Greater Sage-Grouse National Research Strategy

Scientific Investigations Report 2013–5167

U.S. Department of the Interior
U.S. Geological Survey

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By Steven E. Hanser and Daniel J. Manier

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Executive Summary

The condition of the sagebrush ecosystem has been declining in the Western United States, and greater sage-grouse (*Centrocercus urophasianus*), a sagebrush-obligate species, has experienced concurrent decreases in distribution and population numbers. This has prompted substantial research and management over the past two decades to improve the understanding of sage-grouse and its habitats and to address the observed decreases in distribution and population numbers. The amount of research and management has increased as the year 2015 approaches, which is when the U.S. Fish and Wildlife Service (FWS) is expected to make a final decision about whether or not to protect the species under the Endangered Species Act.

In 2012, the Sage-Grouse Executive Oversight Committee (EOC) of the Western Association of Fish and Wildlife Agencies (WAFWA) requested that the U.S. Geological Survey (USGS) lead the development of a Greater Sage-Grouse National Research Strategy (hereafter Research Strategy). This request was motivated by a practical need to systematically connect existing research and conservation plans with persisting or emerging information needs. Managers and researchers also wanted to reduce redundancy and help focus limited funds on the highest priority research and management issues.

The USGS undertook the development of this Research Strategy, which addresses information and science relating to the greater sage-grouse and its habitat across portions of 11 Western States. This Research Strategy provides an outline of important research topics to ensure that science information gaps are identified and documented in a comprehensive manner. Further, by identifying priority topics and critical information needed for planning, research, and resource management, it provides a structure to help coordinate members of an expansive research and management community in their efforts to conduct priority research.

This Research Strategy was developed by the USGS using a four-step process:

1. Research needs, questions, ideas, or uncertainties about sage-grouse populations, sagebrush habitats, and change agents were identified by conducting a thorough review of National and State conservation assessments, plans, and strategies.
2. Research questions were categorized into themes and topics.
3. Topics were prioritized using a focus group made up of representatives from Federal and State agencies.
4. The written report was drafted by USGS staff, followed by colleague and technical review and revision. The review and approval of the final publication was consistent with USGS Fundamental Science Practices (Fundamental Science Practices Advisory Committee, 2011).

Despite being one of the most well-studied upland game birds in North America, key gaps in the knowledge of sage-grouse biology remain, and many of these information needs directly affect management planning and implementation. Filling these gaps can inform future adaptive management in a complex and changing environment. The development of population models that incorporate information about the complexities of the biological processes and dynamic habitats in which sage-grouse occur is a first step. A starting point for this modeling is aggregation of the wealth of existing demographic and population data, followed by analysis of these data using modern statistical tools. In addition, new understanding of links among population connectivity, habitat conditions, and arrangements or patterns of habitat is important for understanding meta-population processes. Sage-grouse genetic analyses would provide the necessary information to describe relatedness among breeding locations, delineate population structure, and describe movements among populations throughout the sage-grouse range. Implementation of a unified approach for monitoring sage-grouse across its range, including the multiple periods of its life cycle and variations in habitat conditions, would be the foundation for future analysis and increase the power of multi-scale assessments of sage-grouse population characteristics and assessments of the response of populations to change.

Identification of effective management practices to maintain or improve sage-grouse habitat depends on understanding the components of sage-grouse habitat and sagebrush ecosystems that facilitate robust sage-grouse populations. Knowledge of direct and indirect links between habitat condition and configuration and sage-grouse demographic processes at multiple scales will help inform site-level habitat maintenance, rehabilitation, and restoration activities, including placement of those activities within the appropriate landscape context. This information can be gained through integrated analyses of restoration practices, ecosystem succession, recovery rates, ecosystem function, and environmental covariates. Understanding the components of habitat suitability that affect the ability of individual sage-grouse to move within and between seasonal habitats, as well as among populations will help define management options to meet sage-grouse life-history needs and maintain population connectivity.

Human actions and natural processes affect sage-grouse and their habitats through a variety of mechanisms. An important step toward understanding these mechanisms is the determination of the effects of habitat loss and alteration due to anthropogenic surface disturbance and related activities on sage-grouse behavior and population characteristics. By emphasizing the relations between habitat conditions and population responses, these studies could evaluate the effectiveness of current management guidelines and practices and identify new alternatives.

Conifer encroachment and spread of invasive species are both natural processes affected by human influences with the potential for large effects on sagebrush and sage-grouse. The effectiveness of habitat treatments to restore functioning sage-grouse habitat in areas where conifer encroachment occurs and the long-term cost-benefit of those actions needs further study. Development of new practices and improvements to existing ones could help reduce or eliminate the spread of invasive plant species, as well as help rehabilitate or restore invaded sagebrush habitats.

Fire is an important natural influence on sage-grouse and sagebrush ecosystems, and concerns about loss of sagebrush habitats have led to a multitude of approaches to control the spatial extent of areas burned and effects of fire when it occurs. Understanding the effects of these fire reduction activities on sagebrush habitat quality and local sage-grouse populations could improve application of these types of efforts in the context of sage-grouse conservation. Further, assessment of fire history and fire-recovery rates in ways that elucidate the role of past disturbance in determining fire patterns and frequencies will inform planning efforts and deployment of resources to achieve multiple goals, including sage-grouse conservation.

The influence of herbivory, including grazing by wild horses (*Equus ferus*), burros (*Equus asinus*), elk (*Cervus canadensis*), deer (*Odocoileus* spp.), pronghorn (*Antilocapra americana*), and domestic livestock, on sage-grouse populations and habitat conditions is an important question that can be addressed through a coordinated multi-agency effort. Scientific information necessary to help refine management practices and diminish negative effects on sage-grouse and sagebrush habitats is needed for local, regional, and range-wide scales.

Addressing the research priorities presented in this strategy in ways that are integrated and complementary requires improved integration of data and expertise among Federal and State agencies and non-government organizations. Repeated requests for more consistent techniques and meta-analyses that aggregate data across regions indicate the desire for cooperative refinement of population estimation methods and development of consistent approaches to link population responses to environmental conditions, including fire, to use by herbivores, to land-use change, to infrastructure development, and to other human activities. Collaborations by the Bureau of Land Management (BLM), U.S. Forest Service (USFS), FWS, and State wildlife agencies have resulted in elaborate, spatially explicit conservation plans for habitat and population management. These approaches and designations (for example, priority habitats) represent a large experiment in landscape management that balances human land-use demand with conservation of sage-grouse and their habitats. The effectiveness of these landscape approaches would benefit from testing and examination to assess outcomes and additional options. Understanding the implications of a complicated and variable landscape, as related to sage-grouse population dynamics, would benefit from a coordinated and interdisciplinary approach beyond typical population or habitat research.

1.0 Introduction

Sagebrush-steppe vegetation historically covered 89 million ha in North America (McArthur and Ott, 1996). Nearly one-half of this habitat was lost or degraded over the last 100 years (Miller and others, 2011), and sagebrush is now considered one of the most imperiled ecosystems in North America (Noss and Peters, 1995). Sage-grouse are sagebrush-obligate species (Patterson, 1952), and sagebrush provides cover and an important component of their diet throughout the year (Connelly and others, 2011a). With declines in sagebrush habitats, populations of greater sage-grouse (*Centrocercus urophasianus*) have decreased in numbers (Garton and others, 2011) and distribution (fig. 1; Schroeder and others, 2004).

Since the late 1990s, the number of peer-reviewed publications that focused on sage-grouse has increased, and this upturn in publication activity is roughly coincident with the first of eight petitions filed between 1999 and 2003 for the listing of greater sage-grouse under the Endangered Species Act. In 2004, the “Conservation assessment of greater sage-grouse and sagebrush habitats” (Connelly and others, 2004) was compiled for the Western Association of Fish and Wildlife Agencies (WAFWA). The goal was to inform the 2005 range-wide listing decision for greater sage-grouse by the U.S. Fish and Wildlife Service (FWS; U.S. Department of the Interior, 2005). In 2004, the conservation assessment was

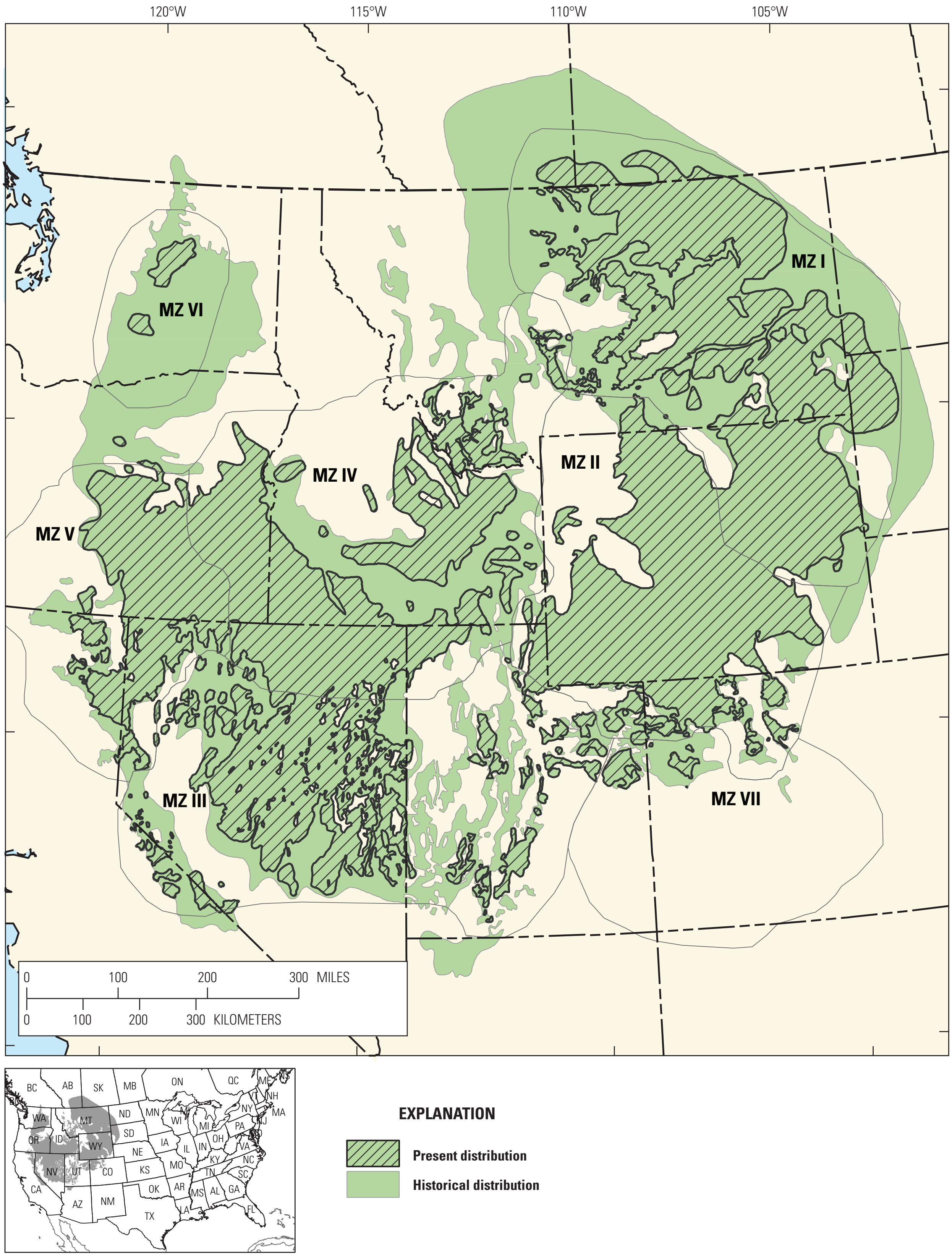

Figure 1. Present and historical distribution of greater sage-grouse in North America (adapted from Schroeder and others, 2004) within Western Association of Fish and Wildlife Agencies designated management zones (Stiver and others, 2006).

the most comprehensive synthesis of information about sage-grouse biology, habitat requirements, and functioning of the sagebrush ecosystem to date.

Other assessments have followed. Markedly in 2006, WAFWA released the Greater Sage-Grouse Comprehensive Conservation Strategy (Stiver and others, 2006), which identified a large number of threats to sage-grouse and created a list of research questions to be addressed. To accomplish many of the goals identified in the 2006 conservation strategy, the 11 Western States (Washington, Oregon, California, Idaho, Nevada, Utah, Montana, Colorado, Wyoming, North Dakota, and South Dakota) and three provinces (British Columbia, Alberta, and Saskatchewan) where sage-grouse occur, joined with several Federal agencies in the signing of a Memorandum of Understanding (MOU) in 2008.

This MOU established the Range-wide Interagency Sage-Grouse Conservation Team (RISCT) and the Greater Sage-Grouse Executive Oversight Committee (EOC). These groups brought together executive (EOC) and technical (RISCT) staff from each organization to implement conservation of greater sage-grouse and their habitat. The Federal agencies involved are within the Department of the Interior [DOI; Bureau of Land Management (BLM), FWS, U.S. Geological Survey (USGS)] and the Department of Agriculture [USDA; U.S. Forest Service (USFS), Natural Resource Conservation Service (NRCS), and Farm Service Agency (FSA)].

States also have been organizing and conducting activities. Between 2003 and 2011, each State wildlife management agency within the sage-grouse's range developed conservation plans and assessments to inform statewide conservation efforts (Wyoming Sage-Grouse Working Group, 2003; Nevada Sage-Grouse Conservation Team, 2004; Stinson and others, 2004; McCarthy and Kobriger, 2005; Montana Sage Grouse Work Group, 2005; Idaho Sage-Grouse Advisory Committee, 2006; Colorado Greater Sage-Grouse Steering Committee, 2008; South Dakota Department of Game, Fish, and Parks, 2008; Utah Division of Wildlife Resources, 2009; Hagen, 2011a). A scientific monograph about the ecology and conservation of greater sage-grouse and its habitats (Knick and Connelly, 2011) also was developed by Federal, State, and non-governmental personnel. The monograph revised information in Connelly and others (2004) and provided new information not addressed in the 2004 assessment. These documents formed a base of knowledge used for the 2010 decision by the FWS that listing sage-grouse range-wide was warranted under the Endangered Species Act but precluded by other priorities (U.S. Department of the Interior, 2010). Subsequent to this 2010 decision, settlement agreements between the FWS and environmental groups established a schedule for a final decision by September 30, 2015. This timeline and associated conservation concerns have increased requests for information about sage-grouse populations and their habitats.

Despite the amount of research conducted over the past two decades, a large number of key research questions remain unaddressed or only partially answered. In addition, the 2006 WAFWA Greater Sage-Grouse Comprehensive Conservation Strategy (Stiver and others, 2006) anticipated revisiting and revising priorities expressed in that document in 2012. It became apparent that a new framework for organizing priority research was needed. With the approaching FWS decision, the EOC requested that USGS take a lead role in the development of a national research strategy.

2.0 Purpose, Scope, and Approach

The purpose of this Research Strategy is to identify, organize, and outline information priorities and research needs to improve the understanding of greater sage-grouse and their habitats[1]. This strategy is targeted at scientists, resource managers, and policy-makers working for Federal, State, Tribal, and non-governmental agencies and organizations. Overarching goals are to provide a framework for sage-grouse research in order to:

- Ensure that research needs are identified and documented in a comprehensive manner to support planning, prioritization, and resource management;
- Identify the highest priority research and science information needs to help guide use of limited financial resources and eliminate redundancy in efforts;
- Expand partnerships and collaborations within the sage-grouse research community;
- Communicate broadly with science and management communities to inform and motivate widespread participation; and
- Promote complementary and (or) coordinated research at regional and range-wide scales.

The Research Strategy addresses sage-grouse life history, habitat management, natural disturbance, and influences of human actions and infrastructure on sagebrush systems and sage-grouse. In many cases, the issues addressed are interrelated, which means inclusive or multifaceted approaches have particular merit. Specific objectives include:

[1]Some of the language of this report describes advantageous or suitable research to support understanding and management decisions. This is done with recognition that many factors besides the evaluations described or cited in this Research Strategy may eventually come to bear in planning and conducting research. Explicit directives or judgments are not intended.

- Identify and characterize the range of questions and issues expressed by managers and researchers relating to the management and conservation of sage-grouse and sagebrush ecosystems; and
- Prioritize research topics according to management need.

A phased approach was used to develop the Research Strategy. First, a review was conducted of the National and State conservation assessments, plans, and strategies (table 1) to identify research needs, questions, ideas, or uncertainties about sage-grouse populations, sagebrush habitats, and threats to either or both. Then research needs were categorized into three broad themes—sage-grouse biology, sage-grouse habitat management, and change agents. These themes contain multiple topics, and at least one research question was associated with each topic (appendix A). Sources of original topics and questions were preserved in a database for reference and to help identify patterns and variations in priorities. Prioritization was accomplished using a focus group of representatives from Federal and State agencies (table 2). The initial expectation was that an explicit ranking of research needs would emerge, but the complexity and breadth of the issues resulted in intermixing of topics, disparities among regions, local-to-regional incompatibilities, and differences in opinion among experts. This resulted in thematic categories being developed using a matrix approach for coordinated or interrelated efforts[2].

[2]Detailed narratives are presented in section 4.0, "Research Themes and Topics." The narratives include a discussion of the research topics that represent the issues and questions used to identify and characterize strategic themes and topics. These topics and narratives provide a synthesis of research needs, but are not an exhaustive list.

Table 1. Conservation and management documents reviewed to identify research needs and management issues.

Citation	Year	Title
Wyoming Sage-Grouse Working Group	2003	Wyoming greater sage-grouse conservation plan
Nevada Sage-Grouse Conservation Team	2004	Greater sage-grouse conservation plan for Nevada and eastern California
Stinson and others	2004	Washington state recovery plan for the greater sage-grouse.
Montana Sage Grouse Work Group	2005	Management plan and conservation strategies for sage grouse in Montana – Final
McCarthy and Kobriger	2005	Management plan and conservation strategies for greater sage-grouse in North Dakota
Stiver and others	2006	Greater sage-grouse comprehensive conservation strategy
Idaho Sage-Grouse Advisory Committee	2006	Conservation plan for the greater sage-grouse in Idaho
South Dakota Department of Game, Fish, and Parks	2008	Greater sage-grouse management plan South Dakota 2008–2017
Colorado Greater Sage-Grouse Steering Committee	2008	Colorado greater sage-grouse conservation plan
Utah Division of Wildlife Resources	2009	Utah greater sage-grouse management plan
Stiver and others	2010	Sage-grouse habitat assessment framework
Hagen	2011a	Greater sage-grouse conservation assessment and strategy for Oregon: A plan to maintain and enhance populations and habitat
Knick and Connelly	2011	Greater sage-grouse: Ecology and conservation of a landscape species and its habitats
Sage-grouse National Technical Team	2011	A report on national greater sage-grouse conservation measures
U.S. Department of the Interior	2012	Sage-grouse conservation objectives draft report
Range-wide Interagency Sage-Grouse Conservation Team	2012	Near-term greater sage-grouse conservation action plan
Manier and others	2013	Summary of science, activities, programs and policies that influence the rangewide conservation of greater sage-grouse

Table 2. Participants in the review and prioritization meeting held in Boise, Idaho, March 4–5, 2013.

Name	Agency
Aaron Robinson	North Dakota Game and Fish Department
Cameron Aldridge	Colorado State University and U.S. Geological Survey
Christian Hagen	Oregon State University
Clint McCarthy	U.S. Forest Service
Jack Connelly	Idaho Department of Fish and Game
Mike Schroeder	Washington Department of Fish and Wildlife
San Stiver	Western Association of Fish and Wildlife Agencies
Shawn Espinosa	Nevada Department of Wildlife
Steve Knick	U.S. Geological Survey
Sean Finn	U.S. Fish and Wildlife Service
Tom Christiansen	Wyoming Game and Fish Department
Tom Rinkes	Bureau of Land Management

3.0 Strategic Research Approach

Agencies and individuals interested in sage-grouse and sagebrush ecosystems have specific missions and goals associated with their organizational contexts. This Research Strategy identifies important areas for emphasis or collaborative involvement that respects those contexts as well as provides common ground for actions and understanding. The research priorities provide a framework for expanding scientific understanding of sage-grouse biology and the sagebrush ecosystem to inform the management needed to maintain or restore sage-grouse habitat and conserve populations (see "Strategic Sage-Grouse Research Framework"). The organizational structure of the strategy is simple. Priority research topics are categorized in three themes: sage-grouse biology, habitat management, and change agents. Sage-grouse biology addresses topics that inform adaptive management of populations dependent on a complex, changing environment. Habitat management addresses topics that foster conservation and management of functioning sage-grouse habitat and sagebrush ecosystems. Change agents addresses topics that incorporate awareness and consideration of the factors associated with major changes in the sagebrush ecosystem, including their mechanisms, synergies, linkages, and effects on sage-grouse. Research within each of these topics and themes may be considered of equal importance, and it is recognized that different organizations will become involved in addressing the topics and themes to varying degrees based on their respective missions and resources.

Cutting across the prioritized topics are several important, unifying issues that help to characterize a research strategy that supports regional and range-wide conservation efforts. Methods and analytical approaches are needed that can efficiently and appropriately compile data across regions to assess the effects of spatial and temporal variation in environmental conditions on sage-grouse populations and their habitats. Importantly, this includes standardization of methods for collecting new data so that future analyses can benefit from the consistency and reduced variability in effort across projects and regional programs. Standardization would improve population demographic estimates, including lek counts, nest monitoring, and population productivity estimation, as well as habitat condition monitoring (for example, rangeland condition assessments) particularly in seasonal and disturbed habitats where comparisons among years and across local and regional boundaries are desirable. The establishment of a standardized core set of variables collected on any project addressing sage-grouse biology and habitat conditions would substantially improve the ability of the research community to aggregate data into regional or range-wide datasets. This core-variable approach would recognize the individuality of research projects while providing a mechanism for leveraging the large number of on-going and future site-specific data-collection efforts. The standardization of methods, approaches, and target variables will benefit both management and research by helping to support multi-scale comparative analyses that can lead to an understanding of drivers of sage-grouse population dynamics at the appropriate spatial scales. This outcome would then provide context for local actions and regional planning, and inform adaptive management and assessments of change over time.

Investigation of multiple research topics using consistent methods within a single research project or management application would reduce costs, expedite the process of obtaining results, and help define an integrated understanding of sage-grouse population dynamics and habitat roles and functions. Large landscape assessments have shown that the practice of incorporating multiple research topics into a single project can increase the power of an assessment and provide opportunities unavailable when assessing single questions. For example, incorporating estimates of habitat patterns and conditions, population demographics, and disturbance by human activity in the same project would enhance understanding of relations between sage-grouse and habitat conditions and permit the identification of correlations, synergies, or divergences in these measures that may be important for management. Although population demographics are the ultimate concern of National, State, and local wildlife management and conservation specialists, habitat conditions are the most likely and available target for management. Therefore, better understanding of effects of habitat pattern and condition on sage-grouse habitat selection and population dynamics is essential. Within this context, integration of the influence of human activity on habitat conditions and direct effects on sage-grouse populations can guide decisions, and discerning effects of multiple environmental factors requires an integrated, multivariate approach.

Strategic Sage-Grouse Research Framework

Increase knowledge of sage-grouse biology to inform adaptive management of populations in a complex and changing environment.

- Develop spatially explicit population models that incorporate the complexities of biological processes and dynamic habitats and derive scenarios that reflect local management possibilities (options, opportunities, and obstacles) to support planning decisions.
- Determine links among functional connectivity (intermixing of birds), habitat conditions, and habitat configuration using genetic evidence and sage-grouse movement patterns.
- Develop options for a unified approach for monitoring sage-grouse across its range and within multiple periods of its life cycle.

Understand the components of sage-grouse habitat and sagebrush ecosystems, and identify effective management practices to improve habitat conditions.

- Determine links between multi-scale habitat condition and configuration and sage-grouse population processes.
- Inform site-level management, restoration, mitigation, and rehabilitation activities through integrated study of restoration practices, ecosystem succession, recovery rates, ecosystem function, and environmental covariates.
- Determine the components of habitat suitability that affect the ability of individual sage-grouse to move through the landscape and populations to mix.

Identify factors (change agents) that affect sage-grouse populations and their habitats, and identify management practices that ameliorate negative effects.

- Determine the effects of loss of habitat and the ecological influence of new or altered landscapes due to surface disturbance on sage-grouse behavior and population characteristics.
- Examine the effects of conifer encroachment on sagebrush, and the effectiveness of management treatments to restore functioning sage-grouse habitat in areas where encroachment occurs.
- Develop new practices or improve existing practices to reduce or eliminate the spread of invasive species and to restore sagebrush that is affected by invasive plant species.
- Assess fire history and fire-recovery rates in a way that informs planning efforts and deployment of resources for future fire events, improve the understanding of effective post-fire restoration methods, and link these to sage-grouse population and behavioral data to increase understanding of the response of sage-grouse to fire.
- Determine the influence of herbivory, including grazing by domestic livestock and wild horses (*Equus ferus*), burros (*Equus asinus*), elk (*Cervus canadensis*), deer (*Odocoileus* spp.), and pronghorn (*Antilocapra americana*), on sage-grouse populations and habitat conditions, and develop options that minimize negative outcomes.

