-RP-617. Northwest Climate Hub, U.S Department of Agriculture, Forest Service, Pacific Northwest Research Station, p. 32.	Beaver dam analogues can improve habitat for fish and wildlife, including GRSG, but implementing this tool may require navigating new or yet-to-be established regulatory pathways and obtaining by-in from private landowners and ranchers is an important consideration for increasing implementation of this tool.	X	X	Technique refinement; Mitigation; Habitat restoration	Innovative method for habitat resotation; habitat expansion	Expands mesic areas making them more resilient (potentially usefull for drought/climate mitigation and/or conservation offset).
Mitigation-Restoration of Habitat - Pinyon-Juniper removal									
	Farzan et al.	2015	Western juniper management—Assessing strategies for improving greater sage-grouse habitat and rangeland productivity: Environmental Management, v. 56, no. 3, p. 675–683.	The study showed that juniper removal can benefit both GRSG and cattle forage production, but the benefits depend on site characteristics and how sites were selected. Sites chosen to maximize forage did not substantially benefit GRSG. Sites chosen for GRSG habitat did benefit forage production, but larger habitat treatments had decreasing returns on investment. The benefits achieved for either goal were altered by agency coordination, budgetary constraints, and wildfire.	X	X	Technique refinement; pinyon-juniper removal	Management can be prioritized to benefit GRSG habitat and cattle forage	Management actions can have a dual purpose.
	Coates et al.	2017	Pinyon and juniper encroachment into sagebrush ecosystems impacts distribution and survival of greater sage-grouse: Rangeland Ecology and Management, v. 70, no. 1, p. 25–38.	From the authors: "Collectively, these results provide clear evidence that local sage-grouse 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 populationvital rates. To increase sage-grouse survival, our model predictions support reducing actual pinyon-junipercover as low as 1.5%, which is lower than the published target of 4.0%."	X	X	Technique refinement; Improved standards for pinyon-juniper removal	New threshold for pinion-juniper removalprovided greater benefits to GRSG	
	Prochazka et al.	2017	Encounters with pinyon-juniper influence riskier movements in greater sage-grouse across the Great Basin: Rangeland Ecology and Management, v. 70, p. 39–49.	The authors conclude that GRSG are negatively affected by pinyon-juniper encroachment because this habitat type stimulates faster, high-risk movements, such as flight, which likely attract visual predators. Further, the study quantifies age-specific GRSG mortality risk when individuals move through landscapes containing pinyon-juniper stands.	X	X	Pinion-juniper; predation risk	Cause and effect mechanism explaining predation risk	

	Reinhardt et al.	2017	Next-generation restoration for sage-grouse—A framework for visualizing local conifer cuts within a landscape context: Ecosphere, v. 8, no. 7, article e01888, 18 p	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 conifer removal treatments. Topics: broad-scale habitat characteristics, conifer expansion, new geospatial data, habitat restoration or reclamation	X	X	Technique refinement; conifer removal	Prioritization of management	Improved methodology
	Davies and Bates	2019	Longer-term evaluation of sagebrush restoration after juniper control and herbaceous vegetation trade-offs: Rangeland Ecology & Management, v. 72, no. 2, p. 260-265.	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.	X	X	Technique refinement; pinion-juniper removal and sagebrush restoration		
Mitigation-Wildfire									
	Davis and Crawford	2015	Case study—Short-term response of greater sage- grouse habitats to wildfire in mountain big sagebrush communities: Wildlife Society Bulletin, v. 39, no. 1, p. 129–137.	The authors sought to identify the short-term (<11 year) response of GRSG nesting and brood-rearing 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 nesting and brood-rearing habitat. The application of fire treatments in less mesic sagebrush communities with fewer forbs may not produce the desired results, which emphasizes that management decisions need to be made in light of existing conditions and documented GRSG seasonal habitat needs.	X	X	Technique refinement; prescribed fire	Selective use of prescribed fire to improve GRSG habitat.	Supresedes NTT because fire treatments may benefit higher elevation mountain big sagebrush communities i.e. not a one-size-fits-all strategy.