While it may be desirable to clearly and simply rank the list of priority topics (for example, those described in Section 4.0, "Research Themes and Topics"), differences in population status, regional land use, regional habitat conditions, and different research histories result in different priorities depending on focus (for example, population versus habitat) and region (for example, Southern Great Basin versus Northern Plains). Integration of methods and concepts across spatial scales is needed in all regions, and specific topics and management issues will dictate differences in the topics that are combined in future, integrated research projects. In addition, sometimes important research is overlooked or is inaccessible to wildlife and habitat-management specialists for various reasons. Improved, ongoing coordination between managers and researchers would mitigate this situation. Managers would ask questions that can be addressed in scientific designs, and scientists could design and conduct research that focuses on managers' questions. This approach would not limit scientists from adding additional questions or otherwise adding perspective to their research beyond specific management questions.

4.0 Research Themes and Topics

This section contains narrative summaries for the multiple research topics identified during the review of Federal and State conservation plans and strategy documents. A hierarchical structure was developed to organize the list of research needs around three broad themes: sage-grouse biology, sage-grouse habitat management, and change agents. Each theme contains multiple topics, and at least one research question is associated with each topic (appendix A). The organizational structure is designed to capture and represent important topic areas, and because of the integrated, correlated, or otherwise interrelated nature of many of the topics, some categories and issues occur repeatedly. This structure may be most valuable to readers when used for topical reference, as opposed to a linear reading progression. Each topic is ranked in priority as either low (L), medium (M), or high (H) based on input of a focus group (tables 3–5). Although it is possible to get a superficial view of research priorities by considering the hierarchy of themes and topics alone, sufficient understanding of the topics to develop relevant research projects requires details about questions and connections described under those headings. Those details are presented here.

4.1 Sage-Grouse Biology

Despite decades of research on sage-grouse life-history attributes, key knowledge gaps persist in the understanding of biological processes (table 3). Population models that incorporate understanding of multiple, complex biological processes with information about the dynamic qualities of sage-grouse habitat would help integrate information about sage-grouse population and habitat dynamics. Consistent and spatially explicit estimation of variables representing population and habitat conditions and dynamics would facilitate comparative analyses and facilitate research and management across the sage-grouse range. Improved techniques and consistent multi-scale applications would support regional population modeling while also providing information about local conditions for immediate planning and implementation of habitat and population management activities. Expanding knowledge about the condition and connectedness of sage-grouse populations across the landscape is a critical component of this effort. This is because variability in the environment and populations across regions and range-wide remains an obstacle to comparative analyses and extrapolation of information to unsampled areas, even though completed studies document reactions of individuals and populations to particular events (for example, a wildfire).

4.1.1 Population Modeling [H]

Relationships between sage-grouse and their habitats vary by season, region, and environmental condition. Managers seek knowledge of how their practices affect sage-grouse locally and regionally, and how they affect sage-grouse in a range-wide context. This level of understanding requires information about sage-grouse population characteristics, such as survival, mortality, and dispersal rates, and requires additional information about how those characteristics change over time and vary by habitat. Sophisticated population models can associate population changes with spatially explicit information about habitat conditions and trends. Habitat models used in these analyses need to address factors that explicitly affect populations, for example land use, as well as chance fluctuations that can result in extinction, such as weather events or disease. These analyses would provide spatial representations of information about conditions that affect the viability of populations over short and long periods of time; for example, the combination of current and potential dynamics in land-use and climate patterns may interact to determine the habitat patterns and productivity in the future. Additionally, habitat conditions will affect individual health and population demographics, which means that all these factors need simultaneous consideration in population models [for example, population viability analyses (PVA)]. Informative modeling approaches will highlight integration of spatially and temporally explicit representations of population and habitat dynamics to define connections and support scenario modeling.

Assessment of population viability is a clear priority, along with several other topics that directly inform these assessments. In addition, parameter estimates that are used in population models have implications for many other topics related to populations and habitat conditions (fig. 2). The importance of integrating demography and population dynamics with spatial and stochastic processes to provide spatially explicit population models was stressed throughout the prioritization process. These types of analyses linking vital rates, metapopulation structure, and dynamic habitat models have been conducted for ovenbirds (*Seiurus aurocapillus*; Larson and others, 2004), blue alcon butterflies (*Maculinea alcon*; Radchuk and others, 2012) and ruffed grouse (*Bonasa umbellus*; Blomberg and others, 2012b), but not for sage-grouse. These analyses require inclusion of spatial variation (for example, rescue effects), temporal variation in underlying processes (both within and among populations), individual- and population-level heterogeneity including differences in survival and reproductive parameters (for example, influence of super females), and deterministic and stochastic changes in habitat and other environmental factors. Importantly,

Table 3. Research topics in the sage-grouse biology theme and priority designations (low [L], medium [M], or high [H]) based on input from a focus group of representatives from Federal and State agencies.

Topic	Priority designation	Topic No.
Population Modeling	H	4.1.1
Demographics	H	4.1.1.1
Mortality	H	4.1.1.2
Habitat Conditions and Change Agents	H	4.1.1.3
Implications of Priority Areas for Conservation	H	4.1.1.3.1
Movement Patterns and Connectivity	H	4.1.1.3.2
Population Dynamics	M	4.1.1.4
Reproduction	M	4.1.1.4.1
Juveniles	H	4.1.1.4.2
Productivity and Recruitment	M	4.1.1.4.3
Implications of Population Cycles	L	4.1.1.4.4
Genetics Applications and Effective Population Size	H	4.1.1.4.5
Connectivity	H	4.1.2
Movement Patterns	M	4.1.2.1
Habitat	H	4.1.2.2
Barriers and Inhospitable Conditions Between Habitats	H	4.1.2.3
Genetic Evidence	H	4.1.2.4
Population Monitoring	H	4.1.3
Lek Counts	H	4.1.3.1
Demography	M	4.1.3.2
Sex Ratios	H	4.1.3.3
Genetics	H	4.1.3.4
Brood and Juvenile Surveys	M	4.1.3.5
Isolated Populations	M	4.1.3.6
Pellet Counts	L	4.1.3.7
Multiple Scale Relationship and Inference	H	4.1.3.8
Mortality Agents and Factors	H	4.1.4
Sources, Rates, and Influences	M	4.1.4.1
Predation	M	4.1.4.2
Interactions with Habitat Condition	M	4.1.4.2.1
Interactions with Infrastructure	H	4.1.4.2.2
Control Effects	M	4.1.4.2.3
Harvest	M	4.1.4.3
Population Dynamics	M	4.1.5
Demography	H	4.1.5.1
Reproduction	M	4.1.5.2
Productivity and Recruitment	H	4.1.5.3
Isolated Populations	M	4.1.5.4
Behavior	M	4.1.6
Dispersal	H	4.1.6.1
Seasonal Movement Patterns	M	4.1.6.2
Seasonal Habitat Selection	M	4.1.6.3
Food	M	4.1.7
Adaptation	L	4.1.8
Translocation	L	4.1.9

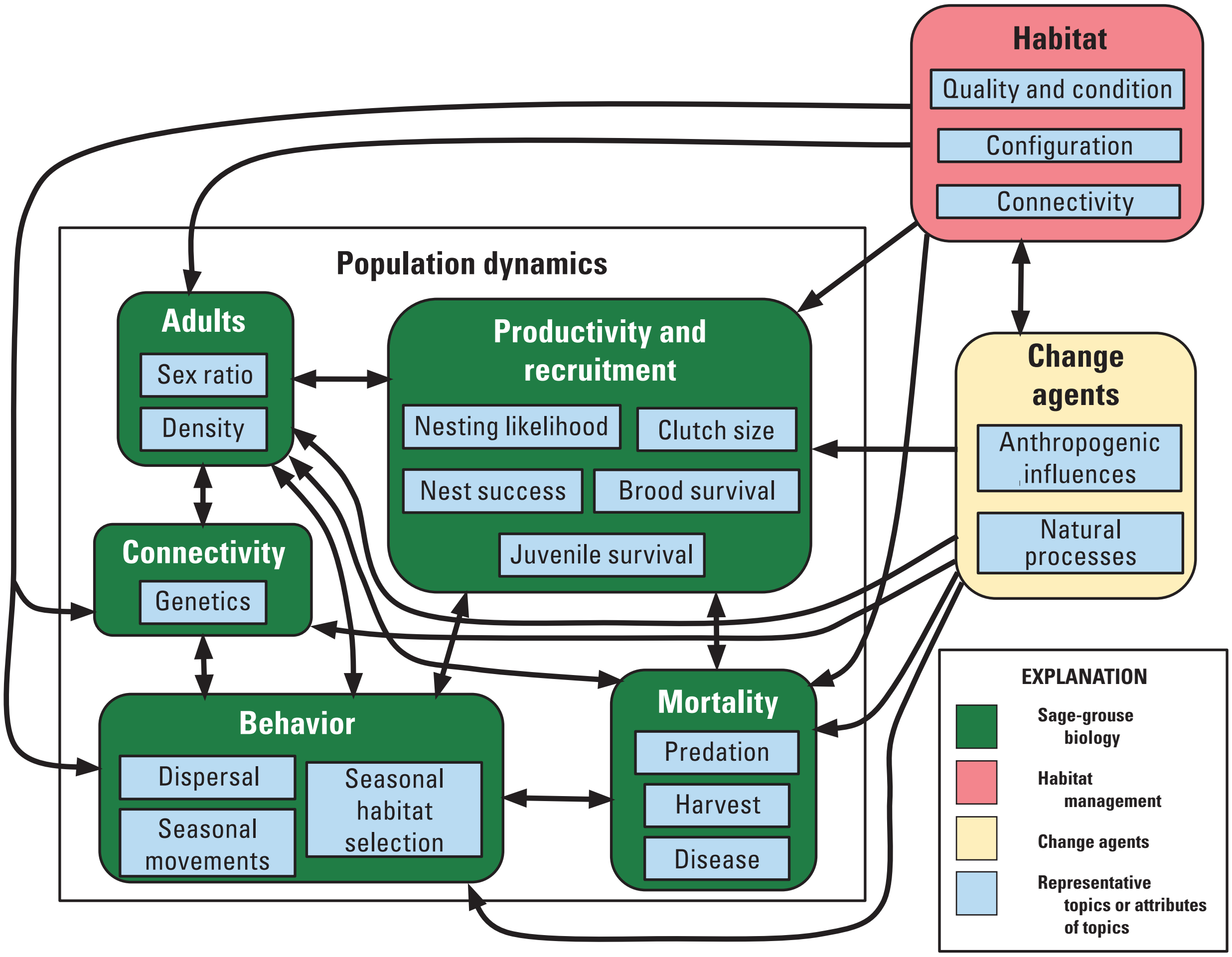

Figure 2. Conceptual model of research topics within the sage-grouse biology theme. Boxes represent research topics or representative attributes within a theme and arrows provide interactions between themes and topics.

population and habitat parameters that are used in population models also are valuable for numerous management and planning activities, such as habitat management, monitoring population dynamics, assessing reproductive success, and specifying the type and timing of mortality.

4.1.1.1 Demographics [H]

Sage-grouse populations have been counted and monitored for decades, yet variations in count methods, dynamic populations, including short- and long-term trends, and variability among populations and environmental covariates, have made regional assessments and population monitoring challenging (for example, Connelly and others, 2003, 2004; Dahlgren and others, 2010a, 2010b; Bruce and others, 2011; Fedy and Aldridge, 2011). Standardization of methods will help with some of the demands and requirements for data to assess changes in population demographics. Use of multivariate modeling and nonlinear equations in assessments may be necessary to clarify trends and identify relevant correlation and covariation.

4.1.1.2 Mortality [H]

Estimates of annual survival and seasonal mortality for different sage-grouse age and sex classes are important for understanding sage-grouse population dynamics. Experimental manipulation of environmental variables, such as habitat or predation, may help assess causal mechanisms for changes in these vital rates. Determining the actual cause of sage-grouse mortality can be extremely difficult, but understanding these patterns would help with population management. Quantitative estimates of mortality are needed in particular life stages (for example, chick mortality during early brood-rearing) to understand how variability in survival affects population growth. Survival during the interval known as "survival to recruitment" appears to be much more variable than adult survival (Moynahan and others, 2006, 2007; Sedinger and others, 2011; Blomberg and others, 2013; Nonne and others, in press).

Population management would benefit from an assessment relating sage-grouse mortality rates and the factors that influence them to the effectiveness of actions taken to reduce them, explicitly considering variation in survival due to age, sex, region, habitat type and condition, and specific management actions. Importantly, estimates of mortality rates would directly inform population models by focusing estimates across the full (multi-season) distribution of the target population and associated habitats. Refer to section 4.1.4, "Mortality Agents and Factors" for additional information about causal mechanisms.

4.1.1.3 Habitat Conditions and Change Agents [H]

Habitat research was not prioritized by the participants at the focus group meeting (table 1) because of the extensive research already done that addresses sage-grouse habitat use (Connelly and others, 2011a). However, ongoing efforts of land-management agencies suggest that additional understanding of ecosystem function and effects of habitat management on sagebrush ecosystems would be useful. A greater understanding of the relationship among disturbance cycles, natural recovery, including restoration and rehabilitation processes, the composition and productivity of vegetation, and site potentials could lead to improvements in habitat conservation and management. For population modeling, accounting of the distribution of quality seasonal habitats and the value of all available habitats, and particularly potential threats to those habitats, could provide a frame of reference for population viability estimates. Importantly, accounting for relations between seasonal habitat conditions and the population response in the same time period would establish connections between habitat quality and survival and discern net-negative population effects from compensatory effects (for example, high early season mortality may be offset by increased survival later in the season). In this context, an understanding of the effects of anthropogenic development and associated land uses on habitat quality, for projections and scenario assessments would support improvements in population models. Development of a spatially explicit population model incorporating current estimates of demography, with appropriate representation of spatial-temporal variation and movements, to evaluate the relative effects of changing land uses on sage-grouse populations would support management planning for all populations of sage-grouse.

4.1.1.3.1 Implications of Priority Areas for Conservation [H]

Because definitions and application of "priority-area" concepts vary by State, questions arise that could be addressed by comparison of strategies and effects on habitat conditions, sage-grouse behavior, and sage-grouse population dynamics. An assessment of the Wyoming Priority Areas indicated that those areas provide better protection for nesting locations than summer or winter locations (Fedy and others, 2012). Similar assessments within each State would help determine the effectiveness of a priority-area approach for conserving habitat necessary for resident sage-grouse populations. If conducted using similar methods, these State-based assessments could be used to identify implementations that have been most successful and help adapt the boundaries of priority areas to better meet conservation objectives.

4.1.1.3.2 Movement Patterns and Connectivity [H]

Connectivity among populations and subpopulations can have major influences on effective population size and is an important habitat consideration (for example, Wisdom and others, 2005a; Aldridge and others, 2008; Bush and others, 2011). Although some assessments of sage-grouse connectivity have been conducted (Knick and Hanser, 2011; Knick and others, 2013), habitat and population connectivity are poorly documented (for example, as evidenced in genetic similarity). Connectivity assessments can help delineate important habitats between (and beyond) priority areas and seasonal habitats, as well as provide information about metapopulation dynamics for use in conservation planning and management efforts. A detailed discussion is in section 4.1.2, "Connectivity."

4.1.1.4 Population Dynamics [M]

4.1.1.4.1 Reproduction [M]

Rate of reproduction is an important population factor. Nesting hens and young broods are sensitive to habitat conditions, disease, and weather events (Moynahan and others, 2006), and they are vulnerable to predation (Taylor and others, 2012). Further, because there is considerable variability in reproduction among sites and years (Taylor and others, 2012), monitoring of reproductive success and research involving questions about causal and correlative mechanisms would support modeling and assessments. For example, determining relationships among the conditions of the hen during the pre-laying period, chicks at hatching, and chick survival would improve models of habitat-hen-reproduction relationships. This relationship may be influenced by genetics or individual fitness, which highlights the utility of research that can discern the difference among multiple determinant factors. The predictive quality of models may improve by incorporating information about relationships among habitat conditions, environmental patterns (for example, weather) and population parameters, particularly pre-laying condition of females, chick survival, and brood-rearing success.

4.1.1.4.2 Juveniles [H]

Differentiation between causes and rates of juvenile sage-grouse mortality from other stages of development is necessary to inform estimations of production; these related variables have important effects on long-term population viability. Estimates developed on range-wide, regional, and local bases would provide information for multi-scale assessments. Developing a better understanding of survival rates, particularly for juveniles under different conditions, also is important for developing effective conservation actions (Blomberg and others, 2012a, 2013; Nonne and others, in press).

4.1.1.4.3 Productivity and Recruitment [M]

Productivity and recruitment are essential components for maintenance of sage-grouse populations at local, regional, and range-wide scales. Accurate and consistent estimation of these attributes, including variability in vital-rate estimates by age of individual, region, habitat conditions, weather, and predation pressure, feed into assessments and conservation planning. Because recruitment at the population level is an aggregate of multiple vital rates, it is important to understand the contributions of each component and life stage and the ecological factors that affect them.

4.1.1.4.4 Implications of Population Cycles [L]

Population cycles have been documented for sage-grouse but remain largely unexplained (Fedy and Doherty, 2011). Cyclical patterns in population numbers may affect interpretation of population trends and minimum viable population estimates. Identification of explanatory factors for cycling at the range-wide, regional, and local population levels would improve the overall understanding of long-term population processes and would help identify individual population drivers in the context of longer-term cycling. This information would improve models and assessments, including those describing population demographics.

4.1.1.4.5 Genetics Applications and Effective Population Size [H]

Application of genetic information would inform conservation decisions addressing population connectivity, isolation, adaptation, plasticity, dynamics, and effective size. The National Conservation Objectives Team report (U.S. Fish and Wildlife Service, 2013), among others, noted the absence of robust range-wide genetic analyses as a potential limitation on long-term sage-grouse conservation efforts. Several ongoing projects have begun to address these issues. Genetic information also would help with population-size estimation, including determination of minimum effective population size to avoid inbreeding depression, as well as estimation of the population size necessary to balance changes in population genetics caused by drift, mutation, or adaptation.

4.1.2 Connectivity [H]

Understanding connections between populations and subpopulations is important for management of the genetic diversity that helps maintain adaptive and evolutionary potential and avoids inbreeding depression and other genetic disorders. In addition, connectivity of habitats used by each population (or subpopulation) is related to the configuration and condition of seasonal habitat within the home range, as well as lands (habitats or corridors) that are used by sage-grouse during seasonal movements. Thus, the structure and condition of habitats within a population home range is important for the functional use and movement of individuals within that range. Functional connectivity occurs when individuals migrate to a neighboring population and breed. The genetic diversity of the species is maintained by distribution of genetic traits from one population to the other. In addition, small or peripheral subpopulations may act as intermittent population centers (sink populations) for years, but habitat dynamics, climate, land use, and (or) disease may result in these subpopulations acting as refugia, instead of sinks, in the future. Thus, maintaining metapopulation structure and connectivity is understood to be a component of long-term resilience (Gilpin and Hanski, 1991; Hanski, 1994). Research that simultaneously addresses population and habitat connectivity would inform management of habitat configuration and conditions and address circumstances that might influence sage-grouse movement behaviors. The results also would make explicit connections between conservation of genetic diversity, metapopulation structure and maintenance of peripheral subpopulations, and environmental factors that affect habitat use, such as land use and climate.

Connectivity patterns of sage-grouse have been examined with a focus on connections between neighboring breeding habitats (Knick and Hanser, 2011; Knick and others, 2013). These studies have added to our understanding of connectivity patterns, but further investigation of sage-grouse movement patterns, the habitat characteristics that are conducive or restrictive to those movements, and the genetic structure of populations will help inform management practices to improve or maintain connections.

4.1.2.1 Movement Patterns [M]

Sage-grouse are highly mobile and often require large areas to meet their annual habitat needs (Connelly and others, 2011b). Several important questions about sage-grouse movements remain despite the many studies that have been conducted assessing movement patterns using radio-tracking (for example, Berry and Eng, 1985; Aldridge and Brigham, 2002; Holloran and others, 2005; Gregg and others, 2007; Moss and others, 2010) and global-position-system marking (for example, Dzialak and others, 2012; Fedy and others, 2012). Identification of the causes of dispersal and variation in seasonal movement patterns, as well as the habitat conditions suitable for dispersal or seasonal movements, would improve sage-grouse habitat management and provide a context for assessing the importance of areas within the non-breeding portion of the annual cycle. Analysis of the condition of habitats used during dispersal and migration would help determine if these conditions differ from seasonal habitats. In addition, integrated studies that incorporate genetic similarity, habitat connectivity, and details of movement patterns would enhance understanding of metapopulation structure and effective population size.

4.1.2.2 Habitat [H]

Suitable habitat in the matrix between populations and seasonal ranges is necessary to facilitate movement and connectivity. Matrix habitat must provide essential requirements of food and cover, and ultimately facilitate health and connectivity of populations and subpopulations (for example, Wisdom and others, 2005a; Walker and others, 2007; Aldridge and others, 2008; Meinke and others, 2009; Tack and others, 2012). Several fundamental questions about sage-grouse habitat requirements remain despite extensive research involving many populations. Due to differences among populations and habitats in different regions (for example, sage-grouse management zones), it will be important to use data from different regions to answer these questions. These datasets may be available and questions could be addressed using meta-analyses; for questions where data are lacking, regional coordination would improve the effort to develop new data. Important questions that require habitat perspectives will inform research and management through integration with other methods, including requirements and interactions among habitat patch size, size and juxtaposition of seasonal and year-round habitats, habitat linkages important to movements and dispersal, and linkages between small and large populations (for example, Knick and others, 2013). Refer to section 4.2.2, “Connectivity,” for additional information regarding habitat connectivity.

4.1.2.3 Barriers and Inhospitable Conditions between Habitats [H]

Information about barriers to sage-grouse movements between populations and between seasonal habitats has come from studies of habitat selection (for example, Bruce and others, 2011; Fedy and others, 2012; Tack and others, 2012). Studies of genetic similarity (Bush and others, 2011) have provided some descriptions of suitable habitat conditions. However, habitat selection and movement are different processes. An individual sage-grouse may be able to move large distances and through undesirable habitat to reach distant habitats (for example, Fedy and others, 2012; Tack and others, 2012), yet it is not clear that this capability is consistently realized. Critical restrictions on seasonal movements, as when hens move broods from the nest site to late brood-rearing habitat, may affect annual population dynamics and connectivity among populations over long periods of time. An assessment of existing movement data collected using radio or global-position-system tracking technology may identify topographic, vegetative, or anthropogenic features avoided or preferred by sage-grouse while they move between seasonal habitats, migrate long distances, or generally disperse. This type of assessment also may help address questions related to habitat condition and sage-grouse use within designated “General Habitats.” Relating sage-grouse use to habitat conditions would help define and maintain migration habitats that support safe movement, forage for stopovers, and otherwise provide connections and intermediate habitats between “priority habitats.” Additionally, research could determine the minimum-distance threshold(s) between occupied subpopulations that effectively restrict(s) the movement of sage-grouse.

4.1.2.4 Genetic Evidence [H]

Genetic data can provide evidence for long-term and relatively recent patterns of gene flow following movement and reproductive success of sage-grouse between populations and subpopulations (Benedict and others, 2003; Connelly and others, 2004; Oyler-McCance and others, 2005; Bush and others, 2011). Genetic connectivity is necessary to avoid problems associated with isolation of genetically limited populations, such as inbreeding depression and bottleneck effects. This information is relevant to inform population viability estimates and conduct local population management, for example, conserving habitat connections to avoid isolation of small subpopulations within a management zone.

The basic question, “How are populations and subpopulations connected?” may be usefully asked at local, regional, and range-wide scales. Information about range-wide genetic and habitat connectivity, coupled with knowledge of dispersal dynamics, represented by individual movement patterns through a habitat matrix, would help clarify the causal mechanisms of behavioral responses to habitat conditions and provide meaningful interpretation of landscape connectivity. Related questions include, “What are important landscape features that influence gene-flow movements?” and “How do dispersed individuals and subpopulations relate across the matrix of habitat with other subpopulations?”

Several fundamental questions relate to application of genetic evidence to assess connectivity. These questions consider relations among physical connections between habitats, population movement, and dispersal, genetic change through drift, mutation, or adaptation, likelihood of a bottleneck (or similar, limiting effect) event, and how these factors could affect the long-term survival of the species.