	Coates et al.	2016	Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems: Proceedings of the National Academy of Sciences of the United States of America, v. 113, no. 45, p. 12745–12750.	The authors describe, "Using three decades of sage-grouse population count, wildfire, and climate data within a modeling framework that allowed for variable postfire recovery of sagebrush, we provide quantitative evidence that links long-term declines of sage-grouse to chronic effects of wildfire. Projected declines may be slowed or halted by targeting fire suppression in remaining areas of intact sagebrush with high densities of breeding sage-grouse."	X	X	Technique refinement; targeted wildfire supression	Prioritization of fire suppression to minimize deleterious effects to GRSG	Important preplanning strategy to reduce threat of wildfire.
	Ellsworth et al.	2016	Ecosystem resilience is evident 17 years after fire in Wyoming big sagebrush ecosystems: Ecosphere, v. 7, no. 12, article e01618, 12 p., https://doi.org/10.1002/ecs2.1618.	Results demonstrate post-fire resiliance of the xeric Wyoming big sagebrush system, possibly because of its high quality and presence of unburned patches within the fire perimeter. The conditions are representative of xeric 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 xeric sagebrush systems that are in good condition and dominated by natives 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."	X	X	Wildfire; mitigation strategy	Selective use of prescribed fire	
	Foster et al.	2018	Potential effects of GPS transmitters on greater sage-grouse survival in a post-fire landscape: Wildlife Biology, v. 2018, no. 1, p. 1-5.	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.	X	X	Post-fire study; GPS transmitters affect survival	GPS transmitters reduce survival compared to VHF transmitters	Authors appropriately recognize that the GPS may have biased the conclusions. As such, this study better informs future study designs.
	Shinneman et al.	2018	A conservation paradox in the great basin-altering sagebrush landscapes with fuel breaks to reduce habitat loss from wildfire: US Geological Survey, v. XXX, no. XXX, p. XXX*Open File Report.	The authors conclude that more research is needed to document fuel break effectiveness, effects on plant communities, and effect on wildlife. However, they suggest that installing fuel breaks in an effort to protect intact sagebrush habitat may provide long-term benefits to sagebrush-associated species, even if these benefits come at a cost to some individual species at local scales.	X	X	Wildfire; fuel breaks	Supports the reality that historical habitat was not a vast sagebrush sea, but rather an ecosystem made up of sagbrush islands.	Suggest additional review due to significance as a mitigation measure.
	Foster et al.	2019	Greater sage-grouse vital rates after wildfire: Journal of Wildlife Management, v. 83, no. 1, p. 121-134.	GRSG continued to use areas within the wildlife perimeter, but had lower nest and adult survival rates compared to other reported values for GRSG in the Great Basin. Apparent decreased nest site fidelity within the fire perimeter may relate to increased habitat fragmentation. Increased nest survival in the second year may relate to increased vegetation in the burned area. Findings suggest that fire suppression activities to maintain intact habitat patches may be a critical tool for managers of GRSG populations and habitat in landscapes prone to fire.	X	x	Wildfire; mitigation strategy	Improved Wildfire firefighting strategy to benefit GRSG.	
	Shinneman et al.	2019	The ecological uncertainty of wildfire fuel breaks: examples from the sagebrush steppe: Frontiers in Ecology and Environment, v. 17, no. 5, p. 279-289.	To produce a robust cost-benefit analysis regarding fuel break effectiveness and ecological impacts, more research is needed. The authors suggest several specific research questions that could provide useful information to policy and decision-makers "to disentangle their ecological costs and benefits."	X	X	wildfire; fuel breaks	Ecological cost benefit analysis of fuel breaks	
	Stenvoorden et al.	2019	The potential importance of unburned islands as refugia for the persistence of wildlife species in fire-prone ecosystems: Ecology and Evolution, DOI: 10.1002/ece3.5432.	Population dynamics of leks located within fire perimeters are negatively impacted. Unburned islands play an important role as refugia, and maintaining unburned vegetation may be vital for the success of GRSG populations after a wildfire event. The recovery of natural vegetation postfire may also benefit GRSG populations.	X	X	Wildfire; fire suppression	Prioritization of fiire suppression to maintain unburned refugia and enhance pos- wildfire restoration	
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: hunting season	Reducing population effects but shifting hunting season	Applies only to where GRSG are hunted
	Wing and Messmer	2016	Impact of sagebrush nutrients and monoterpenes on greater sage-grouse vital rates: Human-Wildlife Interactions, v. 10, no. 2, p. 157–168.	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 monoterpene 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		