4.1.3 Population Monitoring [H]

A long history of counting sage-grouse at leks has resulted in datasets that can vary by agency, region, population, and in other important ways. Comprehensive evaluation of the strengths and weaknesses of different protocols would help determine which datasets can be combined and effective ways of doing so. This evaluation could help identify standard protocols that could improve estimates of population parameters and reduce variability associated with methodological differences. Many population parameters are of interest to State and Federal wildlife managers because managers often focus on population responses (counts and trends) to manage habitat change and other potential effects. These parameters include female-to-male ratio for annual and regional comparisons; variation in lek attendance by age, time of day, time of year; relationships between lek attendance and peak timing of female nesting and potential relations among environmental drivers and population responses. Further, lek counts can provide an aggregated indication of population dynamics, yet understanding of the mechanistic impacts of habitat and disturbance factors and the life-stage specific responses requires other monitoring approaches. For example, reliance on data from lek counts presents major limitations for understanding mortality of juvenile sage-grouse in relation to extreme weather events or describing variation in nesting or brood-rearing success under changing land uses, such as energy developments. In addition, comparison and calibration of historical (sentinel site) designs with spatially explicit, representative designs would help define sage-grouse abundance and probability of habitat use, which would then increase the usefulness of historical and modern inventory efforts. Furthermore, investigation of the relation between historical survey designs (series of distributed sentinel, lek sites) and spatially explicit designs representing the entire population across seasons would help standardize and modernize population assessments.

4.1.3.1 Lek Counts [H]

Despite the limited portrayal of sage-grouse populations by lek counts (single sex, single season), these counts remain an indispensable component of research and monitoring for conservation. Lack of standard definitions of lek status and standard methods for conducting lek counts affects inferences across large regions and comparisons among populations (Beck and Braun, 1980; Walsh and others, 2004). Importantly, lek counts typically are used as an estimate of total population counts and, over time, an aggregated indicator of population trends. Estimates may be used for local and regional comparisons, impact studies (of development, for example) and local population management (hunting regulation, for example). Lek counts have not proven to be accurate for understanding regional or population-level differences in important population demographics, such as juvenile survival, because of count biases involving males and season of year. Difficulties with count standardization may arise from lack of endorsement and use of published methods rather than absence of the necessary protocols (Connelly and others, 2004), and differences in project objectives. Standardized methods and analytical approaches would include and explicitly address spatial patterns and temporal variability, while providing parameter estimates for population. Methods that increase statistical power to detect small changes in population size over short time spans would be useful. Beyond these methodological challenges, current uncertainty in lek counts suggests a need to better understand and account for variability in observations over time and the spatial representation of populations (Walsh and others, 2004). Clarity may come from comparison and evaluation of methods to identify the best approaches to effectively survey leks, given the variability in lek counts within a year and between years, to provide relevant numbers for long-term monitoring and annual planning. Similarly, it is important to determine the best methods for surveying lek complexes and (or) best methods for use in Before-After-Control-Impact (BACI) designs to assess development impacts. Advanced modeling and decision-support tools should work to provide projections of future conditions based on consistent, current estimates. For example, definition of the relationship between productivity in one year and the coefficient of variation in lek counts in the subsequent year, with consistent application, would guide both harvest rates and habitat protections.

The location of leks is another monitoring consideration. Not all sage-grouse leks have been located, and the majority of leks are not monitored on an annual basis. A standard approach for searching for new or previously unknown sage-grouse leks could be incorporated into revised sampling designs. Furthermore, not everyone agrees that the relationship between lek counts and true (male and female, multiple age-groups) population numbers is sufficiently understood. The correlation and time lag between the variation in annual sage-grouse productivity and subsequent lek counts affects the precision of population estimates, among other factors. Thus, dependence on lek counts perpetuates uncertainties about the relationship between lek attendance, population numbers, and population dynamics, including the previous years' productivity, rates of inter-lek movements by males, condition of males, climate fluctuations, and importantly, how these variations influence population estimates. For example, previous research demonstrated a significant effect of drought and habitat conditions (only partially correlated) on male attendance at leks (Blomberg and others, 2012a), and although these trends are presumed to mirror trends in the entire population, differentiation of mechanisms and effects on different population segments is not well documented.

Development of a probability-based, spatially balanced sample of breeding males and females would alleviate the limitations associated with non-random population sampling targeting known leks. Garton and others (2011) recommended integrating a wide survey across all habitats, systematic sampling of large leks, and intensive sampling at sentinel leks. This would require the development of a range-wide probabilistic sampling approach, which would lead to an evaluation of limitations associated with extrapolation and trend analysis from the current lek counts. Such an approach also would provide opportunities for more explicit treatment of biases based on location of leks, estimation of population and lek sizes, and development of statistical relationships between lek counts and independent estimates of population size. Ultimately, this could lead to a statistically informed sampling design that reduces the number of lek surveys required for robust population estimates. Further, clarification of the effects of development on lek attendance in comparison to nesting behavior, brood-rearing success, and juvenile survival would be useful for planning and mitigation of industrial activities, and would improve understanding of population dynamics. Thus, it would be beneficial to improve value and cost effectiveness of lek counts by improving connections between counts and population numbers and by accounting for variation in male and female attendance rates and seasonal and daily attendance rates among sampling approaches and among observers, habitats, regions, and topography. A statistically reliable trend-monitoring protocol for inventorying lek attendance of male sage-grouse also would be useful.

4.1.3.2 Demography [M]

As alluded to previously, development and standardization of accepted, common methods for population demographics that result in data necessary to address fundamental questions that cannot be addressed directly by lek counts, are needed. The important relations that need to be addressed surround direct and indirect connections between environmental variables (for example, surface disturbance, range condition, climate and weather events, and (or) predator populations) and population demographics. To estimate the needed parameters and relations, research projects need to use populations, and their entire (multi-season) range, as replicates to monitor the effects of changing conditions within seasonal range conditions on specific components of population demographics. For example, suitable projects would address differences among sage-grouse age distributions, seasonal mortality, nesting, and (or) productivity rates, due to land-use trends, habitat treatment effects, and related spatial patterns, such as habitat loss or fragmentation. Population estimation methods could be integrated with traditional lek-count surveys to provide the demographic resolution necessary to assess conditions within and between seasons and management units (for example, sage-grouse management zones). Further, the role of population and habitat relationships in other seasons needs to be investigated to assess density-dependent behaviors at different times of the year.

4.1.3.3 Sex Ratios [H]

Sex ratios have been estimated by State agencies with considerable variation in methods and estimates (Connelly and others, 2011b). Establishment of accurate sex ratios with fine spatial and temporal resolution is important for establishing population size when male-focused lek counts are used to estimate population size. Refinement of existing techniques, that is, traditional hunter-harvest-based assessments, and development of new techniques will improve estimates of sage-grouse sex ratios. Resolution of estimated sex ratios should be fine enough to differentiate sex ratios within individual populations. Promising genetic methods have been developed using DNA from fecal pellets (Baumgardt and others, 2013), but these need further testing and refinement for field application. For example, in order to avoid sex-bias, previous knowledge of the distribution of males and females of a population, in a given season, would need to guide the sampling design.

4.1.3.4 Genetics [H]

The most immediate uses for genetic information include an understanding of relationships with demographic patterns and population dynamics of sage-grouse, including sex ratios, male genetic contributions, dispersal, and other parameters that determine effective population size and viability. Although less immediate to population management, an understanding of the genetic connections to morphological, physiological, and behavioral differences among sage-grouse populations across the range will facilitate recognition and conservation of diversity. Continued development of methods and data could provide basic biological knowledge of genetic and phenological adaptations to local conditions, as well as practical applications for conserving genetic variation.

A better understanding of the effects of fragmentation, isolation, and landscape barriers on sage-grouse dispersal and population genetics is needed. Genetic methods, such as micro-differentiation of genetic segments using micro-satellites (Oyler-McCance and St. John, 2010; Bush and others, 2011; Gregory and others, 2012) or amplified polymorphic fragments (AFLP) for detecting short-term differentiation and drift (Veith and Schmitt, 2008) exist, but study designs and specific applications for analysis across landscapes are currently under development.

4.1.3.5 Brood and Juvenile Surveys [M]

Brood and juvenile surveys are not a common practice in the sage-grouse research or management community, yet an evaluation of effectiveness, efficiency, and accuracy of methods (such as Dahlgren and others, 2010b) could determine values of different approaches. Brood surveys provide an alternate method for collecting information that can be applied to the long-term monitoring of sage-grouse populations or to the identification of crucial habitat. Currently (2013), information about juvenile abundance is collected primarily through hunter-harvest surveys. Comparison of several methods for population monitoring would clarify methodological questions, such as how estimates from brood or juvenile surveys compare with lek counts and harvest surveys.

4.1.3.6 Isolated Populations [M]

Monitoring small, isolated sage-grouse populations is complicated by the availability and allocation of time and resources and because physical access to these populations can be difficult. Effective, efficient approaches for determining the demographic attributes of sage-grouse populations in isolated areas are lacking. Use of remotely controlled aircraft (drones) with heat-sensing imaging equipment (remote sensing) has been proposed, but use and methods are not currently established.

4.1.3.7 Pellet Counts [L]

Pellet counts may be an effective, non-invasive, spatially explicit, and temporally explicit method for estimating sage-grouse population numbers and use patterns (Dahlgren and other, 2006; Hanser and others, 2011; Schroeder and Vander Haegen, 2011). To investigate the potential for widespread implementation of pellet counts, core questions first need to be addressed to determine if pellet counts are an effective survey technique for sage-grouse abundance or for obtaining presence and absence information. It is also important to know how pellet-based approaches relate to other techniques.

4.1.3.8 Multiple Scale Relationship and Inference [H]

Development of consistent and representative data for input to models assessing relationships between key demographic parameters and environmental variables (for example, vegetation characteristics, habitat configuration, topography, biogeography, and predator distributions) is important for bridging the gap between large-scale population and habitat monitoring and detailed demographic studies. Even coarse estimates of population trends and cycles, if related to regional patterns of land use, climate, and other anthropogenic factors will support planning and encourage actions to offset any negative trends. The analytical methods exist (Blomberg and others, 2012a; 2013), but widespread application to sage-grouse has not occurred.

Successful inventory and monitoring methods will likely require implementation of an integrated remote-sensing and field-based sampling design focused on habitat and sage-grouse demographics. The design could be used to simultaneously assess individual populations and local and regional habitat conditions, followed by statistical modeling to develop and define relationships, indices, and interpretations.

4.1.4 Mortality Agents and Factors [H]

Distinguishing causes of mortality, in general, is ranked high as a priority, and State wildlife biologists who are responsible for addressing predation, harvest, and other mortality agents expressed the strongest interest in these topics. Priority issues within this topic are indicative of concerns about interactions of multiple factors, such as interactions between infrastructure and predator distributions, or effects of over-grazing on vegetative cover and nesting success. Seasonal, life-history stage, and habitat-specific mortality effects are used to inform population models and assessments of habitat condition.

4.1.4.1 Sources, Rates, and Influences [M]

Research often focuses on specific sources of mortality independently. Comprehensive assessments of mortality sources that collectively evaluate the effects of predation, insecticides, disease, and other sources of mortality on sage-grouse populations could help identify interactions among mortality sources. Explicit consideration and differentiation of the causes of mortality in different sage-grouse age and sex classes, and the consequences of mortality for population dynamics would inform management. One possibility is to establish correlations between mortality rates and environmental variables. Brood-rearing and juvenile stages are the most important starting point for this research.

4.1.4.2 Predation [M]

4.1.4.2.1 Interactions with Habitat Condition [M]

Management could benefit from better information about predation rates in relation to local and landscape-scale habitat variables. This work could increase the understanding of relationships among habitat structure, population dynamics of sage-grouse, and the predator community within an area (Coates and Delehanty, 2010). It has been suggested that sufficient growth (height, cover, or both) of grasses is required to provide sufficient cover to protect sage-grouse nests and young broods (Sveum and others, 1998a, 1998b; Baxter and others, 2009). Standardization of methods to provide consistent estimates of habitat conditions associated with predation events would help clarify this relation and reduce emphasis on factors that are less important, as well as reduce variability between studies caused by differences in methods and analytical processes. Knowledge about specific predator-habitat associations would help develop future management practices (that is, adaptive management) by identifying features that increase or reduce predation risk, thereby enabling promotion or avoidance of specific practices or patterns. Thus, general knowledge about predation relations is less important than improved understanding of specific relations between infrastructure types and patterns that can be applied in development planning.

4.1.4.2.2 Interactions with Infrastructure [H]

Evaluations of habitat-predation relationships should include the effects of infrastructure, powerlines, roads, and fences on sage-grouse populations. Specifically, to support planning and mitigation, documentation of the incidence and extent of avian predation on sage-grouse nest success, and juvenile and adult survival in areas with and without extensive infrastructure are needed for comparison. Research could document a change in the abundance and distribution of predator populations in relation to changing infrastructure, thereby helping to establish direct and indirect effects-distances (or areas) that can be applied during development planning and in general land-use plans. Application of BACI designs would be useful for demonstrating effects of the infrastructure development. This research also would help elucidate the extent that human-subsidized predators limit individual sage-grouse vital rates and overall population growth. In most cases, these topics have been mentioned, but not assessed.

4.1.4.2.3 Control Effects [M]

Predator control remains a tool for population management in some States; however, the effects of these efforts often are contested and debated (for example, Schroeder and Baydack, 2001; Mezquida and others, 2006). Discrimination of sources and rates of predation by different species would help determine background rates, target concerns, and provide comparative measures of effects. The effectiveness of various predator-control measures, as indicated by positive response in sage-grouse numbers, is an important topic (but see Hagen, 2011b). In addition to measuring the population response of sage-grouse in relation to control efforts, the population response of predator species is needed to recognize compensatory reproductive and behavioral responses that would reduce effectiveness. Further cost-benefit analyses could be used to help inform practicality and effectiveness of predator-control actions.

4.1.4.3 Harvest [M]

Although there is limited evidence of the influence of harvest on sage-grouse population viability, harvest's on-going role and recurrence in management, policy, and public opinion suggests that a collaborative range-wide assessment of harvest effects is needed. This type of assessment could address demographic and population responses to harvest using different bag limits and seasonal timing, issues of additive versus compensatory mortality (when, where, and why mortality occurs), and changes caused by habitat, weather, and management actions.

4.1.5 Population Dynamics [M]

4.1.5.1 Demography [H]

Information about demographic rates as they relate to population growth and effects of habitat loss and fragmentation would inform many aspects of sage-grouse conservation. Accurate estimates of the demographic parameters and population dynamics of sage-grouse, including nesting likelihood, nest success, clutch size, renesting likelihood, renesting success, hatchability, sex ratios, overall productivity, density-dependent effects, male genetic contribution per generation, dispersal, seasonal mortality, and other parameters would be informative to help assess management outcomes, as well as determine effective population size and transitions within populations that affect viability. Further, standardized methods for estimating demographic parameters, coupled with capabilities for resolution across multiple years and seasons, would inform interpopulation comparisons and enable regional assessments. For some traits for which good estimates exists (for example, nest success), a reassessment of the data using modern statistical methods may be needed to overcome limitations caused by outdated methods and potential bias before the results are used to analyze sage-grouse population dynamics.

In the process of developing standardized methods, comparative analysis of existing techniques would inform translation across management units and may facilitate incorporation of historical data. For example, WAFWA's conservation strategy (2006) suggested a sensitivity and elasticity analysis for demographic parameters, which may be used to discern the best (consistent, representative) indicators of population conditions. A better understanding of contributions of demographic components needed for accurate estimation of sage-grouse population growth also would provide a better understanding of the causal factors contributing to long-term declines. But this requires an understanding of how the different parameters associated with productivity compare across regions and management units (for example, sage-grouse management zones or priority areas).

4.1.5.2 Reproduction [M]

Improving estimation of parameters of reproductive success, such as nesting success and survival rates of chicks and juveniles, will improve population models by differentiating timing and causes of reproductive success or failure. Development of spatially explicit empirical models of the connections between environmental patterns, such as habitat productivity, and reproductive parameters, such as pre-nesting condition of hens and nesting success, would provide the ability to map predicted reproductive success. Resulting population models would inform local management of population trends, which rely on timely reporting of population growth rates to establish annual sage-grouse harvest quotas and to develop plans for range management.

4.1.5.3 Productivity and Recruitment [H]

Experts clearly identified the need for accurate measures of recruitment in relation to conditions in nesting and early brood-rearing habitats, particularly for developing management recommendations to support these life stages. Life-history events leading to recruitment, including female nesting tendencies and post-fledging survival, are poorly understood. Although counting males is the most common technique and may be perceived to be the most direct way of attaining estimates of recruitment, a lack of understanding regarding the connections between this estimate and other critical life stages and demographic components make lek counts inadequate and emphasize the value of testing more comprehensive methods (for example, Blomberg and others, 2012a).

Definition and interpretation of factors that regulate chick survival are important for improving monitoring methods to determine chick-survival rates and mortality factors. These improvements in methods and resulting data could aid future comparisons of adult and brood conditions between multiple populations. Assessments examining the role of habitat components and conditions, as well as climate and predation effects, can lead to a better understanding of year-to-year variability in chick-survival and mortality factors. For example, determination of relationships between condition of the hen and the weight of chicks at hatching and relations between brood-rearing habitat condition and chick survival may facilitate adaptations in habitat management.

Slow maturation and low reproductive rates are characteristic of sage-grouse populations (Johnson and Braun, 1999; Beck and others, 2006). Consequently, mortality of juvenile sage-grouse can have a major influence on population productivity and stability. Understanding juvenile survival rates under different conditions is important to develop effective conservation actions because these young birds represent the reproductive potential of the population into the near future.

Understanding the variability in productivity and recruitment in relation to different populations, regions, habitat conditions, weather, predation pressures, and management strategies is important for the development of robust population models. This variability can be explored using various empirical approaches, including spatially explicit models (Guttery and others, 2013). Because recruitment at the population level is an aggregate of multiple vital rates, it is important to understand the contributions of each component and the ecological factors that affect them.

4.1.5.4 Isolated Populations [M]

Small, isolated populations may be as important as large ones to allow for climate-driven habitat shifts and range expansions. They also may be important for maintaining meta-population structure, genetic diversity, and population refugia, but they also may be less accessible than large populations or present other challenges for research and monitoring. Important considerations about meta-population structure, gene-flow, and population viability may surround these populations, and the populations' size and isolation may introduce genetic limitations. These populations also may harbor genetic adaptations allowing them to persist in environmental conditions otherwise not suitable for sage-grouse in the main populations. Size and isolation may present conservation challenges, but these populations also offer valuable opportunities to assess effects of population size on population viability. To help with time and efficiency issues, it would be advantageous to improve the effectiveness of approaches to measure and monitor small, isolated populations with limited access (for example, through remote techniques such as remotely controlled aircraft).

4.1.6 Behavior [M]

Sage-grouse behaviors hold the key to understanding selection and use of habitats, population growth rates, mortality rates, distribution, adaptation, and a multitude of factors that are potentially useful for sage-grouse conservation. Studies that facilitate interpretation of behavior, such as food habits, characteristics and causes of dispersal and migration, seasonal site fidelity, as well as differences in these factors due to sex, age, and region, would inform research and management strategies. Development of behavioral data and integrated interpretations would inform demographic estimates, habitat associations, and population models.

4.1.6.1 Dispersal [H]

Sage-grouse dispersal is a largely unknown process. An understanding of the dispersal mechanism and factors contributing to dispersal rate and distance will improve predictions of population connectivity and habitat use. Understanding natal dispersal and how that process affects spatial structuring of populations also is important, along with knowledge of habitats and features that act as barriers to dispersal and how distance between habitats restricts movement of dispersing sage-grouse. These assessments will be challenging due to the low rates of sage-grouse dispersal. Coordination of multiple studies would achieve sample sizes needed for statistically robust analyses (for example, Fedy and others, 2012).

4.1.6.2 Seasonal Movement Patterns [M]

Sage-grouse populations and subpopulations have different movement patterns and may travel long distances along migration routes between season habitats (Fedy and others, 2012). These movement patterns involve various strategies, including one- or two-stage migratory movements (for example, use of different areas for breeding, summer, and winter), or non-migratory behavior (that is, year-round use of same area; Connelly and others, 2011a). An understanding of how these movement patterns vary by sex, age, region, habitat, landscape, and weather may lead to focused actions to address or avert problems, such as targeted conservation and management projects to improve degraded seasonal habitats or to consider locations of infrastructure.

4.1.6.3 Seasonal Habitat Selection [M]

Sage-grouse use various habitats throughout their annual cycle. Identification of population and season-specific habitats is required for an accurate understanding of each population. Regional analyses help define important relationships between sage-grouse and habitat conditions, but local adaptations, conditions, and history may affect populations differently. Therefore, accurate information about seasonal habitat selection relies on explicit information about connections between habitat associates and local population dynamics.

4.1.7 Food [M]

Interactive effects of climate and land use, including habitat distributions, application of pesticides and herbicides, timing of brood-rearing, vegetation emergence, vegetation flowering, and invertebrate-prey emergence may be interrupted under plausible future scenarios. Current management practices, for example grazing, may influence food availability for broods, but these effects are poorly understood. An understanding of spatial-temporal climate relationships of key forage species, particularly plants, would support assessment of the sensitivity of sage-grouse food availability to potential future conditions. Monitoring insect availability, abundance, and diversity within specific sites to gain an understanding of the species, timing, and locations important to sage-grouse would improve estimation of sage-grouse response to future scenarios.

4.1.8 Adaptation [L]

Questions related to sage-grouse adaptations are low priority, although potential adaptive differences among sage-grouse populations, including adaptation to different and rapidly changing environmental conditions, can affect population viability through population-habitat relationships. Estimates of long-term viability are fraught with inaccuracies due to difficulties projecting future conditions, but fundamentally, the ability of sage-grouse to adapt to environmental variability will orchestrate population responses. Considerable understanding of the genetic variability and phenological plasticity of sage-grouse with respect to environmental patterns would be needed to address adaptation questions.

4.1.9 Translocation [L]

Translocations have been attempted to re-invigorate isolated sage-grouse populations throughout their range with little success (Reese and Connelly, 1997), although, a few efforts have shown promising results when the habitat and management conditions were conducive to reestablishment (Bell and George, 2012; Schroeder and others, 2012). Continued research associated with translocations is a low priority. If the priority changed, protocols would be needed to outline conditions appropriate for translocations, and agreement would be needed about what constitutes success of a project prior to implementation. The genetic adaptability of individuals to local environmental characteristics may influence the effectiveness of augmenting existing populations with birds from different populations (Oyler-McCance and Quinn, 2011). Monitoring to identify populations that are sufficiently robust to allow trapping of birds for transplant would be needed to determine suitable source populations.

4.2 Habitat Management

The complex dynamics of sagebrush ecosystems present a significant challenge to conservation and recovery of systems that support sage-grouse populations (table 4; fig. 3). Conservation of well-functioning sagebrush ecosystems and recovery of degraded ecosystems to functional condition are important to maintain sage-grouse, but variability in regional conditions and land-use histories, coupled with diverse management strategies, suggest that comprehensive and consistent understanding of what constitutes a "well-functioning" sagebrush ecosystem would benefit from further research. Landscape-scale conservation requires an understanding of the habitat patterns and ecosystem processes that support the targeted habitat conditions. However, consistent descriptions of target conditions have been elusive. Defining the targeted habitat conditions involves knowing key relationships between sage-grouse health and habitat use, habitat conditions and configurations, and the processes inherent to well-functioning sagebrush ecosystems. Although some research and development may be directly tied to sage-grouse population responses to habitat conditions and management techniques, research into the basic processes and functions of these semi-arid shrublands is identified as a critical need for management agencies that rely on managing habitat for species conservation.

4.2.1 Maintenance, Rehabilitation, and Restoration [H]

The fundamental ecological processes of functioning ecosystems and management practices that affect these processes, such as grazing, burning, mowing, and others, can determine habitat conditions, and are therefore important considerations for land managers and land-use planners. Ecosystem functions, such as the productivity of vegetation types that provide high-quality food and cover, are directly associated with habitat quality and the near-term health and productivity of wildlife inhabitants, as well as long-term conservation of habitat and species. Managers would benefit from guidance and better understanding of the basic processes and functions that create desirable sage-grouse habitat conditions in order to accurately anticipate the effects of policies and actions. Evaluation of potential pathways and transitions between ecosystem and habitat conditions can lead to pro-active steps to minimize impacts, potentially negating the need for restoration or mitigation. This evaluation also can inform planning and implementation of modifications, such as active and passive restoration projects, control of invasive species, and mitigation of fire effects. The underpinning of successful habitat management is a sound, mechanistic understanding of patterns and processes inherent to a well-functioning sagebrush ecosystem so that these processes can be addressed, and even used, to meet management targets.

Table 4. Research topics in the habitat management theme and priority designations (low [L], medium [M], or high [H]) based on input from a focus group of representatives from Federal and State agencies.

Topic	Priority designation	Topic No.
Maintenance, Rehabilitation, and Restoration	H	4.2.1
Mitigation	H	4.2.1.1
Effectiveness	H	4.2.1.2
Methods	M	4.2.1.3
Connectivity	H	4.2.2
Priority Areas for Conservation	H	4.2.2.1
Habitat Selection	H	4.2.3
Habitat Quality and Vegetation-Population Linkages	M	4.2.3.1
Genetic Evidence and Tools	H	4.2.3.2
Habitat Condition	H	4.2.4
Understory Vegetation	H	4.2.4.1
Multi-Scale Condition (Monitoring and Research)	H	4.2.4.2
Habitat Quality and Population Response	H	4.2.4.2.1
Variability	M	4.2.4.2.2
Surface Water	L	4.2.4.3
Soils	L	4.2.5
Other Wildlife	L	4.2.6
Restoration and Mitigation Effects	M	4.2.6.1

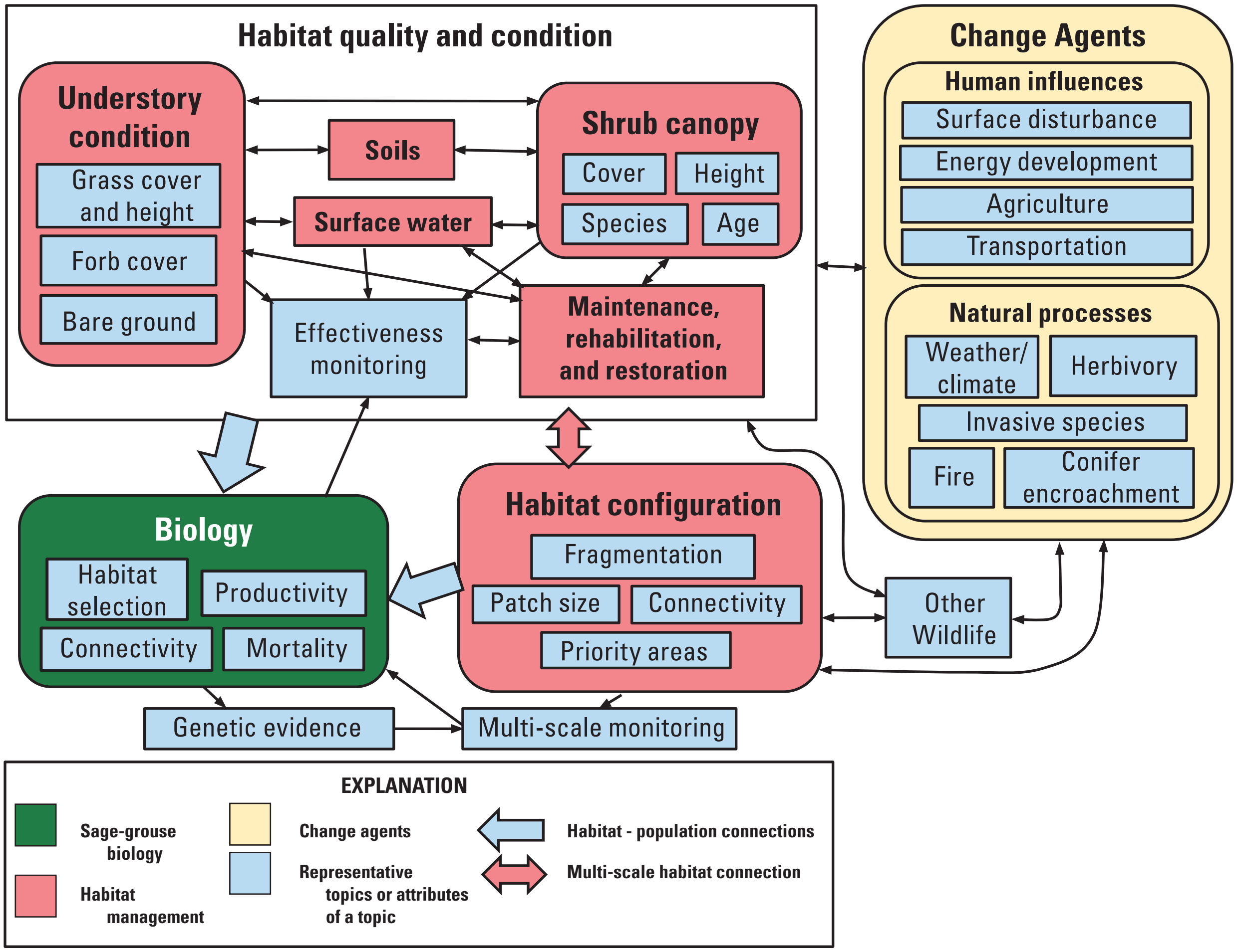

Figure 3. Connections between research topics and components within the habitat management theme. Boxes represent research topics or important attributes within a theme and arrows provide interactions between themes and topics.

Information about patterns and processes inherent to sagebrush ecosystem function enables successful management, including restoration, of disturbed sagebrush habitats. Restoration science can be likened to aiming at a moving target because the work often occurs in changing combinations of land use, disturbance history, recovery rates, and climate, and where the restored landscape typically is different from the pre-disturbance landscape. Dynamic environmental systems will require perspectives on resistance, resilience, and flexibility of native ecosystems. Analyzing restoration practices in this context can inform site-level choices and activities. In addition, landscape-level prioritization to guide investment and implementation would help determine locations for restoration or mitigation.

Many managers have stated preferences to retain and protect as much intact sagebrush habitat as possible. This goal may not be consistent with all landscapes inhabited by sage-grouse, many of which are currently designated for multiple use, but it also is unlikely that attempting to protect these communities and landscapes from large, intense disturbances, such as wildfire, will successfully preserve and protect ecosystem function and health (fig. 3). For example, a BLM goal for habitat management for sage-grouse specifies an optimal ratio of 70 to 30 percent, mature to early-phase, sagebrush communities (National Technical Team, 2011). Following from this goal, managers are implementing landscape-scale plans that address the pattern and distribution of habitats. Important perspectives and applications may be developed to assist planning to meet this goal and help balance the distribution of disturbed, restored, and intact sagebrush communities across large regions, such as core areas and priority-habitat designations. It also would be prudent to determine attainability of this specified ratio of habitats and its effectiveness for maintaining sage-grouse populations. Based on recognized requirements of sage-grouse, habitats available now may be recognized as currently suitable (good to excellent condition), impacted with strong potential for recovery using “passive restoration,” or impacted with limitations due to condition of vegetation or soils to such an extent that “active restoration” may be required (also see Pyke 2011; Manier and others, 2013).

Understanding of ecosystem functions, resistance and resilience to disturbances (Brooks and Chambers, 2010), and pathways for recovery of desired conditions remain poorly developed and irregularly applied when it comes to restoration, rehabilitation, and mitigation practices. Further, these properties become more confounded when considered across vast, heterogeneous target regions. An improved understanding of relations between “natural” processes, such as fire, drought, and habitat conditions, can elucidate the essential ecological processes and patterns that characterize successful recovery trajectories. Because environmental conditions and disturbance histories vary across the landscape, widespread documentation of applications, along with integrated analysis of restoration practices, succession rates, recovery rates, and environmental covariates would to provide an understanding of processes and influences to guide successful implementation. Implementation of successful management practices at landscape scales, while prioritizing the protection of existing sagebrush communities and rehabilitation of degraded areas by minimizing sagebrush removal and maximizing sagebrush recovery, could benefit sage-grouse populations. Notably, the efficacy of “priority-area” concepts for protecting all or a portion of seasonal habitats and stabilizing population trends within designated priority areas was identified as important research need.

4.2.1.1 Mitigation [H]

Mitigation planning is closely aligned with efforts to prioritize the landscape for conservation because a fundamental component of the planning process is identification of places that have value but need protection. Agreement on the currency for mitigation, which could be defined in various ways, is important. Currency could be economically based in the form of funds expended or management based and measured as acres treated. A sage-grouse-oriented currency, such as number of sage-grouse per unit area, most directly links to sage-grouse conservation. Evaluation and prioritization of target landscapes for mitigation also is important, and includes definition of anticipated benefits to wildlife and evaluation of the suitability of mitigation as a means of providing usable and used habitats. Investing in restoration to repair or otherwise manipulate patterns of use by wildlife assumes that project success will include renewed animal activity. This may not be a valid assumption. Thus, at regional scales, research that examines efficacy of recommended mitigation could help avoid, minimize, or reduce the effects of surface-disturbing activities on-site, or replace or enhance suitable habitat off-site. An understanding of the effectiveness of rehabilitating or restoring sage-grouse habitat would help determine if off-site mitigation is a viable option, because if restoration of sites to conditions useful for sage-grouse is not possible (for near-term benefits) then mitigation procedures might warrant reevaluation.

4.2.1.2 Effectiveness [H]

Evaluation of the effects of historical and modern habitat treatments on current habitat conditions, use by sage-grouse, or value to sage-grouse may be key for improving management practices and refining treatment techniques. Effects of management actions and related disturbances, including prescribed fires, wildfires, invasive-plant control, juniper (*Juniperus* spp.) removal, mowing, plowing, seeding, chaining, and other forms of sagebrush reduction are best evaluated based on current conditions (to describe need) and value of previous treatments (to indicate probability of success). These evaluations are most effective when they include different habitat treatments, consider different potential roles and values of treatments, and include assessment of the response by sage-grouse. In addition, comparison of different methods and applications, for example, the effects of passive versus active restoration techniques, could demonstrate and differentiate restoration approaches for degraded sagebrush range and help inform state-transition models, which then could guide future work. Further, discrepancies in restoration condition, restoration rate, and “release” of sites (from lease bonds and use restrictions) when compared to historical, pre-existing, or other defined target conditions need documentation. Without a systematic and thorough approach to these issues, effects of historical treatments, effects of development and reclamation, and effects of planned activities cannot be accurately assessed. Furthermore, establishment of common sampling, methods, protocols, and metrics for monitoring effectiveness of restoration treatments at local, regional, and range-wide scales would benefit application and interpretation of the role and habitat values of treatments.

4.2.1.3 Methods [M]

Development and refinement of existing methods for restoration of habitat are ongoing tasks for managers. Empirical data will help distinguish effects and effectiveness of different restoration methods in different environmental circumstances. A comprehensive assessment of past management practices and policies can aid in the identification of those that have had long-term success maintaining or recovering the sagebrush community and sage-grouse habitats. For example, when assessing practices and policies successful in recovering sagebrush habitat, it is important to establish the time frame necessary to achieve an objective. Another consideration is what techniques are effective for improving herbaceous diversity and density, including the forb component, in previously degraded or restored habitats.

4.2.2 Connectivity [H]

Physical proximity, juxtaposition, and suitability of habitats for safe movements (that is, structural connectivity) are important considerations for sage-grouse management because sage-grouse are a widely ranging species and their habitat is fragmented by land uses and infrastructure. Maintenance or restoration of habitat conditions that support safe movements of individuals between seasonal habitats are vital for population viability. Further, connectivity among populations and subpopulations is important for maintaining genetic diversity. Improvements in habitat connectivity are one way that managers can directly affect the ability of individuals to move and populations to mix. Knowledge of habitat components that facilitate or limit connectivity between populations and among seasonal habitats within populations is important, as this will inform what constitutes a connected landscape.

Connectivity has been identified as an important aspect of conservation for research and development. Although connections between landscape configuration and wildlife health and vitality exist (Saunders and others, 1991; Ryan and others, 1998; Bennett, 1999), tests of the ability of restored habitats to support sage-grouse population connectivity through dispersal and migration are lacking. It is not clear what value corridors and habitat islands have for connecting sage-grouse populations but maintaining connectivity between seasonal habitats has been deemed essential (Fedy and others, 2012). Importantly, how habitat characteristics, environmental patterns, and related circumstances interact to affect sage-grouse behavior (use of those habitats) may be useful for predicting valuable locations for restoration. Identification and evaluation of connectivity linkages to document importance to sage-grouse movements and dispersal are common local and regional priorities, and connections between small populations and large populations are of particular concern. Once identified, prioritization of “intact” existing habitats, large areas, connected networks and connective habitats and relationships to population connectivity, dispersal, and migration can inform conservation and mitigation planning.

Connectivity analyses examine connections between components and can be used to examine relationships between sage-grouse and their habitat. Important habitat components include landscape parameters that represent patterns of use (for example, minimum sufficient habitat patch size) and avoidance (for example, surface disturbance). Knowledge of these components can help guide assessments of migration, other forms of movement, and the habitats involved (Barrows, 2011; Fedy and others, 2012; Tack and others, 2012). For any given population, identification of the areas needed to meet minimum habitat requirements (that is, conditions suitable for persistence of the species) to support year-round habitat needs also can be used to assess probable and plausible travel routes between those habitats (Knick and others, 2013).

Many of the questions in this topic relating to relative importance of habitat patterns, conditions, and connections may be addressed by combining telemetry data with land-cover and land-use data to characterize selection of habitats for movement, lingering, and residence. Land managers, faced with orchestrating the trade-offs among multiple mandated uses, are interested in understanding the difference or relative importance between improved connectivity of habitats or subpopulations and increased habitat area. A common consideration is whether configuration is more important that total area. Other considerations include requirements for the minimum habitat area, the maximum distance of travel, the effects of habitat condition within migration habitats, the extent that populations were connected before recent land-use changes, and site fidelity or plasticity in habitat selection by sage-grouse. Addressing these questions requires an empirical model-driven approach using spatially explicit behavioral, genetic, and habitat-condition data for comparison of different populations and scenarios.

4.2.2.1 Priority Areas for Conservation [H]

Additional information is desired about the condition and importance of habitat features necessary for maintaining connectivity within and among populations protected by priority-area designations and those outside of those delineations. The condition and configuration of habitat patches within priority areas, and the relation of these habitats with configurations and conditions outside the priority (protected) areas are essential attributes of these areas that need further study. Priority area designations represent, from one perspective, very-large-scale adaptive management experiments, and understanding the details of conditions that will affect connectivity between these areas and those effects on local sage-grouse populations and regional conservation efforts is essential for informing revisions of designations and future implementations.

4.2.3 Habitat Selection [H]

Sage-grouse habitat selection has been studied throughout the range of the species on a local and regional scale. Although many consistencies can be seen across the range, there are sufficient differences in vegetation characteristics and available habitats to make inferences across populations difficult. Recent studies have addressed the underlying consistencies in animal-habitat relationships using modeling approaches to identify habitat characteristics that vary least within breeding habitats, and thus, infer a set of essential requirements (Knick and others, 2013). Other studies have used empirical models to describe habitat selection on a seasonal basis in Wyoming (Fedy and others, written comm.). These empirical models, informed by data from across the range, would improve understanding of habitat selection by sage-grouse and help with the prioritization and management of sage-grouse habitats. Further, condition of selected patches is best assessed in conjunction with pattern and juxtaposition of available habitat patches, along with local conditions, to improve understanding of interactions between multiple scales of selection.

4.2.3.1 Habitat Quality and Vegetation-Population Linkages [M]

Models linking sage-grouse demographic processes to the underlying causal mechanisms are the next step beyond empirical models of habitat-selection patterns. These include models of bird health in relation to habitat parameters, including habitat condition, quality, and configuration. Uncertainties to be addressed include (1) which sagebrush taxa are being used by various sage-grouse populations and for what purposes during each season, (2) how do habitat patterns relate to nutritional quality and bird body condition, and (3) what are the differences in habitat selection associated with sex, age, season, management, region, weather, breeding success, and survival. For example, in Idaho, recent results indicate sage-grouse use plant chemistry as a criteria for habitat selection (Frye and other, 2013). These analyses could help identify causal relationships, and if conducted in a multiple-scale, spatially explicit context, these analyses may better inform planning and management than contexts that simply address correlative patterns. Linking the structure and spatial organization of vegetation communities and demographic rates can inform planning and targeted habitat management.

4.2.3.2 Genetic Evidence and Tools [H]

Advances in the identification of fine-scale genetic markers will improve studies of genetic links to behavior and sage-grouse population responses to management actions. This emerging field of study has begun to investigate sage-grouse related questions and is appropriate for multiple lines of inquiry. It could be used to study possible linkages between genetic traits and dispersal patterns or between genetic traits and different degrees of habitat fragmentation or other management actions. Genetic studies also could reveal the relative influence of different habitat features on genetic differences, the conditions and patterns that encourage or inhibit gene flow, and any possible seasonal or regional variations in these conditions and patterns.

4.2.4 Habitat Condition [H]

4.2.4.1 Understory Vegetation [H]

Although an abundance of sagebrush is consistently recognized as an important, defining characteristic of healthy sage-grouse habitats, a healthy herbaceous understory also is an important component of quality habitat, and this resource base is both dynamic and readily affected by natural and anthropogenic processes. The importance of herbaceous vegetation to habitat selection and nesting success has been documented (Watters and others, 2002; Holloran and others, 2005; Beck and others, 2009; Hess and Beck, 2012a; Kirol and others, 2012), but regional assessments and specific guidance for providing herbaceous vegetation as habitat are typically lacking. Limitations of remote sensing using satellite or airborne platforms have led to regional habitat-condition assessments focused on measures of habitat condition or ecological communities' classifications that are coarse scale and based on overstory vegetation (for example, U.S. Geological Survey, 2008, 2011; Homer and others, 2009). As a result, few studies have examined the regional effects of the condition of understory vegetation on sage-grouse habitat quality. In addition to assessments of understory conditions, additional work to determine the causes of suppressed herbaceous understory (for example, soil condition, grazing management, and drought) would help identify and implement appropriate methods for improving understory conditions.

4.2.4.2 Multi-Scale Condition (Monitoring and Research) [H]

Long-term assessments of habitat condition at multiple spatial scales occur with coordination of survey efforts across the sage-grouse range. Landscape-scale habitat monitoring currently (2013) is being conducted by programs such as the NRCS, National Rangeland Inventory project (NRI) and BLM, Assessment, Inventory and Monitoring project (AIM). Evaluation of monitoring methods used in these programs would help determine their applicability for monitoring sage-grouse habitat conditions at multiple spatial scales. Generally, these programs may be used to form the core methods for integrated, range-wide monitoring, but there are important questions about applicability. Clearly, the way these monitoring schemes are implemented across multiple jurisdictions and multiple time periods affects their usefulness for assessing range-wide habitat conditions. Linking multiple spatial scales and traversing the spectrum of existing habitat-monitoring schemes can help identify the best sampling strategies. Aggregation of site-level estimates up to regional and range-wide scales also may be desirable for integrated, multiple-scale evaluations. Ultimately, methods and sampling designs necessary to link habitat conditions and land-use patterns to sage-grouse behavior, distributions, and demographics could inform monitoring designs and help bridge the gap between questions addressed by short- and long-term research.

Development of a universal method and process for evaluating and monitoring short- and long-term changes in habitat conditions at a range-wide scale is needed. Research could help identify methods and data sources for repeatable mapping of land cover, species-specific canopy cover of sagebrush, age distribution of sagebrush, and herbaceous understory of sagebrush habitats. A range-wide evaluation of the herbaceous understory component of sage-grouse habitats based on remote sensing has been limited by the availability of suitable technology and image products, but approaches that link remote sensing with field assessment could support range-wide measurement and monitoring of landscape-scale habitat characteristics with good accuracy for most components (Homer and others, 2012). The repeatability of the methods is vital, and rapid updates of products are necessary to detect short-term changes in habitat condition.

4.2.4.2.1 Habitat Quality and Population Response [H]

As is the case for other topics, useful interpretation of habitat conditions can be gained from simultaneous assessment of habitat conditions and wildlife-use patterns. Therefore, research that elucidates connections, particularly those that are causal between habitat quality and effects on sage-grouse populations, including use, movements, individual health and population demographics, will potentially improve habitat conservation and management. Further, use and value for sage-grouse may vary in different seasons and life stages; therefore, projects that address details of use and selection by grouse are most appropriate. Specifically, in order to facilitate habitat management, relationships between sage-grouse population indicators (for example, seasonal use, nesting success, and mortality rates) and habitat parameters including sagebrush-canopy height and cover, forb and grass height, overall plant diversity and abundance, and nutritional quality warrant further study.

4.2.4.2.2 Variability [M]

Sage-grouse habitats across the species' range vary by species composition of overstory and understory vegetation, quality (for example, nutritional value), and configuration (for example, patch size). It is important to improve the understanding of the relationships between the edaphic, topographic, climatic, and disturbance gradients and habitat conditions suitable for sage-grouse. The sage-grouse management guidelines (Connelly and others, 2000a) outline habitat conditions for sage-grouse seasonal habitats with a caveat for regional variation in achievable results. Identification of factors limiting portions of the landscape from achieving local or regional conditions suitable for sage-grouse seasonal use should help inform future management actions and expectations of success.

4.2.4.3 Surface Water [L]

The importance of surface and subsurface water flow for sage-grouse and sagebrush habitats is poorly understood. Research could assess the effects of water developments that range in size from small impoundments to large diversions. A related consideration is how the condition of the surrounding sagebrush ecosystem is changed by alteration of flow regimes when diversions are present. In addition, research to address the importance of free water for sage-grouse is relevant (see Connelly and others, 2011a). These issues will have additional implications if climate change alters the distribution of water.

4.2.5 Soils [L]

Soils are important predictors of vegetation condition and potential. Questions related to soils and the indirect relationships between soils to sage-grouse were a low research priority during the review process. However, the predictive capabilities associated with soil and vegetation relationships (Schlaepfer and others, 2012) can be useful for management. The development of consistent, range-wide soils data and models that describe how changes occur in response to stress and disturbance are valuable tools for managing across landscapes. The Soil Survey Geographic Database (SSURGO) provides a consistent framework for these data and models, but information gaps exist for key areas within the sage-grouse's range. In general, it is relevant to connect ecological site descriptions and state and transition models to specific types of restoration and dynamic ecosystem processes. In addition, these models could incorporate links to sage-grouse habitat requirements and habitat quality at the scale of regions or sage-grouse populations.

4.2.6 Other Wildlife [L]

The sagebrush ecosystem provides habitat for more than 350 wildlife species (Wisdom and others, 2005b). Conservation and management for sage-grouse may influence these species. For example, studies indicate that sage-grouse may act as an umbrella species for passerine birds (Hanser and Knick, 2011), which means that they might benefit from conservation measures focused on sage-grouse. However, links between sage-grouse and passerine population dynamics or the occurrence of other taxonomic groups (Rowland and others, 2006) remain questions for future research. Some advantages and disadvantages likely will be realized by various species in areas where sage-grouse are the focus of management, including the ongoing designation of areas as priority and general habitat.

4.2.6.1 Restoration and Mitigation Effects [M]

Various game species, such as mule deer (*Odocoileus hemionus*), are managed within the range of sage-grouse. Management decisions could be informed by information about the potential for conflicts between the desired conditions created by actions focused on other species and habitat management goals for sage-grouse, including how sage-grouse and other species are affected by management for the other, and whether the effects vary by region, habitat, or other factors.

4.3 Change Agents

The term "change agents" is often used in land-use planning and evaluation to identify those factors that directly or indirectly affect wildlife populations or habitat conditions. These agents may include positive or negative effects to sage-grouse, sagebrush habitat conditions, or both (table 5; fig. 4). Similarly, some change agents clearly are the result of human activities, others are natural processes, and many are a combination of the two because natural processes have been altered by human activities. Some change agents have unique mechanisms of influence on populations or habitat, but they are typically linked in time and space, and therefore, they may act synergistically to influence ecosystem processes (Leu and others, 2008). For example, fire is a natural process, but human influences on fire regimes also are an important component of contemporary habitat patterns and functions. In addition, the interaction between fire and invasion by non-native annual plants works synergistically to degrade sagebrush habitat conditions (D'Antonio and Vitousek, 1992). Although an understanding of individual mechanisms is important, knowledge of cumulative effects is essential for developing best-management practices that provide long-term conservation of sage-grouse populations and functioning sagebrush. This direction of research is consistent with previously stated strategic priorities, which indicated that large-scale, integrated assessments that consider interactions in space and time are needed to develop understanding at scales appropriate for habitat management.

4.3.1 Anthropogenic Influences

Human actions and infrastructure influence sage-grouse populations and habitat by changing the condition and distribution of suitable locations for breeding, nesting, brood rearing, and wintering. The negative impact of these influences was recognized by the FWS in the most recent sage-grouse listing decision (U.S. Department of the Interior, 2010). Increased knowledge of the relationships between sage-grouse habitat use, demography, and anthropogenic activities, as well as mechanisms of human activity that degrade or improve conditions, could advance management of sagebrush landscapes by informing future development actions, averting negative effects of proposed actions, and meeting obligations for multiple use of public lands. In this Research Strategy, the accumulation of anthropogenic influences and their potential interactions is summarized in section 4.3.1.1, "Surface Disturbance."

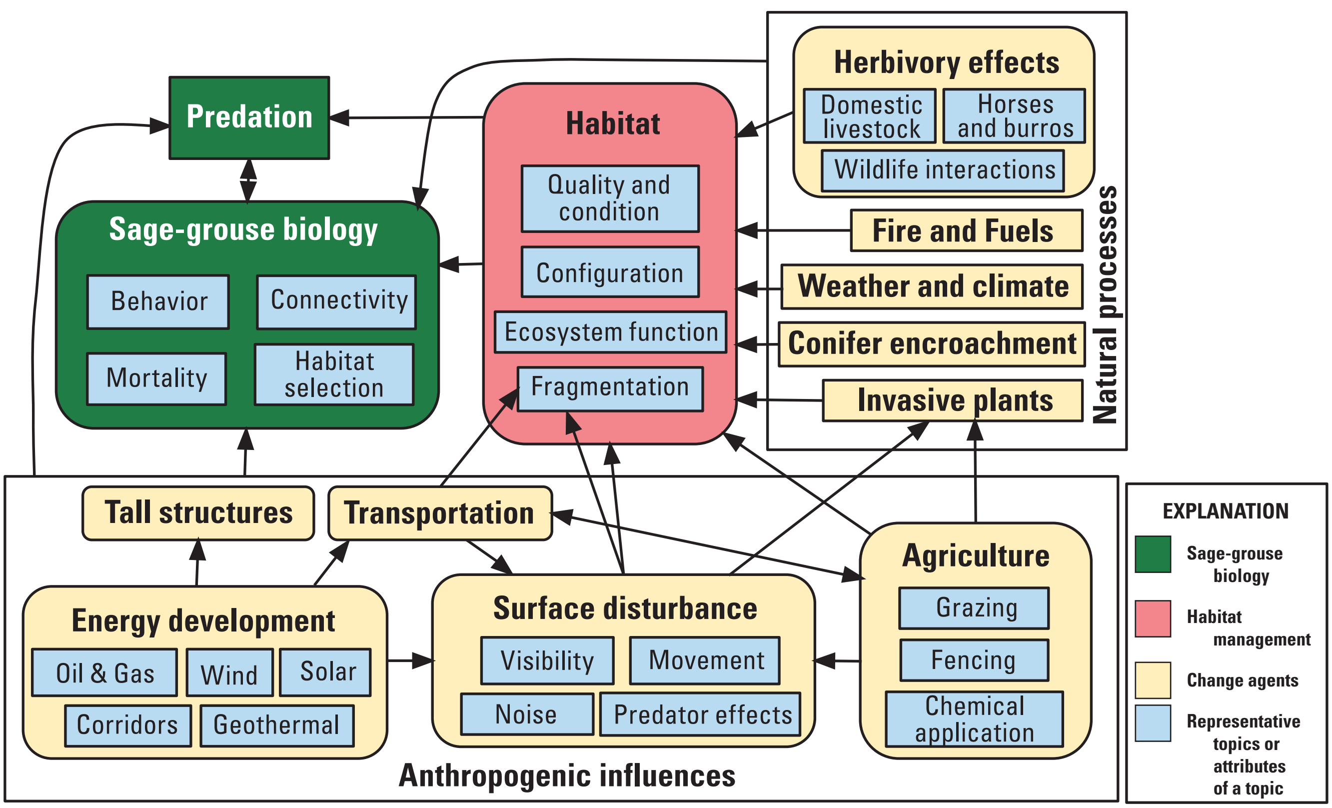

Figure 4. Conceptual model of change agents that outlines important relationships and influences of these factors on sage-grouse and sagebrush habitats. Boxes represent research topics or representative attributes within a theme and arrows provide interactions between themes and topics.

Table 5. Research topics in the change agents theme and priority designations (low [L], medium [M], or high [H]) based on input from a focus group of representatives from Federal and State agencies.

Topic	Priority designation	Topic No.
Anthropogenic Influences		4.3.1
Surface Disturbance	H	4.3.1.1
Noise	H	4.3.1.1.1
Predator Effects	H	4.3.1.1.2
Movement	M	4.3.1.1.3
Visibility	M	4.3.1.1.4
Energy Development	H	4.3.1.2
Oil and Gas	H	4.3.1.2.1
Wind	H	4.3.1.2.2
Corridors	H	4.3.1.2.3
Geothermal	L	4.3.1.2.4
Solar	L	4.3.1.2.5
Tall Structures	H	4.3.1.3
Agriculture	M	4.3.1.4
Transportation	L	4.3.1.5
Natural Processes		4.3.2
Conifer Encroachment	H	4.3.2.1
Invasive Plants	H	4.3.2.2
Habitat Condition and Ecosystem Function	H	4.3.2.2.1
Restoration	H	4.3.2.2.2
Fire And Fuels	H	4.3.2.3
Landscape Dynamics and Connectivity	H	4.3.2.3.1
Habitat Condition/Effects and Recovery	H	4.3.2.3.2
Planning and Control Methods	H	4.3.2.3.3
Restoration and Rehabilitation	H	4.3.2.3.4
Vulnerability and Prioritization	H	4.3.2.3.5
Population Response	M	4.3.2.3.6
Interactions with Climate, Grazing and Other Land Uses	M	4.3.2.3.7
Herbivory Effects	H	4.3.2.4
Domestic Grazing	H	4.3.2.4.1
Practices, BMPs, Systems	H	4.3.2.4.1.1
Monitoring Effects and Conditions	M	4.3.2.4.1.2
Horses and Burros	M	4.3.2.4.2
Wild Herbivores and Herbivore Interactions	L	4.3.2.4.3
Disease	M	4.3.2.5
West Nile Virus	M	4.3.2.5.1
Background Level of Disease and Implications for Population Cycling	L	4.3.2.5.2
Weather and Climate	M	4.3.2.6
Implications for Priority Areas	H	4.3.2.6.1
Demographics	M	4.3.2.6.2
Cycles and trends	L	4.3.2.6.3

4.3.1.1 Surface Disturbance [H]

Surface disturbance is a combination of the vast array of anthropogenic activities that alter or remove natural sagebrush communities, which means that most research addressing surface disturbance automatically encompasses a wide range of anthropogenic activities. Others have established that sage-grouse are sensitive to surface disturbance in occupied habitats (Doherty and others, 2008; Johnson and others, 2011; Naugle and others, 2011a). Additional research could distinguish the effects of different types of disturbances and related activities on sage-grouse, for example, effects of development of oil, gas, and wind resources. Important topics include effects of disturbances in different seasons and under various habitat conditions, such as sagebrush type, topography, fire history, and vegetation treatments. These studies could focus on identification of thresholds beyond which effects on sage-grouse behavior or population response(s) are minimized. Thresholds could be evaluated based on distance from the location of the surface disturbance, intensity of the disturbance, and similar criteria describing habitat patterns. For example, the Sage-Grouse National Technical Team (2011) outlined levels of acceptable surface disturbance within priority areas for conservation as discrete anthropogenic disturbances covering less than 3 percent of the total sage-grouse habitat regardless of ownership. Additional research could evaluate the effectiveness of this standard with measures of sage-grouse response.

The ecological influence of anthropogenic activity can extend beyond its own physical footprint (Leu and others, 2008) and may take the form of increased noise, changes in predation, and behavioral changes, such as altered movement patterns and habitat use. Additionally, outcomes of widely dispersed disturbances, such as invasive plants and dust, on habitat conditions are poorly understood. Understanding immediate and cumulative effects of surface disturbances could improve siting of future infrastructure developments, mitigate deleterious effects of existing developments, and present new options for management of landscapes for multiple uses. In addition, physical habitat loss may decrease population and habitat connectivity when losses are substantial enough to create functional barriers.

4.3.1.1.1 Noise [H]

Noise has the potential to influence sage-grouse behavior, including habitat use, movement patterns, and breeding activities (Blickley and Patricelli, 2012), with associated implications for population characteristics. Sage-grouse have been shown to have elevated corticosteroid levels when subjected to increased noise (Blickley and others, 2012). Additional field studies could help distinguish the effects of noise and elevated stress hormones on population vital rates, demographic trends, and seasonal patterns of space use and sensitivity to noise. Considerations include responses to intermittent versus continuous noise and the potential influence of wind direction and topography on noise effects.

4.3.1.1.2 Predator effects [H]

Construction of utility corridors, communication towers, wind turbines, and other infrastructure may influence distributions and hunting effectiveness of predators. If construction does occur, it could affect sage-grouse mortality, and through indirect means, affect sage-grouse habitat use. The magnitude and direction of such effects may vary depending on environmental factors and construction designs that affect use of structures by aerial predators as perches for hunting or as nesting platforms. Understanding links between infrastructure, predator population size, and subsequent changes in predation rates on sage-grouse are important for the development of effective management and mitigation strategies.

4.3.1.1.3 Movement [M]

Surface disturbance changes the quantity and configuration of habitats, which may influence movement patterns (Lyon and Anderson, 2003; Holloran and others, 2010). Additional research would reveal the effects of surface disturbance on sage-grouse movement patterns and clarify the potential for various disturbance types and configurations to serve as barriers to movement and connectivity (Refer to sections 4.1.2, “Sage-Grouse Biology, Connectivity” and 4.2.2, Habitat Management, Connectivity”).

4.3.1.1.4 Visibility [M]

Infrastructure often has different elevations and visibility profiles than natural environmental features. These differences may influence the perceived risk from these structures and associated population level effects. Research could assess the influence that visibility has on sage-grouse behavior and identify possibilities for adjustments in construction design and materials to mitigate potential influences of infrastructure development on sage-grouse behaviors and habitat use.

4.3.1.2 Energy Development [H]

A host of potential effects, measured and assumed, have been associated with industrial development of public lands for energy resource extraction (Walker and others, 2007; Tack, 2009; Naugle and others, 2011a, 2011b). The longest, most variable, and most contested developments in these landscapes are oil and natural-gas wells (Braun and others, 2002; Holloran, 2005; Walker and others, 2007; Copeland and others, 2009; Harju and others, 2010; Hess and Beck, 2012b). The presence of these wells is accompanied by networks of roads, pipelines, power lines, pumping stations, and consolidation facilities. Various changes have been associated with oil and gas developments (Connelly and others, 2004; Taylor and others, 2012), including new traffic associated with daily maintenance of equipment (Blickley and others, 2012), intense activities and noise during drilling, fragmentation, dust and weeds associated with road networks (Connelly and others, 2004; Bergquist and others, 2007), and new opportunities for predators. New developments and technologies, such as wind-turbine arrays, solar arrays, geothermal facilities, coal-bed methane wells, and hydraulic-fracturing installations, are assumed to have similar effects in cases where infrastructure and activity levels are similar. This assumption is largely untested, and further, activities and infrastructure associated with these developments are not identical (for example see, LeBeau, 2012). In addition, different locations have unique attributes that may affect sage-grouse or habitats in unique ways and may require specific research and management attention.

Improved understanding of disturbance intensity and population response is important, and efforts to gain essential knowledge would include testing of implemented and proposed stipulations (for example, buffer distances and development density). Identification of thresholds and accounting for spatial variability across regions also are important topics.

4.3.1.2.1 Oil and Gas [H]

Most research documenting the response of sage-grouse populations to intensive land use has focused on roads, wells, pads, pipelines, and related infrastructure for oil and gas extraction (Walker, 2007; Doherty and others, 2008; Carpenter and others, 2010; Harju and others, 2010; Holloran and others, 2010; Doherty and others, 2011; Hess and Beck, 2012b). Some aspects of land-use intensity, fragmentation, noise, and buffer distances can be investigated in association with oil and gas development, but most sage-grouse biologists are interested in identifying landscape priorities in order to conduct conservation and mitigation, improve restoration and rehabilitation practices, and potentially influence siting of new developments to minimize impacts and reduce the need for mitigation. Common goals are to decrease the presence or influence of invasive plants, increase native vegetation, particularly sagebrush cover, and increase sage-grouse use of restored areas. Pad reclamation activities provide an opportunity for research and development of new methods for restoration of functional sagebrush communities.

4.3.1.2.2 Wind [H]

Wind-energy development is a relatively new change agent within the range of the greater sage-grouse. The pace of change is rapid as agencies and industry strive to meet the U.S. Department of Energy's goal to have wind power supply 20 percent of the U.S. power generation by 2030 (U.S. Department of Energy, 2008). Protocols have been developed by groups, such as the National Wind Coordinating Council, to study the effects of wind-energy developments. The primary focus has been on the net reaction of sage-grouse populations rather than mechanistic assessment of specific, direct or indirect, effects through time. Birds avoid the vicinity of wind facilities, but the causal mechanisms are poorly understood. An understanding of what sage-grouse avoid, thereby causing displacement, will inform decisions regarding siting and permitting of facilities that reduce impact to sage-grouse populations. Wind turbines are tall structures and may be perceived as potential raptor perches. They also may influence individual bird movements because of the noise, motions, or human activity associated with wind production. Long-term effects may manifest themselves through changes in the survival rate in areas surrounding wind facilities, and these changes may only occur during certain life stages or seasons. The potential for lag effects in population responses confounds research into these causal mechanisms. Therefore, addressing these issues may require long-term monitoring. A complete understanding is not essential for immediate planning.

4.3.1.2.3 Corridors [H]

Different types of linear features, referred to as corridors, are associated with most of the dispersed energy activities in sage-grouse habitats. These are placed to gather and distribute power and products. An understanding of the effects of existing and proposed energy corridors and associated facilities on sage-grouse and sagebrush habitats would include a combination of observational studies, field sampling, and scenario modeling to address current and potential influences. Effects to be considered include fragmentation, invasive species, noise, and predation. Research designed to include experimental controls and data collection before and after development occurs would greatly enhance understanding and the extrapolation of results.

4.3.1.2.4 Geothermal [L]

The mechanisms of disturbance caused by geothermal-power generation are similar to oil and gas development (discussed in section 4.3.1.2.1, "Oil and Gas") and can be attributed primarily to a proliferation of roads and pipelines. However, due to a limited number of operating facilities in sage-grouse habitats, little direct information about the relationship between sage-grouse and geothermal-power facilities exists. Potential for increased geothermal energy production in the sage-grouse range is located primarily in Nevada and southern Oregon (Knick and others, 2011). In these areas, this topic may be a locally important issue.

4.3.1.2.5 Solar [L]

Large-scale solar developments are not common within the sage-grouse's range at this time, but improvements in technology and incentives to increase use of renewable energy resources may change this situation. Studies addressing the potential effects of solar developments on sage-grouse could help minimize negative effects if these developments begin to occur. Topics of study could include effects on vegetation, predation, and changes in availability of water supplies.

4.3.1.3 Tall Structures [H]

The addition of tall structures to sagebrush shrublands, which lack naturally occurring vertical structures, and the potential effect of those structures on sage-grouse populations has previously been identified as an important research need. The proposed construction of several large transmission lines prompted the development of protocols for assessing the impact of tall structures (Utah Wildlife in Need, 2011). These protocols have not been implemented, and the questions they address remain unanswered. Important considerations are possible avoidance by sage-grouse, reasons for avoidance, changes in predation rates, and contributions to habitat fragmentation. Each of these considerations can pertain to a variety of tall structures, for example, power lines, cell towers, and wind turbines. Established protocols could be helpful for addressing comparable considerations associated with these different types of structures. Assessment of impacts caused by the spectrum of tall structures may help inform future design and siting considerations for these types of development projects and help identify modifications that could be made to existing structures to mitigate negative effects.

4.3.1.4 Agriculture [M]

Agricultural conversion has been associated with decreasing lek trends (Johnson and others, 2011) and increased risk of sage-grouse extirpation (Aldridge and others, 2008; Wisdom and others, 2011). In addition, pesticide application within agricultural fields can have toxic effects on sage-grouse (Blus and others, 1989). Programs established under the national Farm Bill, particularly the Conservation Reserve Program (CRP), have had positive influences on sage-grouse populations (Schroeder and others, 2011). Several factors warrant further study to maximize the benefits of such programs. Considerations include where lands are most effectively set aside under the Conservation Reserve Program to benefit sage-grouse; the appropriate size, configuration, and juxtaposition of these set-aside lands; and the effectiveness of various habitat modifications on set-aside lands. Questions could be answered using relative use, reproductive success, movement patterns and other metrics to differentiate between source habitats versus sink habitats, differentiate use patterns, and differentiate costs and benefits across seasons of use.

4.3.1.5 Transportation [L]

Although not singled out as a research priority, roads are a large source of surface disturbance within many types of landscapes across the sage-grouse range. Accurate, high-resolution road datasets, with all roads categorized by type (for example, unofficial, off-highway vehicle, unpaved, paved) throughout the sage-grouse range would be useful in efforts to account for the effects of this surface disturbance. These datasets also could provide the information needed to further differentiate the effects of road size, traffic levels, and nature of disturbance (noise, dust, visibility, and associated infrastructure) to sage-grouse. Roads are an important conduit for the introduction and spread of invasive species (see section 4.3.2.2, "Invasive Plants"), and fine-resolution transportation maps may help manage issues associated with invasive species.

4.3.2 Natural Processes

Change agents involving natural ecological processes, some of which have been altered by human activities, lead to management challenges associated with maintaining natural processes while managing detrimental effects on sage-grouse habitat conditions, such as invasive species, conifer encroachment, fire, herbivory, weather, and climate. Although there is evidence these have each been altered by human actions, the underlying dynamics of plant growth and propagation, weather, and fire are natural processes and, as such, may require different treatment in research and management compared to specific anthropogenic activities.

4.3.2.1 Conifer Encroachment [H]

The pattern and processes of conifer encroachment have been investigated, and active management of encroachment is underway in many regions. Cost-benefit assessments of conifer treatments in different regions, successional stages, and environmental conditions may help determine the long-term efficacy of these management actions. An understanding of the effects and effectiveness of these management actions in restoring functioning sage-grouse habitat are important factors in this determination. It is important that research addresses appropriate size and location of treatments, characteristics of the target community, effective removal methods that reduce the immediate negative effects of treatment, and the time frame for reuse by sage-grouse populations following treatment. This importance stems in part from the value of woodland habitats to other wildlife, including game species and songbirds (Noson and others, 2006; Anderson and others, 2012).

Interest in management of conifer encroachment stems from two main factors. Conifer trees can provide perching habitat for predators, which could result in increased sage-grouse predation, and conifers displace sagebrush and native herbaceous species. In the modern era, conifer encroachment may result from altered fire regimes (Miller and Rose, 1995, 1999); however biogeographic evidence also indicates long-term, climate-driven trends in juniper woodland expansion (Lyford and others, 2003). Important considerations are the overall consequences of conifer encroachment to sage-grouse habitat relationships and demographic viability, and how long-term changes in conifer abundance have shaped population trends. Management currently focuses on restoring sagebrush habitats by removing trees with as little negative effect on surrounding vegetation and habitat as possible, although, the effects and effectiveness of these treatments on sage-grouse are not understood. For example, the NRCS Sage-Grouse

Initiative is working with private landowners in Oregon, Nevada, and Washington to improve habitat conditions on private lands in regions where conservation success likely depends on private-owner actions. Since its initiation in 2010, projects funded by the Sage-Grouse Initiative have removed more than 115,000 acres of pinyon pine (*Pinus* spp.) and juniper trees from sagebrush communities (Manier and others, 2013, table 27).

More immediately, the effectiveness of tree removal for meeting vegetation, habitat, and wildlife targets is not clear. Some considerations are mechanistic and focus on the condition and successful management of vegetation, for example, determining the most effective control measures for conifer species, and the most effective techniques for restoration of sagebrush and a perennial herbaceous understory in areas with a conifer overstory and depleted sagebrush understory. Other fundamental questions remain about pre- and post-treatment use of these areas by sage-grouse, as well as restoration costs versus benefits. Answers to these questions could help refine methods and improve practices. Addressing these questions requires a full inventory of the distribution and condition of conifer-sagebrush woodlands, including differentiation of stand-ages, description of cover and density of trees and shrubs, and documentation of use and behaviors of sage-grouse in these same regions. Once these are addressed, additional questions can be asked about where conifer encroachment has a negative effect on sage-grouse habitat values, habitat use, and distributions.

4.3.2.2 Invasive Plants [H]

The invasion of the sagebrush landscape by non-native plants has consequences for sage-grouse habitat and may increase fire risk, particularly in cases of widespread cheatgrass (*Bromus tectorum*) infestations. Therefore, the development of new or improved management practices to reduce or eliminate the spread of invasive species is important. Of particular importance is development of methods that eliminate or reduce the distribution and abundance of invasive plants and also promote the re-establishment and productivity of native, herbaceous species. Work by the USDA using natural soil inhibitors (for example, Kennedy and others, 2001) is promising, but test applications are not ready for management implementation. In addition, techniques are needed to restore invaded landscapes to functioning sage-grouse habitat and minimize the risk of reinfestation after treatment. Improved understanding of interactions between invasion history, surface disturbance, habitat condition, and fire history would support the development of these management methods.

Currently (2013), concerns and interests of the wildlife community about invasive plants are focused primarily on annual grasses, including cheatgrass; medusahead wildrye, *Taeniatherum caput-medusae*; and field brome, *Bromus arvense*. Considerations about cheatgrass outweigh all other species. Emphasis on treatments also predominates, namely discovery and development of treatments to remove cheatgrass without increasing or facilitating its spread. There is recognition that other species can negatively affect habitat conditions, but these threats are not perceived as a current priority. A prudent approach would be to recognize these threats, and develop risk assessments and control options in advance of severe infestations.

In general, habitat managers are seeking integrated invasive-species control methods (for example grazing, mowing, seeding, and herbicides) that minimize negative effects on greater sage-grouse populations and their habitats. Generally, managers recognize that the best techniques may vary by region and local circumstances. Development of improved management practices to minimize the risk of cheatgrass infestation is desired, and progress toward that outcome would benefit from integration and cooperation among managers and researchers. Importantly, the relationship between annual plants and disturbance cycles has been documented (Klemmedson and Smith, 1964; Banks and Baker, 2011; Balch and others, 2012), but practical understanding and control applications are lacking. Research and development needs to focus on interactions between land use, treatment, and disturbance, and emphasize response of vegetation and perpetuation of desirable, perennial species. Adjustment of grazing practices, chemical treatments, biological treatments, physical removal, regional strategies, and regional modeling have been suggested as approaches and applications that warrant consideration in this integrated, adaptive research context.

Although specific applications and treatments are being developed and discovered, developing the information and strategic plans for managing vast acres of public land with perpetual disturbances (creating niches for colonization) and natural variability (affecting restoration and invasion potentials) remain an important consideration. Strategic prioritization, risk assessments, and control approaches that address spatial distributions, seed banks, potential for re-colonization, native species recruitment, and community health have possible value for improving management effectiveness.

4.3.2.2.1 Habitat Condition and Ecosystem Function [H]

The fundamental concerns with invasive plants are the potential and realized detrimental effects on habitat conditions. Besides extreme changes in disturbance regime, as demonstrated by cheatgrass in the Great Basin and Snake River Plain, changes in plant composition can directly affect the forage and cover that sage-grouse require, and also influence the abundance of insects eaten in the spring and during brood rearing (Connelly and others, 2004, 2011a). Therefore, identification of ecological processes and services affected by invasive weeds, with the ability to subsequently prioritize control based on potential for range degradation, would be useful information for habitat management. Potential influences of invasive plants on sage-grouse habitat include loss of native species, altered productivity or palatability, low forage value of invaders, disrupted nutrient cycling, chemical alterations, topsoil erosion, and altered fuel and physical habitat conditions. Functional relationships between invasive plants, disturbances, ecosystem function, ecosystem services, habitat degradation, community resilience, and interactions among ecosystem drivers also need clarification. Interactions between cheatgrass, disturbance, range condition, and probability of wildfire beg better characterization and clarification (Balch and others, 2012). A better explanation of these mechanistic relationships is desired along with more information regarding interactions of climate change with invasive plants and fire regimes.

4.3.2.2.2 Restoration [H]

Research and development of methods for control of invasive plants and restoration of native perennials often is a top priority. This general need (also expressed in section 4.2.1, "Habitat Management, Maintenance, Rehabilitation, and Restoration") encapsulates a suite of specific questions focused on soils, vegetation, and wildlife, as well as disturbance and management treatments to recover or maintain native vegetation. A fundamental issue for restoration includes the determination of optimal seed mixtures appropriate for the soils, climate, and landform of an area. Managers seek information about species to use and seeding practices to prevent reoccurrence of undesirable species. In addition, it is important to consider the effects of variability in species viability and differences between seed sources among regions on restoration success. Long-term control of invasive species, through management of ecological processes, is a key focus for research and development. Important research focuses on the development of methods to prevent non-native plant invasion following fire, reduce threats of short fire-return intervals and related persistence of non-native grassland. A goal of many treatment and restoration projects is to minimize negative short-term effects on habitat quality and distribution and maximize long-term benefits, such as fire prevention, and recovery of shrub and herbaceous productivity. Considerable research and development is needed to develop and evaluate methods to achieve such goals.

4.3.2.3 Fire and Fuels [H]

The threat of large fires and the use of fire-management techniques differ across the range of sage-grouse. Large fires are a primary concern because of the threat they pose to near-term preservation of intact sagebrush ecosystems, and particularly sagebrush cover. A clear understanding of range-wide fire regimes and recovery rates will inform fire management in the sagebrush ecosystem. This information could be obtained, preferably, using historical fire data and by conducting comparative analyses of past fires and fire-related treatments under different environmental conditions. This approach would reduce the need to create new experimental disturbances in intact sagebrush landscapes. Assessments of fire history and recovery rates could inform planning efforts and deployment of resources for future fire events, improve the understanding of effective post-fire restoration methods, improve the understanding of effectiveness and impacts of pro-active fuel management techniques, and when linked with sage-grouse population and behavioral data, increase the understanding of the response of sage-grouse to fire and fire management.

There are differences in perspectives among regions and management agencies about fire. Clearly, fire is a concern for management and conservation of sagebrush because large fires are a threat to sagebrush cover whenever and wherever fires occur. Further, given current land-cover and land-use patterns, fire is a direct threat to sage-grouse habitats. However, ideas vary about control methods and the uses and ecological roles of fire in sagebrush ecosystems. Fire regimes have a high level of natural variability across the range-wide distribution of sage-grouse (Baker, 2011; Miller and others, 2011). Clear questions relating to fire and habitat quality focus on potential adverse effects, such as reducing large intact habitats, promoting the expansion of invasive species' distributions, and threats to conservation of priority habitats. Nonetheless, fire is understood to be a critical driver of the spatial and temporal dynamics of many Western North American ecosystems, and the understanding of the role of fire in sagebrush ecosystems is incomplete.

There is a clear objection among wildlife research and management communities about using fire to remove more sagebrush, even for research, because sage-grouse and other sagebrush obligates are limited by the distribution of this shrub. In addition, fire creates opportunities for non-native plants. An optional perspective could include fire-related research at local and landscape scales. Continued research addressing the vegetation and faunal response to historical wildfires and previous prescribed-burn treatments is an important link to the adaptive management cycle. Comparative studies assessing and differentiating responses to historical fires and treatments in relation to environmental gradients would provide essential information regarding community development patterns, restoration potential, invasive plant distributions, and wildlife use. Studies and programs that take advantage of recent disturbances through rapid-response plans, and thus, do not require the creation of new disturbances for research, are important.

4.3.2.3.1 Landscape Dynamics and Connectivity [H]

A better understanding of the relationship between fire and the sagebrush ecosystem is important for habitat management and conservation. Attributes associated with this understanding include fire-return intervals, post-fire recovery, fire behaviors, fuel accumulation, ignition sources, frequency of ignition events, and patterns of variation in all of these factors among regions. An improved understanding of these topics requires research addressing historical and current conditions and processes. As historical treatments and wildfires, modern wildfires, and multiple land uses complicate the composition and distribution of sagebrush across the landscape, land-use planners and restoration specialists want a better sense of appropriate or desirable ratios of early, mid- and late-seral communities to provide a guide for balancing habitat values and maintaining productive ecosystems and landscapes. Further, spatial variability in fire history and regimes, suppression and mitigation actions, ecosystem conditions and recovery rates, and associated landscape dynamics add complexity such that multiple, appropriately scaled efforts may be more tractable than range-wide studies. An understanding of the natural and desirable structure and patterns inherent in sagebrush landscapes, and the selection and use patterns of sage-grouse within that structure can directly inform connectivity assessments and habitat conservation.

4.3.2.3.2 Habitat Condition/Effects and Recovery [H]

Identification of the role of fire in protecting and maintaining healthy sagebrush communities is lacking, and identification of the balance between loss of intact sagebrush and recovery of young sagebrush required for habitat maintenance needs to be described for different regions, communities, and ecological types. This would include research directed at informing state-transition pathways and specific practices for improving range conditions and thresholds of degradation. This research would be most acceptable if it did not involve new disturbance of intact sagebrush communities and landscapes, but rather proceeded by taking advantage of existing patterns and previous events whenever possible.

Additional studies addressing the relationship between vegetation conditions before fire and habitat conditions after a fire occurs, including historical, desired, and likely responses, are necessary to understand fire-ecosystem relationships and habitat recovery time. Because of spatial variability, post-fire recovery of sagebrush will be influenced by environmental and biological limitations, historical regimes, and similar determinants of conditions. This situation suggests that implementation of this research regionally, including the range of habitat diversity within and across environmental gradients (for example, McIver and others, 2010), could provide an improved understanding of rangewide post-fire conditions. Further investigation of effects of treatments before fires occur (such as green-stripping) on burn-potentials, habitat conditions, and population demographics would help direct land treatments and enhance the effectiveness of these treatments. A better understanding of the effects of fuel treatments, installation of fire-breaks, and similar manipulation of fuels and (or) landscape patterns to reduce wildfire spread and burn-intensities could help minimize the potential detrimental effects of fire-risk reduction measures.

4.3.2.3.3 Planning and Control Methods [H]

Under extreme fire conditions, managers often have to fight multiple active fires with limited resources. Development of decision-support tools and the research to inform models and prioritization would improve fire-control efforts in sagebrush and sage-grouse habitat. New fire-fighting plans incorporating such information would help with efforts to protect important seasonal sage-grouse habitats, enable prepositioning of resources, and identify strategic locations for fire lines to aid in fire suppression.

4.3.2.3.4 Restoration and Rehabilitation [H]

Large-scale wildfires are likely to continue throughout the Western United States (Ford and others, 2012), and a better understanding of effective habitat rehabilitation following these events can help inform efforts to reduce threats of long-term conversion to non-native grasslands and improve success of rehabilitation efforts. Similarly, development of fuels-management approaches and designs that reduce the threat of large fires in priority habitats and maintain, improve, or minimally affect habitat distribution and quality are needed.

An understanding of spatial variability in ecosystem conditions, fuel profiles, fire history, and response of systems after fire, including sage-grouse populations, can be used to prioritize treatment areas and increase long-term success of management actions. Additionally, protocols for burned-area stabilization and rehabilitation have not been developed for priority sage-grouse habitats. Profiling fuel and erosion risks are just two relevant approaches to defining priorities for restoration projects.

4.3.2.3.5 Vulnerability and Prioritization [H]

Questions remain as to how wildfire should best be managed to minimize detrimental effects on sage-grouse habitat and how to establish priorities for protecting sage-grouse habitat if infrastructure also is in jeopardy. Due to near-term needs for functional (providing food and cover) sagebrush-dominated habitats, focused research on “jump-starting” regeneration of sagebrush and native grasses and forbs to encourage rapid re-establishment of sagebrush and enable re-colonization by sage-grouse as soon as possible may help off-set effects of fire and help mitigate potential effects of future fires. After development, fuel treatment and restoration methods would require testing for effectiveness.

4.3.2.3.6 Population Response [M]

A fundamental component of most sage-grouse research associated with fire is increasing the understanding of how sage-grouse populations respond when seasonal habitats burn. Understanding this response is particularly important when large portions of seasonal habitat burn within a population. Although notable contributions exist from previous work in south-central Idaho (for example, Fischer and others, 1997; Connelly and others, 2000b; Nelle and others, 2000; Pederson and others, 2003), many regional and range-wide perspectives are lacking (but also consider, Knick and others, 2005; Baker, 2011). Changes in sage-grouse demographic rates, including survival and subsequent reproductive success, and movement patterns in response to burned areas, as well as the interactive effects of fire or treatment size and the timing on response of sage-grouse individuals and populations warrant further assessment.

4.3.2.3.7 Interactions with Climate, Grazing, and Other Land Uses [M]

Development of management practices to achieve optimum overstory and understory conditions is an issue because of the complex effects of fire, disturbance, and other land use on these habitat components. Clarifying interactive and determinant effects of climate, fire, and grazing on community composition and ecosystem functions, particularly understory conditions, will inform management for near and long-term ecosystem sustainability, fuels, and habitat management.

4.3.2.4 Herbivory Effects [H]

4.3.2.4.1 Domestic Grazing [H]

Livestock grazing is the most widespread, long-term anthropogenically driven influence on sagebrush ecosystem conditions. It is a contentious issue, and opinions and management approaches vary among regions, States, and localities. Sage-grouse conservation, management of sagebrush ecosystems, and the long-term sustainability of domestic grazing on these lands could benefit from research that informs the relations between grazing practices (for example, intensity, rotation, duration, and other aspects of grazing systems) and regional and local environmental patterns, including soils, climate, fire, and other land uses. Research has provided some insights into relationships between grazing and sage-grouse habitat conditions (Beck and Mitchell, 2000; Beck and others, 2012); however, variability in environmental patterns (for example, climate and vegetation) and grazing practices causes tremendous variability in local and regional effects. An expanded research program would inform immediate decisions and practices to balance grazing practices with conservation practices benefiting wildlife.

Although domestic grazing practices often receive the most attention, wild and domestic herbivores, different types of animals, current and historical conditions, climate, fire, and invasive plants all received notation for their potential interactive effects on habitat conditions. Critical information describing the roles of grazing management in determining ecosystem conditions and the effects on sage-grouse are currently lacking. For example, utilization of forage by elk or wild horses and burros in a drought year may affect availability and use by domestic animals and these interacting uses may further affect sage-grouse habitat conditions. Additionally, research would help refine the timing for re-introduction of livestock after a fire to reduce cheatgrass invasion risk and provide recovery time for perennial grasses and sagebrush. Considerations could include post-fire condition and relationships between weather and climate and vegetation response.

4.3.2.4.1.1 Practices, BMPs, Systems [H]

There is interest in an improved understanding of how grazing systems, including season of use, grazing duration, kind of livestock, and stocking intensity, influence sage-grouse habitats and populations. A series of large-scale, replicated grazing studies that focus on how different livestock species, grazing systems, disturbance history and other environmental conditions affect sage-grouse habitat would help address these issues and clarify the multitude of conflicting results in the literature.

Any lasting effects of historical overgrazing practices may be distinct from modern practices, and range ecologists may want to separately consider these practices and their effects on sage-grouse habitats. Doing so could improve the ability of managers to address consideration about conditions, for example how “passive” restoration might address effects of current practices Conversely, if historical grazing impacts remain influential, then active restoration may be necessary (Pyke, 2011; Manier and others, 2013). The techniques and associated costs are different for passive and active restoration, and matching methods to desired outcomes is important for cost-effective application.

Specific questions of how fire and habitat treatments interact with grazing interrelate with questions about the effectiveness of post-fire and post-treatment grazing restrictions, and how these treatments and restrictions affect vegetation response and habitat quality. Specific trade-offs between different management approaches have been suggested, such as comparison of the short-term (1–3 years) versus long-term (3–10 years) effects of livestock removal in comparison to best-grazing practices on habitat quality and fire risk (fuels).

4.3.2.4.1.2 Monitoring Effects and Conditions [M]

Development of standardized monitoring protocols to detect trends in vegetation response (vigor, production, and diversity) and similarity to condition, as outlined in the sage-grouse habitat guidelines for addressing the effects of grazing management systems, would be helpful. At a local scale, long-term research and monitoring may have a specific focus, for example to address the response of forbs or the compositional diversity of native species to grazing. At a larger scale, questions may be less specific, such as how grazing regimes affect seasonal sage-grouse distributions from year to year. Both perspectives are necessary to address grazing effects on sage-grouse and the practicality and effectiveness of habitat guidelines in the context of current grazing practices.

Fencing to contain livestock and developments to provide water are common infrastructures associated with grazing. In addition, sometimes sagebrush is removed using mechanical or chemical treatments to improve grazing habitat. Fences may be particularly problematic for sage-grouse, because birds occasionally fly into them and die. Conditions affecting likelihood of collisions and modifications that encourage avoidance have been initiated (for example, Connelly and others, 2004; Wolfe and others, 2009; Stevens and others, 2011, 2012) but the results are not yet adequate to inform and prioritize activities. In general, an understanding of the long-term impacts these infrastructures and treatments to support livestock grazing have on sage-grouse populations would help inform future modification or removal of these features to benefit sage-grouse. Cost-benefit analyses of proposed modifications or removal of infrastructures also would be beneficial.

4.3.2.4.2 Horses and Burros [M]

Some effects of horses and burros on sagebrush ecosystem structure and function have been demonstrated (Beever and Aldridge, 2011). A common assumption is that horses and burros are negatively affecting sage-grouse habitat in the western part of the species' range, but data supporting this assumption are largely lacking. In general, much remains to be learned about the effects of free-ranging horses and burros on sagebrush systems, and how effects vary with equid density and seasonal grazing patterns across ecological contexts and key environmental gradients (for example, rainfall, elevation, seasonality, temperature).

4.3.2.4.3 Wild Herbivores and Herbivore Interactions [L]

Domestic and wild herbivores can occupy the same habitats and their effects can be cumulative across species. For example, interactive effects of multiple herbivores have the potential to exceed independent effects on habitat quality, such as grass and forb abundance and diversity and vegetation structure (Manier and Hobbs, 2007). Furthermore, effects of wild ungulates may disproportionately influence one or more sage-grouse seasonal habitats. Therefore, evaluation of the combined effects of all herbivores is important. A systematic inquiry would include a spatial comparison of key sage-grouse habitats and seasonal habitats for all herbivores and an assessment of impacts on vegetation composition and habitat structure on sage-grouse habitats by herbivores. These analyses would determine degree and timing of spatial overlap and conditions in those overlap zones.

4.3.2.5 Disease [M]

4.3.2.5.1 West Nile Virus [M]

West Nile virus is a local threat to sage-grouse populations when outbreaks occur (Walker and others, 2004, 2007; Walker and Naugle, 2011). Land-use activities, such as oil and gas development, can increase the potential for outbreaks (Walker and others, 2007; Walker and Naugle, 2011). Additional research could examine the effects of other management activities, both as potential sources of West Nile virus and as preventative measures against outbreaks. A risk assessment for West Nile virus would predict the potential for spread of the virus in different habitat conditions, configurations, and disturbance regimes. Additional research could support the development and testing of methods for vaccination of sage-grouse to protect against West Nile virus infections. Weather conditions appear to have an influence on outbreaks, and the apparent absence of these conditions in recent years complicates efforts to study this disease. Studies would work best if resources were in place to quickly initiate data collection whenever outbreaks occur.

4.3.2.5.2 Background Level of Disease and Implications for Population Cycling [L]

Sage-grouse are susceptible to various diseases (Christiansen and Tate, 2011). Although the impact of disease on populations is presumed to be small, few studies and apparently no ongoing research actually document range-wide background levels of bacterial, fungal, viral, and parasitic diseases. Without these long-term studies, it is difficult to determine if identified disease agents, such as tularemia, aspergillosis, hematozoa, West Nile virus, avian pox, avian malaria, cestodes, coccidian, and other viral and bacterial pathogens, play a role in population cycling or to make prediction of conditions under which outbreaks occur. A range-wide surveillance program would serve as a framework for assessing background disease levels in sage-grouse populations and provide an early warning system for disease outbreaks.

4.3.2.6 Weather and Climate [M]

Under future climate scenarios, the distribution of sage-grouse habitat is predicted to shift as climate and vegetation change (Neilson and others, 2005; Bradley, 2010). Information about the relationship between sage-grouse populations and weather conditions may be particularly important for management as climate patterns shift, causing changes in seasonal patterns and weather variability. In Nevada, certain segments of sage-grouse populations reproduce successfully even under extreme drought conditions (Blomberg and others, 2012a), but it is not clear that all populations can perform similarly. For example, in the Nevada populations, up to 75 percent of annual variability in population size was explained by precipitation (Blomberg and others, 2012a). An understanding of what habitat or landscape features allow populations to survive and reproduce despite climate stresses will help adapt conservation and management plans for future conditions. In general, further study would help characterize the relationship between weather and climate conditions, and timing of use and location of seasonal habitats.

4.3.2.6.1 Implications for Priority Areas [H]

Climate scenarios suggest long-term shifts in the distribution of sage-grouse habitats (Neilson and others, 2005). If this occurs, areas currently designated as sage-grouse priority areas may not serve the same function in the future if sage-grouse habitat no longer occurs there. Assessments are needed to address the adequacy of the current distribution of priority areas to maintain sage-grouse populations under different scenarios of climate change. Additionally, assessment would determine if there are important areas that should receive additional protection as connectivity corridors if or when habitat distributions change. Climate-related research also could help determine if future restoration, mitigation, and rehabilitation efforts should focus on areas predicted to be conducive to supporting future sage-grouse habitat. A high degree of uncertainty about future climate scenarios and high variability in information to address climate-change effects confound research addressing climate change and priority areas.

4.3.2.6.2 Demographics [M]

Seasonal timing of precipitation and temperature may affect vegetation phenology (White and others, 1997; Shen and others, 2011; Friggens and others, 2012) and insect activity (St. Pierre and Lehmkuhl, 1990; Gordo and others, 2010). In Idaho and Utah, sage-grouse chick survival was related to seasonal precipitation and temperature (Guttery and others, 2013). These results highlight the importance of understanding phenological patterns and the development of linkages between these patterns and sage-grouse nest success, adult and juvenile survival, and other processes that affect populations. Further, assessments need to address how birth rate, survival, and mortality and other demographic characteristics are likely to be affected by future climate scenarios and how these patterns influence long-term population viability.

4.3.2.6.3 Cycles and Trends [L]

Sage-grouse populations have undergone population cycling over the past 50 years (Fedy and Doherty, 2011; Garton and others, 2011), and the underlying causes of those cycles are unknown. Climate and weather exhibit multiple cyclic patterns, including drought cycles, oceanic oscillations, and long-term warming (Solomon, 2007). Weather patterns and climate cycles may cause or influence population cycles, although this link has not been established. Further research could assess the cause and effects of these cycles and possible influences on sage-grouse population viability.

4.4 Socio-Economic Considerations

4.4.1 Adaptive Management [M]

There is general agreement that maintaining a tight feedback loop between research and management is important to ensure availability of research results and the use of those results by management. Opportunities for cooperation are abundant, and these efforts may provide feedback regarding implications and effectiveness of local treatments and buffers, as well as measures to achieve regional protections and develop related policies. Understanding and managing the effects of ever-changing forms of industrial developments will require cooperation between planning, management, and research to establish response designs and collect the data necessary to inform decisions.

4.4.2 Economics [M]

Economics and politics are important determinants of policy, potentially affecting land-use developments, habitat protections, and project initiation. Conversely, policies designed to protect sage-grouse potentially restrict economic activities. Therefore, there is value in conducting cost-benefit analyses of the economic impacts of different sage-grouse management options.

4.5 Inventory Data and Products

Data requirements were discussed regularly by participants involved in developing this Research Strategy. Some of the data collections identified emphasize inventory, mapping, or monitoring to acquire data rather than conduct research. Priority data products that could be developed or refined include vegetation composition and community structure, including shrub height, shrub cover, age structure of shrubs, fuel profile, fire frequency, herbaceous cover, productivity of herbaceous vegetation, and exposed mineral soils. Efforts by multiple agencies, such as the BLM Rapid Ecoregional Assessments and FWS Landscape Conservation Cooperatives, are directed toward compilation of data describing infrastructure and surface disturbance, including roads, energy developments, tall structures, and fences. The scale, resolution, and accuracy of these data can be improved as observation technologies advance. Habitat alteration, development, and land use also are ever changing, and ongoing assessment is important to maintain up-to-date data. In addition, continued development, refinement, and downscaling of global and continental scale climate and land-use model projections would improve assessment of landscape change.

Proper data management also is important to maximize use of data that already exist and avoid duplicative data collection. An improved, endorsed, supported, and used means of storing and accessing data related to sage-grouse and sagebrush habitat ecology and management is essential. Modern technologies allow for centralized web storage with a web-interface for data dissemination. Many options exist to develop such a data system, and engagement of the research and management communities is important to ensure that the system works for the sage-grouse user community.

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Appendix A. Research Questions Identified from a Review of Federal and State Sage-Grouse Conservation Document, Peer-Reviewed Papers, and Input from the Scientific Community

Questions have been categorized into a hierarchical organizational structure by theme and topics addressed. The PDF (portable document format) file can be downloaded at http://pubs.usgs.gov/sir/2013/5167/.

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Hanser and Manier— **Greater Sage-Grouse National Research Strategy**—Scientific Investigations Report 2013–5167

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed.

Theme/topic	Question or Issue	Citation
Sage-Grouse Biology		
Adaptation	How well can sage-grouse adapt to rapidly changing environments?	18
Adaptation – Genetics	Are there adaptive differences among sage-grouse populations across the range?	18
	How do we identify and conserve adaptive genetic variation?	18
	Are sage-grouse populations genetically adapted to local conditions?	9
Behavior	Inform interpretation of behavior, such as vocalizations, food habits, characteristics and causes of dispersal and migration, territoriality, seasonal site fidelity, and differences in behavior and productivity by sex, age, and region.	6
	Are there other behaviors in sage-grouse that can have relevance to improved survey methodologies, productivity, survival, and management?	6
	Determine population-level responses to a suite of specific stressors (e.g., road density, development intensity, traffic volumes, noise, recreators).	13
Behavior – Genetics	Relationship between genetics and behavior (dispersal) and management (population size or landscape fragmentation) remain relatively unexplored.	6
	Testing, elucidation, and detailed consideration of parentage, inbreeding, outbreeding, and relationships between genetics and behavior and fitness.	6
	Expand and improve local and regional population genetic information—relationships and elucidation regarding dispersal behavior, reproductive patterns, population size, and habitat connectivity/isolation.	6
Connectivity – Genetics	Collect genetic and movement data to evaluate the potential for open or closed populations.	12
	Using results of population genetic testing review prioritization of inter-population linkages.	9
	A more detailed account of sage-grouse sub-populations would be instrumental in determining mechanisms that may be limiting gene flow.	12
	How are primary populations interconnected across regions of lower population densities and less suitable habitat?	17
	Population genetics and the effects of connectivity between populations.	10
	What is the relative importance of landscape features and relevant spatial scales that influence gene flow?	17
	What are the (long-term) connections between habitat/population connectivity, population genetics, and likelihood of a bottleneck (or similar, limiting/reducing effect) event, and the long-term survival/conservation of the species?	17
	Robust range-wide genetics.	15
	How well are populations/subpopulations connected—level of genetic isolation?	11, 15, 18
	Range-wide genetic and habitat connectivity (dispersal dynamics both fine-scale—how individuals move through a habitat matrix- and coarse-scale – gene flow).	18
	Improve link/knowledge regarding population connectivity, gene movement, genetic diversity, and sage-grouse conservation.	14
Fitness – Genetics	What is the mutation rate and heritability in sage-grouse?	9
	What is an adequate genetic effective population size to avoid accumulating mutations?	9
	Parentage, inbreeding, outbreeding, and relationships between genetics and behavior and fitness.	6
Food	How does food availability and quality influence sage-grouse at multiple life stages?	18
Food – Insects	Identify and monitor insect availability, abundance and diversity within specific sites to gain an understanding of their importance to sage-grouse.	1
	Interactive effects of climate and land use, including pesticides and herbicides, on insect-vegetation timing/availability and sage-grouse behavior, brood-rearing, etc.	17
Habitat selection – Habitat quality	Better translation of scales of sage-grouse habitat selection into measures of habitat condition/pattern and management planning and actions – use scale to better connect otherwise/often disparate considerations.	17
	Sage-grouse habitat suitability model.	9

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Sage-Grouse Biology—Continued		
Habitat selection – Seasonal	Determine seasonal habitats such as breeding, nesting, brood rearing.	2
Habitat selection – Veg-Pop linkage	Correlate bird health with habitat condition parameters.	2
	Determine/verify use (food and shelter) of sagebrush taxa used by the various sage-grouse populations (Big vs. Black/Silver), especially in wintering habitats.	10
	Better define and establish the relationship between sage-grouse habitat selection and multi-scale assessment of habitat conditions and multi-scale considerations for planning and policy, and multi-scale considerations for implementation (relevant scales, topics, concerns, foci, etc.).	11
	Uncertainties about potential differences in habitat selection associated with sex, age, season, management, region, weather, breeding success, and survival.	6
	Link between occupancy and habitat characteristics – Causal vs. Correlative.	13
Habitat selection – Winter	Winter habitat selection and availability – test and examine the interplay of depth of snow, movement of snow and height of sagebrush; likely requires micro-habitat delineation and assessment(s).	17
Landscape – Genetics	What is the sage-grouse “genetic landscape”?	9
Methods – Genetics	Develop and refine, if it proves feasible, techniques to obtain DNA from sage-grouse fecal droppings.	9
Monitoring – Genetics	Can genetics be used as a standard technique to monitor and evaluate population structure, spatial configuration, and health?	6
	Genetics of feathers/pellets to monitor population size or trends.	6
Mortality	Assess sage-grouse mortality rates, factors that influence them, and effectiveness of actions taken to reduce them.	4
	Variation in survival due to age, sex, region, habitat, and management.	6
	Initiate studies to better understand sage-grouse mortality rates, factors that influence these rates, and effectiveness of management actions to change them.	4, 5
Mortality – Brood-rearing	Determine the cause(s) of chick mortality during early brood-rearing.	1
Mortality – Causes	Determine the causes of mortality in different sage-grouse age and sex classes and the consequences for population dynamics.	9
	Are there population impacts from research-related mortalities?	10
	Understanding annual survival and seasonal mortality is critical and largely undocumented.	12
Mortality – Juveniles	Evaluate and publish the effects of predation, insecticides, disease, and other sources of mortality on the juvenile segment of sage-grouse populations.	10
	Determine when, where, and why sage-grouse chicks fall out of the population will be important both to determine risks and recommend conservation actions.	2
Movement patterns	How does movement vary by sex, age, region, habitat, landscape, weather, and management?	6
	Characterize brood movement patterns.	12
	Determine movement patterns.	2
	Continuing, expanding, initiating additional radio/GPS marked grouse studies to better capture/relate specific distributions and behavior to conditions.	13
Movement patterns – Connectivity	Level of connectivity of populations and the sedentary and/or migratory behavior of sage-grouse.	12
	Condition, roles, and risks to “fringe populations” (ND, SD, northern MT, Canada, and WA?)	13
Movement patterns – Dispersal	Evaluate the potential for dispersal of individuals into currently unoccupied suitable habitat.	9
	Natal dispersal parameters in sage-grouse.	3
	Natal dispersal of sage-grouse, and how that process impacts the spatial structuring of populations.	12

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Sage-Grouse Biology—Continued		
Movement patterns – Migratory	Identify resident and migratory populations of sage-grouse, key habitats, and movements, relevant to local conservation efforts.	4
	Need a better understanding of sage-grouse movements, habitat selection, and which areas should be considered high priorities for sagebrush management efforts.	8
	Identify the migratory status of all sage-grouse populations.	12
Movement patterns – Seasonal	Identify and protect traditional breeding, brood-rearing, migration corridors, and wintering habitats (local populations).	10
	Movements of grouse from leks to nesting and brooding areas.	5
	Movements from summer to winter habitat.	5
	A better understanding of sage-grouse movement patterns and seasonal ranges and its application to management actions.	2, 12
	Identifying seasonal movements and migrations are key factors in assessing and monitoring core sage-grouse habitats (seasonal and yearlong).	12
Multi-scale condition – Monitoring – Methods	Develop, adapt, coordinate, and unify implementation of monitoring and monitoring protocols for sage-grouse distribution, population trends – should link with habitat monitoring.	14
	Development of a monitoring program that adequate resources are appropriately assigned to both large-scale and small-scale measurements to achieve sufficiently precise estimates of key population parameters.	2
Population – Biases – Monitoring	Observational biases associated with observer, habitat, region, and topography.	3, 6
	Bias associated with using “trend” leks to assess population change.	2
Population – Brood survey – Monitoring	How do estimates from brood surveys compare/correlate with lek counts and harvest surveys (if at all)?	6
	Do brood surveys or routes provide useful information that can be applied to the long-term monitoring of sage-grouse populations or to the identification of critical habitat?	6
	Do brood surveys/routes provide useful information that can be applied to monitoring?	6
Population – Cycles/Trends	Do sage-grouse populations in certain areas have cyclic population trends?	9
Population – Demographics	What should target population levels be for a sage-grouse management zone (SMZ) and how do they vary geographically based on inherent productivity of associated landscapes/ecosystems?	18
	Evaluate nest success based on sagebrush plant structure in addition to sagebrush and herbaceous plant cover and height.	1, 12
	Better understanding of realized contributions of individual demographic rates to sage-grouse population growth would provide a better understanding of the causal factors that have contributed to long-term declines.	18
	Little is known regarding population demographics of the isolated populations.	7
Population – Demographics – Genetics	Investigate the demographics and population dynamics of sage-grouse. Sex ratio, male genetic contribution per generation, dispersal, and other parameters that determine effective population size and population viability.	3
Population – Demographics – Monitoring	Population demographics are challenging due to seasonal mortality differences and low productivity – what are the implications for population viability? And what are links to habitat loss/fragmentation trends?	13
	Population demographics – breed propensity, nesting likelihood – habitat condition/use * behavior interaction (need insight across multiple years and seasons).	13
	Describe, develop, and otherwise standardize (accepted/common) methods for population demographics?	13
	Assess density dependence in sage-grouse populations to improve population dynamics estimates.	13
	Understanding demographic parameters within population management units.	2
Population – Demographics – Productivity	How do the different parameters (nest likelihood, clutch size, renesting likelihood, nest success, hatchability) associated with productivity compare across regions?	6
	How do aspects of productivity fit into a sensitivity/elasticity analysis?	6

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Sage-Grouse Biology—Continued		
Populations – Genetics	Do populations vary genetically and if so how do they vary?	9
	What is the relative amount of genetic diversity contained in each population?	9
	Genetic variability within populations.	9
	What population size is necessary to avoid inbreeding depression? Current thought is 500 but appears to be low.	9
	Population size necessary for balancing between mutation and genetic drift?	9
	What are the effects of genetic isolation of small, isolated populations? – Is there inbreeding depression? – Is there loss of genetic variability?	10
	Genetic health (represented by adequate genetic heterogeneity) of sage-grouse populations.	3
	Fine-scale, population-level genetic analyses – within and inter population comparisons (e.g., sage-grouse vs. GUSG vs. Lyon-Mono)	13
	Fine-scale genetics work: Example: How do lek counts relate to actual and effective population sizes?	18
	What are biologically meaningful populations?	18
Population – Isolated	Determine and publish the susceptibility of small isolated and fringe populations to habitat and population factors, and the contributions of these populations to the larger meta-population.	10
Population – Isolated – Monitoring	Develop a more effective approach to determine sage-grouse populations in isolated areas.	7
Population – Juveniles	Mortality of juvenile sage-grouse or the level of production necessary to maintain a stable population.	10
	Developing a better understanding of survival rates, especially for juveniles under different conditions is also important to develop effective conservation actions.	2
Population – Leks – Monitoring	Develop standardized methods for estimating breeding population size of both males and females.	13
	What are the best methods to effectively survey lek complexes?	3
	What are the best methods to effectively survey the variability in lek counts within a year and its relevance to long-term monitoring?	3
	What are the best methods to effectively survey the relationship between productivity in one year and the coefficient of variation in lek counts in the subsequent year?	3
	Evaluate typical “baseline” data; early vs. modern count methods; known/suspected cycling.	14
	Development of a statistically reliable trend monitoring protocol for inventorying lek attendance of male sage-grouse.	4, 5
	Limitations associated with extrapolation and trend analysis from the lek count data.	2
	Lack of standard definitions for lek status.	2
	Develop a probabilistic sampling scheme for lek counts.	2, 12
	Develop and implement a probability based, spatially balanced sample of breeding males AND females. Approach recommended (Garton and others, 2011) with wide survey across all habitat, systematic sampling of large leks, and intensive sampling at sentinel leks.	13
	What are the attendance rates of males and females?	6
	Variation in attendance due to age, time of day, time of year, and relationship with the peak of female nesting.	6
	What data are necessary to estimate attendance rates?	6
	Can lek attendance rates be used to provide an indication of the previous year’s productivity? Are there other techniques that can be applied to the issue such as infra-red photography, GPS transmitters, active transponders, and PIT tags?	6
	Can female attendance provide useful information related to the timing of nesting, male visitation, habitat condition, and estimation of sex ratio?	6

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Sage-Grouse Biology—Continued		
Population – Leks – Monitoring	Improve value of lek counts by better connecting to population numbers, accounting for variation in male and female attendance rates, seasonal and daily attendance rates, among sampling approaches, and among observers, habitats, regions and topography.	6
	What is the relationship between lek attendance and the previous years' productivity?	6
	What is the influence of lek attendance on population estimates?	9
	What is the influence of disease (e.g., avian malaria) on lek attendance rates and lek counts?	9
	How does body condition influence lek attendance?	9
	Determine and publish the relationship of lek attendance to the population as a whole, effects of possibly double counting males, and reasons for unoccupied leks.	10
	What percentage of leks are actually counted? Are there biases based on population size and lek size?	9
	Evaluate whether sage-grouse lek counts can be calibrated and measurements of accuracy and precision can be assessed using mark-resight or sightability models.	9
	Examine the correlation (and time lag) between the variation in annual sage-grouse productivity and subsequent lek counts and its impact on the precision of population estimates.	9
	Develop technique to use in searching for new or previously unknown sage-grouse leks.	9
	What are the rates of inter-lek movements by male and their influence on population estimates?	9
	What is the female/male ratio and how does it vary annually and regionally?	9
	All sage-grouse leks have not been located and the majority are not monitored on an annual basis.	4
	How close do lek counts reflect sage-grouse population size and change?	10
	Continue searching for unidentified leks.	10
	Uncertainty in lek counts (and other pop. estimates) confounds information in data – need to better elucidate and account for these sources of variability.	17
Population – Mapping	Improve spatial delineation of breeding populations of sage-grouse.	17
Population – Monitoring	Develop inventory technique for searching "vacant/unknown" habitat areas for sage-grouse use.	9
	Establish standardized wing collection protocol to evaluate the influence of environmental conditions on sage-grouse productivity and population trends.	4
	Protocols sufficient to insure the consistent collection of data throughout the range?	6
	Determine the most efficient survey aircraft and survey design for operational surveys.	2
	Develop a monitoring protocol that would more accurately document long-term population trends.	1
	Develop and refine techniques to measure productivity where wing data are unavailable.	1
	Evaluate and adapt population monitoring techniques.	3
	Establish protocols for future population monitoring and record keeping, including mechanisms to assure consistent implementation and reporting.	9
	Develop and evaluate protocols for the inventory and monitoring of sage-grouse populations and to evaluate factors that influence the population ecology of sage-grouse.	9
	Evaluate alternative methods for estimating sage-grouse population abundance (e.g., line transects or DNA fingerprinting using fecal samples).	9
	Refine methods to estimate population sizes.	12
	Develop an efficient method for estimating population size, especially for regions where only a subsample of leks can be monitored.	12
Population – Multi-scale condition – Monitoring	Develop local statistical relationships between key demographic parameters and environmental variables, such as vegetation characteristics or predator abundance, to bridge the gap between large-scale population monitoring and detailed demographic studies.	2

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Sage-Grouse Biology—Continued		
Population – Multi-scale condition – Monitoring	Inventory and monitoring methods/implementation to assess individual populations and habitats as well as regional conditions.	14
	How effective are data collected from a small numbers of leks or single populations at assessing conditions across regions/rangewide? – Related to connecting survey and sentinel approaches (e.g., for monitoring).	13
Population – Pellet counts – Monitoring	Are pellet counts an effective survey technique for sage-grouse abundance or presence/absence?	6
Population – Productivity	Does productivity vary by age, region, habitat, weather, predation pressure, and management?	6
Population – Recruitment	A better understanding of recruitment and more accurate measure of recruitment in certain areas is vital to developing management recommendations for nesting and early brood rearing habitats.	2
	Some components of recruitment, such as post-fledgling survival and female nesting propensity, are poorly understood.	18
	Because recruitment at the population-level is an aggregate of multiple individual vital rates, it is important to understand the contributions of each and the ecological factors that affect them.	18
Population – Regulation	Determine the nature of interaction between population status of sage-grouse, as expressed by estimated vital rates, and habitat condition.	4
	What portion of sage-grouse life-history are limiting?	15
	What role do top-down and bottom-up processes play in regulating sage-grouse populations?	18
	How do top-down and bottom-up mechanisms influence individual vital rates, and how those vital rates contribute to population growth?	18
Population – Reproduction	Determine relationships between condition of the hen during the pre-laying period and the weight of chicks at hatching and chick survival.	2
	Determine relationships between brood-rearing habitat components and chick survival.	2
	Determine the factors that are important in regulating chick survival (and ultimately population conservation) by comparison of health and reproductive parameters, habitat components, and chick survival rates.	2
Population – Scoring – Monitoring	What metric should be used to develop a region-wide score-card to track progress toward desired outcomes and point to areas or population needing improvement?	6
Population – Sex ratio – Monitoring	Sex ratio for sage-grouse – The data needed to accurately estimate sex ratio and the potential techniques to provide a reliable estimate of sex ratio are not clear.	6
Population – Spring Count – Monitoring	Can another tool be developed (e.g., distance sampling) to monitor numbers in late summer or early fall that would be less confounded by previous year's conditions and management than spring lek counts when evaluating annual management?	18
	Statistical relationship between lek counts and populations. Sampling design so states do not have to spend time sampling every lek.	18
Population – Survival	Determine survival rates.	2
Population – Technology – Monitoring	Variation in the technology used to capture and mark birds for monitoring.	6
	New techniques for capturing and monitoring sage-grouse?	6
	Development and application of improved techniques and technology including satellite transmitters, GPS transmitters, and transmitters capable of recording physiological data.	6
	Are there new methods, approaches, technologies to population estimates that could improve the accuracy, reduce effort, decrease time-frames for estimation?	6
	Can modern technologies improve accuracy of counts?	6
Population – Translocation – Monitoring	Evaluate translocation methods (egg transplant, captive incubation, captive breeding and release as young, release as adults, etc.) to develop protocol for future sage-grouse translocations.	3, 9, 10

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Sage-Grouse Biology—Continued		
Population – Trends – Monitoring	Develop statistically defensible methods to estimate sage-grouse population size and/or trends.	9
	Causal mechanism for population cycles in sage-grouse populations.	2, 3
	A rigorous monitoring protocol is needed to assess population status and trend at the fine and mid-scale.	4
	Develop a monitoring strategy that will measure long-term statewide sage-grouse abundance and distribution trends.	4
Population – Trends – Monitoring	Develop robust methods for be establishing estimated population size.	12
	Relate variation in annual rates of population change to habitat and environmental change/ trend/conditions (ID/define/characterize causal linkages between populations and habitat).	13
Risk assessment	What is the definition of an at-risk sage-grouse population?	9
	Identification, at a broad scale, of ecosystem units (hundreds or thousands of acres) which constitute strongholds for large populations of sage-grouse, which are in relatively good ecological health, but which are ‘at risk’ by threat of wildfire and/or imminent invasion of cheatgrass or other exotic species from adjacent areas.	2
	Prioritize sage-grouse populations by risk status.	1
Risk assessment – Population modeling	Legitimate population viability analysis that focuses on threats, population dynamics, and habitat that leads to range-wide prioritizing for conservation efforts.	18
	Refine the population viability assessment of sage-grouse based on more accurate and precise estimates of demographic parameters.	9
	Importance of understand threats and their influence on population viability.	9
	Is a 500-breeding-bird-minimum a biologically defensible population count to maintain or sustain a healthy sage-grouse population?	10
	Population viability analysis (PVA) – number of populations required for long-term conservation.	15
	Refine and improve PVA inputs, estimation of quasi-extinction thresholds, variances in growth rates, etc. Improve upon the classic approaches, including models that are based on estimates of both long-term changes (time or year effects) in carrying capacity recent changes in rates of change in the last 20 years (period effects) and a variety of forms of density dependence (linear vs. log-linear and zero- to two-year time lags).	13
	Using a hierarchical analytic structure (similar to orders/levels of selection), identify regions where greater sage-grouse are likely to persist and whether we can focus conservation actions on specific regions or components to avoid global extinction.	13
	Holistic assessment of a diverse set of environmental factors (including , but also beyond those typically considered in literature) including biotic, abiotic and anthropogenic as predictors/determinants of sage-grouse population persistence/extirpation potential.	13
	Population viability analysis.	10
Seasonal	Identification of seasonal habitats and movements (migratory or non-migratory) for all populations, including those on private lands (local populations).	10
Seasonal – Nesting	How does the lag time in grass cover for spring nest concealment from prior and this year’s precipitation affect nest success? How about for summer forbs?	18
Seasonal – Winter	How adaptable are grouse to changing winter conditions, especially snow depths? Can this be monitored with winter survival rates?	18
Translocation	What is the effectiveness of re-introduction of sage-grouse into formerly occupied portions of their range?	6
	What protocols need to be developed for translocation and how is project success determined?	6
	How effective is it to augment existing populations of sage-grouse with birds from different populations?	6
	Where are populations sufficiently robust to allow trapping of birds to transplant where genetically appropriate?	18

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management		
Condition – Composition	How do sage-grouse relate to habitat composition at landscape scales, and how do landscape-scale requirements interact with site-specific vegetative composition?	18
	Determine the reason for suppressed herbaceous understory (e.g., soil condition, historical grazing management, drought) and identify/implement methods for improving understory health.	5
Condition – Grazing	Identify reasons for lack of grass and forb cover in sagebrush communities and recommend/implement practices to increase the native herbaceous understory.	4, 5
Condition – Habitat quality	Identify areas of dense mature cover that do not appear to be serving as quality habitat and assess condition and value of these areas within the context of a larger landscape.	4
Condition – Historic	Assessment and comparison of long-term/historic grazing, and other dominant land-use effects, on condition and function of the sagebrush ecosystem – comparisons with relict and protected sites; historic interpretation; field tests.	17
Condition – Mapping	Identify and evaluate habitat suitability.	6
	Map and inventory areas believed to be deficient in quality of habitat or exhibiting poor health.	4
	Identify and map key sage-grouse habitats and where other wild (all, discriminantly?) herbivores are having significant impacts. Is the use seasonal? What is timing of overlap? Condition of overlapping use areas?	4, 5
	Identify and map land cover, species specific canopy cover of sagebrush, age distribution, and herbaceous understory of sagebrush habitats. Evaluate habitat quality of herbaceous understory of sage-grouse habitats at local levels. Develop methods for regular updates.	1, 4, 5, 6, 7, 9, 10
	Except for a few areas, accurate vegetation data to delineate existing and potential habitats at the subbasin scale for sagebrush steppe are lacking.	4
	Maintaining (current) data on populations, habitat conditions/suitability, connectivity, seasonal delineations, and threats – e.g., habitat maps.	15
	What regions within the sage-grouse range share common ecological attributes?	6
Condition – Monitoring	Monitoring long-term changes in habitat quantity and quality.	6
	Document (and frequently update) current conditions.	6
Condition – Monitoring – Methods	Habitat monitoring techniques available to monitor long-term change in habitats.	6
	What is the most effective way to conduct a range-wide scale assessment of habitat condition?	6
	Develop, adapt, coordinate, and unify implementation of monitoring and monitoring protocols for habitat conditions. (This will also require development of methods/scales/indices/etc. for interpretation of range/habitat conditions.)	14
	Calibrate monitoring with sage-grouse orders of habitat selection (multi-scale),	6
	Develop, consolidate, document, and otherwise implement “established habitat monitoring techniques.”	6
	Universally adopted methodology or process in place for evaluating and monitoring habitat characteristics.	7
Condition – Other wildlife	What is/are the effects of “increased use” (and/or other land-use ramifications) of non-priority areas on sagebrush and other semi-arid habitats, and species.	13
	Assess habitat characteristics/values for multiple species, across multiple scales – landscape scale matrix-patch distribution, community structure, and variability within “the matrix” (patch heterogeneity). Can the habitat distribution/requirements and behavior of sage-grouse and other sagebrush obligates be used to define the range of conditions (landscape and within patch) required across the landscape to support these species?	13
Condition – Recommendations	How general or specific do habitat recommendations need to be given the similarities and/or differences in habitat requirements among populations and regions?	18
Condition – Soil	Develop high quality, consistent, and accessible soil and vegetation data and models that describe how changes occur in response to stress and disturbance.	7

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Condition – Surface water	How can changes in water management increase the productivity of sagebrush ecosystems and enhance sage-grouse populations? What is importance of surface-water flow? Importance of “free water” for sage-grouse?	4, 6
Condition – Variability	What is the influence of shrub steppe habitat variability on sage-grouse populations (distributions, use, seasonal, etc.)?	13
	Where on the landscape are habitats meeting the Guidelines (Connelly and others, 2000a)?	6
	Increase understanding of limiting factors such as drought, grazing management, predation, human disturbance, soils, and other environmental variables on sagebrush ecosystems.	4
Condition – Veg-Pop linkage	Evaluate the impact of vegetation condition on sage-grouse populations.	9
	Evaluate the effects of vegetation “quality” (e.g., vegetation structure, sagebrush canopy height/cover, forb/grass height, diversity, and abundance, nutrition available to sage-grouse) on sage-grouse productivity, adult survival, and population dynamics.	6, 9, 12
	Investigate and elucidate connections (especially causal) between habitat quality and response/effects on sage-grouse populations.	17
	Assess, monitor, and evaluate shrub cover characteristics capable of supporting sage-grouse seasonal habitat requirements.	1
Condition – Veg-Pop linkage – Ecosystem function	Age, vigor, or health of sagebrush ecosystems and the subsequent impacts on sage-grouse.	6
Condition – Vegetation structure	Within each ecological unit, determine the appropriate range and distribution of canopy cover classes for each sagebrush alliance.	4
Configuration – Composition	Identify the appropriate mix of sagebrush habitats and seral stages necessary for sustainable sage-grouse populations, consistent with site capabilities.	9
	Determine multi-scale changes in land cover composition and configuration in sagebrush ecosystems.	6, 9
Configuration – Connectivity	How do plans/abilities/implementation of habitat conservation, enhancement and restoration promote and/or enable movement, connectivity and genetic diversity within sage-grouse pops.	14
	Is there a difference (relative importance) between improved connectivity (of habitats/sub-populations) and increased habitat area? Is more simply better, or is configuration more important that total area? What is the balance? Is there a threshold?	17
	How do position and patterns in the landscape distribution of sagebrush habitats affect connectivity of sage-grouse populations?	13
	Evaluate, prioritize, and map connectivity linkages that are most important to sage-grouse movements and dispersal. How linked are small populations with large populations?	3, 9, 10
	How does the loss of habitat or degradation of habitat affect the connectedness/continuity of populations?	10
	Identify habitat fragmentation effects on sage-grouse. Determine the sufficient minimum habitat patch size for sage-grouse, as it relates to habitat fragmentation.	9
	Identify the habitat interspersion and juxtaposition that meets habitat requirements and facilitates connectivity among groups.	4
	Is there a difference between natural and unnatural fragmentation?	6
	Investigate the suggestion “that sage-grouse may have adapted to a scale of natural fragmentation in sagebrush habitats organized at 4.5 to 9 km…”	17
	Need to determine optimum patch sizes and connectivity for year round habitat needs. Important to understand dynamic needs within and across years as likely affected by weather/climate; development/reclamation patterns; underlying population cycles; etc.	18
	What type of habitat ‘barrier’ or how much distance between occupied sub-populations is needed to effectively restrict the movement of sage-grouse?	6
	Identify how habitats are connected and determine if improvements can be made.	10

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Configuration – Connectivity	Better understand relationships between landscape-scale habitat patterns, sage-grouse seasonal use, and connections to population genetics.	17
	Identification and prioritization of "intact" existing habitats, large areas, connected networks and connective habitats and relationship to population connectivity, dispersal and migration.	13
	Role of areas with perceived "lower biological values" but may have particular values as transitional, connective or other habitats,	13
	Importance of habitat features (vegetation types, core habitat areas, etc.) for maintaining connectivity within and among populations.	13
	What landscape features act as barriers to or facilitate movement?	18
	What blocks of habitat have highest priority for protection for birds nesting in one country or state that traverse international and state borders and the intervening scores of miles to adequate wintering habitat? What is the network of connectivity among habitats and birds across federal, state, and private lands?	18
Configuration – Mapping	Where are the areas of habitat loss and fragmentation?	9, 11
	Use remote sensing and other techniques to determine the current state of fragmentation in sage-grouse habitat.	9
Configuration – Quantity	Determine habitat loss thresholds for sage-grouse populations using spatially explicit landscape models (i.e., how much habitat is needed to sustain a population).	9
	What are the causal mechanisms between habitat loss, juxtaposition, and population demographics? – sage-grouse declines with habitat conversion as low as 1.5–2.5 percent results in declining counts; 16 percent causes substantial decline and 25–27 percent extirpation.	17
	Investigate the quantity of habitat (i.e., patch size) needed to sustain sage-grouse.	9
	What is the optimal size and configuration of habitat patches occupied by sage-grouse and what are the effects of habitat fragmentation on sage-grouse? (Direct impacts on habitat selection and movement and indirect impacts on genetic interchange and extinction risk.)	1, 4, 6, 9
Conifer encroachment – Mapping	Map current area of conifers and evaluate expansion rates. Prioritize areas with greater potential loss.	16
Disturbance – Mapping	Use and refine existing vegetation and other map data to develop a better understanding of piñon-juniper/mountain shrub, industrial, agricultural, and urban encroachment on sage-grouse habitat.	9
	Application of GIS and remote sensing to map habitat and habitat threats (Cheatgrass, juniper, restoration progress).	6
	Developed habitats – areas where vegetation manipulation or other activities have fragmented, degraded, or removed habitat.	4
	Develop maps of sage-grouse habitats for both statewide and local conservation planning and management efforts. Include documented positive or negative influences to sage-grouse or their habitat (e.g., land treatments, wildfire, utility corridors, etc.).	1
Disturbance – Monitoring	Evaluation and re-evaluation (monitoring of status and trends) of balance between multiple-uses and wildlife habitat requirements.	17
Dynamics – Mapping	Quantify vegetative changes during the last 50 years in terms of overall cover, species composition, sagebrush community seral changes, and sage: grass: forb: bare ground ratios. Investigate correlations between vegetative and sage-grouse population changes.	1
Ecosystem function – Disturbance	Define the capability of ecosystems and vegetation communities to withstand stress and/or disturbance and maintain capability of full recovery.	7
	Acquire quantitative knowledge of ecological thresholds, indicators of change, and key decision points in the framework of comprehensive monitoring systems	7

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Ecosystem function – Resilience	Identify and differentiate establishment, survival and growth requirements for sagebrush and perennial herbs and model potential effects on future landscape and habitat conditions given: fire, grazing/herbivory, and weather/climate.	13
	In addition to sage-grouse, a broader understanding of other aspects of the sagebrush ecosystem such as invasive plants, natural dynamics, restoration processes, wild and domestic grazing effects, disease, climate, and other drivers of system function and habitat conditions is needed.	13
	Identification and details of causes of degradation or invasion of sagebrush ecosystems (habitats), including remedies.	13
	Better characterize recolonization and growth of key spp. and community composition and functions with respect to disturbance, reclamation, and landscape restoration.	13
	Development of “accelerated restoration” processes to decrease community recovery rates and ultimately increase the probability of reestablishing sage-grouse use, post-development.	13
	Test this statement: “Climate, soils, precipitation, and characteristics of the previous community affect resistance and resilience of sagebrush communities to disturbance” – and use results to help guide prioritization and implementation.	13
	Does the resistance and resilience of sagebrush communities increase with increasing moisture?	13
Effectiveness – Monitoring	Improve upon and standardize disturbance buffers. Monitor the effectiveness of recommended disturbance buffers.	7
	What are “suitable” buffer distances for different/similar anthropogenic features/ disturbances?	14
	Determine the effectiveness of habitat management methodologies including other wildlife.	3
	Develop and implement a valid monitoring plan for reclamation activities in sage-grouse habitat.	9
	Effectiveness Monitoring – protocols/methods development, distribution, compilation of data, analyses.	15
	Develop and maintain cumulative records for all vegetation treatments to determine and evaluate site specific and cumulative impacts to sage-grouse habitats and identify best management practices for successful vegetation treatments.	1
	Provide objective appraisal of conservation actions, plans, treatments, etc. via monitoring of effects and effectiveness – local projects/actions in the context of regional; regional assessment that includes treated and non-treated site conditions.	14
	Evaluate impacts of treatments and policy implementation.	6
	Assess habitat restoration, disturbance-recovery, and sage-grouse utilization.	6
	What monitoring protocols/methods are best for assessing restoration success?	15
	What are the appropriate response variables that should be used to monitor management effectiveness? Understanding how management actions promote positive changes to sage-grouse populations requires appropriate post-treatment monitoring.	18
Effectiveness – Monitoring – Methods	What are the best protocols for recording vegetation treatments and monitoring efforts?	6
	How (e.g., what scales, what indicators) do we estimate that … “at least 70 percent of the land cover provides adequate sagebrush habitat”? AND – will this “maintain or increase current populations”?	14
	Develop a consistent approach for monitoring, evaluating and reporting restoration efforts.	7
Habitat selection – Scaling	At what scales (temporal and spatial) should we focus research regarding sage-grouse ecology? More information is needed on what scales capture individual ecological relationships (e.g., habitat selection or reproductive success).	18
	Research should focus on resolving issues with identifying appropriate scales for specific influential environmental factors.	18

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Landscape – Modeling – Management and policy	Improve science-based tools for predicting habitat distributions across areas of concern is important for effective management planning.	18
Landscape – Monitoring – Methods	Protocols to assess landscape change (disturbance and dynamics).	13
Maintenance/Rehabilitation/ Restoration – Conditions	Define what constitutes meaningful mitigation to meet site- and/or issue-specific sage-grouse population and/or habitat objectives.	9
	What are the current conditions, including values for wildlife and livestock, in historic (circa 1950–79) habitat treatments (plow and seed with crested wheatgrass)?	13
	Design and implement vegetation manipulations that benefit sagebrush ecosystems in the long-term with consideration for the needs of sage-grouse.	1, 4
	Monitor, compile, compare, and assess the effects of rest (passive restoration) and active restoration on condition and function of degraded sagebrush range.	17
	Relative role/importance/value of different habitat components for sage-grouse in different seasons; Is there net benefit or loss for sage-grouse when “mature sagebrush” is treated? short- vs. long-term impacts; grouse vs. vegetation community.	17
Maintenance/Rehabilitation/ Restoration – Conditions – Veg-Pop linkage	How strong is the population-habitat relationship? Can habitat restoration compensate for other disturbances and influences?	14
	Can we quantify objectives related to habitat quantity and condition as they are expected to affect sage-grouse population numbers/trends? (Is this even practical, meaningful, attainable, etc.)?	14
	Evaluate the role of habitat treatments (current role/impact of historic treatments) as sage-grouse habitat, or keeping livestock off sage-grouse habitat or … What is the current role, could it be improved (with sagebrush planting, for example)?	14
	What is the role/suitability (ability) of mitigation to provide usable and used habitats? (If we re-build it, will they come?)	14
Maintenance/Rehabilitation/ Restoration – Connectivity	Test the ability/role of restored habitats to support connectivity, dispersal and migration – Do corridors and habitat islands have value for birds? What are interactions between habitat characteristics, environmental patterns/circumstances and sage-grouse behavior (use of those habitats)?	13
Maintenance/Rehabilitation/ Restoration – Effectiveness	What is the effectiveness of herbicides, fires, and mechanical treatments for improving conditions for sage-grouse? Are negatives compensated for by positives?	4, 6, 9
	Effectiveness, effects, and differentiation of effects (based on environmental and land-use covariates) of conservation reserve program (CRP) easements and SGI habitat management; can comparable program for public lands be implemented?	17
Maintenance/Rehabilitation/ Restoration – Effectiveness – Ecosystem function	Effects of management actions, and related disturbances, including Rx burn, wildfire, invasive spp., veg. restoration, other forms of sagebrush reduction… on sagebrush ecosystem conditions and habitat values [and how do birds respond].	13
	Effects of management actions – should also include recovery rates, environmental factors/ correlates, monitoring/BACI, etc.	13
Maintenance/Rehabilitation/ Restoration – Effectiveness – Veg-Pop linkage	Evaluate whether vegetation treatments improve sage-grouse habitat in a way that affects sage-grouse population parameters, such as nest success.	9
	Document and evaluate the demographic and population level response of sage-grouse to habitat creation and/or improvement are desperately needed.	9
	Response of sage-grouse to habitat modifications in a rigorous (i.e., replicated, controlled, experimental) fashion.	9
	Examine the effects of different habitat treatments on the quality, quantity, and configuration of sage-grouse habitat, and the responses of sage-grouse populations.	9
	Determine the ecological relevance of the “70/30 objective” using monitoring and inventories.	12

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Maintenance/Rehabilitation/ Restoration – Management and policy	Design/develop post-restoration management guidelines/best management practices (BMP) to ensure/promote long-term value and persistence.	14
Maintenance/Rehabilitation/ Restoration – Mapping	Identify potential locations where there may be opportunities for offsite mitigation for sage-grouse. Identify suitable mitigation practices within those areas.	9
	Create a central GIS database to track all sagebrush modification treatments and natural disturbances across sage-grouse range.	9, 12
Maintenance/Rehabilitation/ Restoration – Methods	Design, plant, evaluate, and report on field trials for establishing desired vegetation to serve as sage-grouse habitat in CRP, cropland, and large monocultural non-native grass plantings.	9
	Improve the commercial availability and supply of native grasses and forbs suitable for restoration in arid and semi-arid environments.	7
	What management practices and policies maintain or recover sagebrush habitat? What practices have worked/not worked in the past?	6
	Methods for rehabilitating areas lost to fire, so that cheatgrass invasions are minimized.	12
	Develop techniques to increase herbaceous diversity and density in sagebrush steppe.	4
	Research practical methods for restoring the forb component required by sage-grouse.	3
	What are the available restoration methods and their effect across the full range of habitat types and degrees of disturbance? What are the best planting techniques? How can specialized equipment be improved and increase durability?	6
	Document and publicize both effective and ineffective sagebrush treatment methodologies to enhance knowledge of treatment technologies and avoid repeating treatment failures in similar sites.	10
	What are the procedures for growing and producing desired seed species?	6
	What are the priorities for developing propagation procedures?	6
	What species will be required and the amount of seed necessary to restore identified restoration sites on an annual basis?	6
	When should non-native species be used to meet community restoration goals?	6
	What are the best methods for determining the restoration potential of particular habitats that have been degraded?	6
	What are the desired attributes of restored habitat (by region and life cycle requirements of sage-grouse) and what techniques are likely to achieve those results?	6
	What is the most effective monitoring program to evaluate the effectiveness of treatments and management adjustments toward meeting restoration goals?	6
	Establish common sampling, methods, protocols, metrics, for monitoring effectiveness of restoration treatments and management adjustments at local, regional, and range-wide scales. Included sampling in areas reflecting life cycle requirements.	6
	What are the potential seed and equipment needs for implementing restoration efforts?	6
	Develop more effective habitat restoration techniques for sage-grouse habitat to improve success of rehabilitation efforts to restore previously degraded sagebrush communities, meadows, and riparian areas in uplands.	10
	Documentation will help evaluate levels of surface disturbance needed for sagebrush seeding, identify the best seed mixes for local use, and help other land managers benefit from previous restoration efforts and results.	3
	Research is needed to improve current knowledge of habitat maintenance (prevention) and enhancement (rehabilitation).	12
	Effectiveness and use of nonnative plantings (namely crested wheatgrass) as a stabilizing mechanism for disturbed sagebrush communities.	12
	Methods to return sites planted with non-native to native shrublands and grasslands.	12
	What are the ecological ramifications of seed type selection?	6
	What are the seed viability and germination rates?	6
	Importance of locally adapted seeds?	6

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Maintenance/Rehabilitation/ Restoration – Methods	Developed programs to produce or increase production of native seeds for rehabilitation efforts, preferably seeds of 'local' origin?	4, 6
	What are the best techniques for revegetation?	6
	Can inter-seeding be used to re-establish specific types of vegetation in native habitat or CRP?	6
	Develop and research techniques to re-establish sagebrush vegetation and how do these techniques differ by basic habitat type, region, soil type, and landscape configuration?	6, 7
	Develop and implement techniques to increase herbaceous diversity and density within ecological limits.	5
	Identify large areas of introduced crested wheatgrass (*Agropyron cristatum*) and determine if restoration efforts are appropriate (used by wildlife, decrease pressure on adjacent habitats, etc.).	5
	Expansion, application and effectiveness evaluations for suite of range condition treatments for a range of starting conditions (slightly degraded to poor condition).	17
	Restoration methods to restore functioning sagebrush ecosystem.	15
	Lack of understanding of the processes necessary to restore sagebrush ecology.	15
	Determine how to restore historical habitat functionality, including connectivity, total area and condition.	14
	Develop native seed sources, harvest areas, etc. – including target species, and range/ environmental considerations; also consider potential future climate and long-term viability and ecosystem productivity.	14
	How do we restore herbaceous plants (grasses and forbs) in the intershrub spaces without killing sagebrush?	18
	Are there techniques that can be employed to decrease the amount of bare ground and restore biological soil crusts in locations where they are missing?	18
	What is the ideal size and pattern of burned sites for enhancement of foods for sage-grouse chicks?	9
	How do we restore ecosystem functions? Can we increase the rates of growth and recovery of perennial vegetation? What about soil nutrients, stability and moisture retention capabilities? What level constitutes "restoration"? How long does it take?	14
	Develop, design, enhance, and improve recovery and restoration methods to reduce invasion by noxious spp., and improve native spp. Responses – especially sagebrush re-establishment.	14
Maintenance/Rehabilitation/ Restoration – Monitoring	How do we determine restoration success when establishing a functioning sagebrush ecosystem may require decades or centuries?	15
	Develop protocols for assessment of restoration effects/effectiveness on sage-grouse populations (demography and behavior).	13
	Develop and implement a valid monitoring plan to assess sage-grouse habitat restoration and to measure success with respect to sage-grouse.	7, 9
	Develop and publish methods to better evaluate the effects of habitat improvement projects on sage-grouse populations; and use those methods to monitor and evaluate the effects.	10
	Develop a consistent approach for monitoring, evaluating, and reporting restoration efforts.	7
Maintenance/Rehabilitation/ Restoration – Planning	Development of approaches/case studies for collaborative, landscape and conservation planning; inter-agency, trans-boundary, inter-office coordination and integration.	13
Maintenance/Rehabilitation/ Restoration – Population response	Determine whether sage-grouse will move to mitigation areas as mine and energy development sites develop in active habitat.	9
Maintenance/Rehabilitation/ Restoration – Prioritization	Develop priorities and implement habitat enhancements in historical or potential sage-grouse habitats.	1
	Develop priorities and implement habitat enhancements in areas currently occupied by sage-grouse.	1

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Maintenance/Rehabilitation/ Restoration – Prioritization	What is a realistic extent (acres and/or percent of historic) that can be restored to support the needs of sage-grouse?	6
	What is the appropriate scale for assessing restoration potential?	6
	Where are areas that restoration can be accomplished via management changes versus active intervention?	6
	Where and what is the extent of historic range that is unlikely to be restored without substantial mechanical involvement or cost? What is the definition of unlikely?	6
	Where and what is the extent of area likely to be restored with adjustments in management, limited involvement, and/or reasonable cost? What is the definition of likely?	6
	What are the important criteria for prioritizing likely restoration areas, by SMZ?	6
	Identify and prioritize areas for restoration.	3
	Prioritize implementation of projects/areas based on environmental variables that improve chances for success – these priorities and variables need to be defined/developed and implemented.	14
	Identify restoration potential (characteristics of these areas, and the methods for delineation/ definition, are also needed) – prioritize base on the value/context of the site coupled with the site restoration potential.	14
	Determine potential to replace lost priority habitat caused by disturbances; increase connectivity via restoration/mitigation.	14
	Develop and refine regional prioritizations, assess restoration potentials, assess restored habitat conditions for potential threshold in condition that leads to increasing use – regional assessments of current habitat status.	13
	Development of habitat restoration directives/directions – broad perspectives/priorities, restoration potentials, economic barriers and opportunities, environmental effects/ covariates; multi-scale habitat selection – nested habitat restoration approaches.	13
Maintenance/Rehabilitation/ Restoration – Recovery	Does the short-term increase in forb cover post-fire offset the long-term recovery of sagebrush canopy? (Addressed with respect to the distribution, abundance and quality of seasonal sage-grouse habitats.)	9
Maintenance/Rehabilitation/ Restoration – Veg-Pop linkage	Better characterize the relationships and behavioral responses between sage-grouse and disturbance, reclamation and landscape restoration – if we repair it, how long until grouse re-establish and use these areas?	13
	Habitat restoration (vs. typical restoration) – characterization of conditions, actions and activities, measures and monitoring required for successful habitat restoration (characterized by condition and use).	13
Maintenance/Rehabilitation/ Restoration – Prioritization – Viability	Interactions of restoration cost/values, long-term recovery rates and climate change effects on spp. and ecosystem potentials – when/where are efforts warranted? Where are risks of disturbance/stochasticity greatest (to avoid)?	13
Maintenance/Rehabilitation/ Restoration – Weather/ Climate	Investigate potential impacts/influences of climate/climate change on restoration practices and long-term success.	14
Methods – Mapping	Can SPOT imagery be used to develop a habitat layer where other methods (e.g., QuickBird) are not affordable?	18
	Repeatable, rapid approach to broad-scale habitat mapping.	18
	How can remotely sensed data (e.g., Landsat, MODIS, NDVI) relate to aspects of the environment (at various spatial resolutions) – when is use of these data layers informative, and in which contexts are they not informative. Ultimately, if we can get a remotely sensed layer that accurately reflects life-history needs of sage-grouse, then we could do all kinds of landscape-ecology analyses (some have been done, already), including relevant measures from FRAGSTATS.	18
	Use remote sensing to map sage-grouse habitats.	6

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Methods – Monitoring	What are the best long-term monitoring protocols to measure the effectiveness of the conifer treatments?	6
Methods and Coordination – Mapping	Develop mapping techniques that are consistent.	1
	Coordinate mapping efforts within and among agencies to eliminate duplication of effort.	1
	Integrate sage-grouse mapping with across state boundaries where sage-grouse are a concern.	1
	Evaluate alternatives to a radial buffer approach in sage-grouse habitat, such as incorporating local topographic conditions or habitat communities for defining geometry.	9
Multi-scale condition – Monitoring – Methods	What is the best sampling strategy that can be used to monitor habitats at the site scale and aggregate up to the range-wide scale? How effective are current habitat monitoring efforts?	6
	Investigate multi-scale implications from sage-grouse habitat selection orders to multi-scale habitat condition monitoring: connecting plant community structure, sage-grouse behavior, and landscape/land-use patterns to distributions and demographics.	14
	Investigate, develop, coordinate and otherwise adapt implementation and assessment of NRCS NRI, BLM AIM, and other methods for integrated habitat condition assessments, cooperative analyses and products, and direct feedback for management/planning.	14
	How can habitat monitoring schemes across multiple jurisdictions and multiple time periods be “joined” with more sophisticated statistical techniques?	18
Population dynamics	How do habitat characteristics influence population dynamics? A holistic approach that combines selection and success, and focuses on the overall importance of habitat at the population level is needed.	18
Prioritization	Define and identify source habitats – based on assessment of population dynamics and places where sage-grouse populations are increasing or stable.	4
	Define and identify “scarce habitats” – as areas that are limited and/or limiting and help define priority for maintenance and restoration.	4
	Prioritize areas of importance and those needing protection to maintain sage-grouse populations.	8
	Preliminary priority habitats have been identified/delineated; evaluate conditions and threats within; evaluate sage-grouse use in and around these areas.	14
	What are the best criteria for assessing and prioritizing habitats? By region and seasons?	6
Prioritization – Mapping	Sagebrush communities and potential restoration areas that are susceptible to agricultural development should be identified.	7
	What sites have appropriate characteristics (e.g., soil characteristics, sagebrush understory; also review historical photographs) to support sagebrush communities?	9
	Where can habitat easements be most effective when considering future land use and climate change?	18
	Develop an approach that will allow managers to identify critical habitats and prioritize those habitats for protection and management using strategies that will also maximize connectivity.	18
Priority Areas – Management and policy	What is the landscape juxtaposition of protected areas and land uses on persistence of sage-grouse?	15
	Determine the relationship between designated sage-grouse habitat and occupied sage-grouse habitat. Evaluate habitat designations based on outcome.	10
	Should specific areas be set aside for the protection of localized sage-grouse populations?	6
	Testing and evaluation of effects and effectiveness of sage-grouse priority areas (SGPA) (theoretical value and effectiveness as implemented).	17
	Is the “priority area strategy” affective for protecting current populations (e.g., use within vs. use outside)? Do current priority area designations continue to have the (same) value in the future – after time for changes in populations and environments?	17
	Priority habitat designation needs evaluation; many pops. multiple regions, and rangewide	14

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Priority Areas – Management and Policy	What is the ability/capability of designated "General Habitats" to provide safe migration, movement, foraging and otherwise provide connection and intermediate habitats within/between "Priority Habitats"?	14
	Risk, Cumulative Effects and Policy Integration – multiple approaches/perspectives, one is evaluation of effects of SGPA approach – considering things like: values protected, values sacrificed, population response, habitat conditions with and outside, etc.	13
Priority Areas – Other wildlife – Management and policy	In sagebrush habitats that are not Priority or General designations – what/where are the protected, rare and otherwise valuable resources/species in these areas?	14
Priority Areas – Viability – Management and policy	What location, size, configuration, or management of refuge areas would be needed to support a viable population of sage-grouse?	4, 6
	The SGPA policy should be evaluated for capacity to maintain long-term viability of sage-grouse populations, including critical winter habitat; connectivity; science-based evaluation; etc.	18
Risk assessment	What habitats are at risk? – Areas with a reasonable, foreseeable development potential, e.g., conversion to cropland. [Manier and others, 2013, does this rangewide, not locally explicit.]	4
	Develop predictive models for risk assessment and identification of use areas for wildlife species dependent on sagebrush ecosystems.	6
Seasonal – Brood-rearing	Map important brood-rearing habitat by vegetation type, range site, seral stage, and annual weather patterns.	1, 4, 5, 6, 9, 10
	Better understanding of chick habitat, especially forage, requirements; composition and abundance of forbs and insects.	17
Seasonal – Conditions	Analyze springs, seeps and pipelines to determine effects on habitat conditions.	14
Seasonal – Configuration	Evaluate juxtaposition requirements between seasonal sage-grouse habitats (i.e. mosaic requirements for nesting and early brood-rearing habitats).	1
Seasonal – Leks	Identify and map lek and lek associated habitats.	1, 4, 6, 9, 10
Seasonal – Mapping	Can we predict/identify good winter habitat across a landscape?	18
	Identify areas of overlap between seasonally important sage-grouse habitat and aquatic and riparian ecosystems.	9
	Map important nesting habitat by vegetation type, range site, seral stage, and annual weather patterns.	1, 4, 5, 6, 9, 10
	Habitat selection assessments that utilize approaches that address multiple spatial scales to represent selection processes of the animals; and development of linkages between assessments and management planning and implementation at these multiple scales.	17
	Mapping of seasonal habitats via population tracking and use patterns.	6
	Determine and map each population's seasonal habitats.	10
Seasonal – Population – Methods	What is the most effective way to assess seasonal habitat use?	6
Seasonal – Predation	Better understand, improve connection between habitat quality, nest site quality, predator behavior and predation avoidance – especially w.r.t. grass/stubble heights, community composition/structure/condition, landscape/land-use context.	17
Seasonal – Winter	Is there sufficient understanding and protection of winter habitat?	18
	Map winter habitat by vegetation type, range site, seral stage, and annual weather patterns. Develop a measure of snow depth on the landscape for predicting winter habitat. Where does severe winter range occur?	1, 4, 5, 6, 9, 10
Soils – Data	Establish baseline information for evaluating soil conditions and ecological processes and when monitoring seasonal sage-grouse habitats.	5
	Refined, improved, updated soils (complete SSURGO) – provide detailed and accurate state-transition models to compliment ESDs and SSURGO mapping – to directly inform habitat management and planning.	11

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Theme/topic	Question or Issue	Citation
Habitat Management—Continued		
Soils – Models	Develop/enhance/adapt Ecological Site Descriptions (NRCS ESDs) within priority sage-grouse habitats; identify/confirm site potentials and BMPs for ecosystem and sage-grouse habitat.	14
	Can NRCS state-transition models be evaluated as a basis for connecting habitat management efforts to annual grouse population responses from an annual life history perspective?	18
Treatment – Chemical	Effects of herbicide and pesticide treatments on sage-grouse and sagebrush habitat (direct and indirect)? Effects of each product on individual birds and in actual rangeland applications.	1, 4, 5, 7, 9, 10, 12
	Evaluate ecological consequences of using pesticides to control grasshoppers or other insects.	4
	Evaluate ecological consequences of broadcast herbicide use on forbs and other important sage-grouse foods.	4
	Investigate effects of herbicide application on sage-grouse other than desired effects (sagebrush removal) – effects on forage base, direct effects on health, etc.	4
	Are pre-emergent herbicides (e.g., Oust, Plateau) effective for controlling cheatgrass germination?	6
	Evaluate ecological consequences of using pesticides to control grasshoppers or other insects on sage-grouse food availability and vegetation cover in control versus treatment areas.	5, 7
	What are the risk, occurrence and distribution of poisoning by pesticides?	6
	Occurrence, distribution, potential and mitigation of risk/threat of poisoning by pesticide and/or herbicides (agricultural chemicals) and/or industrial toxins (e.g., Ozone at CBM sites).	17
Treatment – Conifer encroachment	What are the effects of management actions in pinyon-juniper and other conifers on species of concern and their habitats?	6
	How does reduction of conifer encroachment effect sage-grouse populations or lek attendance.	7
	What are the most effective control measures for encroaching conifer species within greater sage-grouse habitat?	6
	What are the most effective techniques for restoration of sagebrush and a perennial herbaceous understory in areas with a conifer overstory and depleted sagebrush understory?	6
Treatment – Grazing	Evaluate effects of different habitat (grazing) treatments on sage-grouse productivity, survival, and habitat use.	1
Change Agents		
Behavior – Landscape effects	Interactive and/or predictive roles/comparison of habitat distribution, landscape disturbance (especially fire), fragmentation (e.g., by roads and infrastructure), and human activity levels (correlated with development and use) leading to aversion behaviors and lek abandonment (fear vs. fidelity).	13
Behavior – Regional effects	Better relate home-range/seasonal-range requirements, spatial buffer distances, landscape patterns, population interspersion, reproductive rates and environmental covariates that help predict variations in size and impacts/impact distances, etc.	17
Behavior – Site effects	Investigate impacts and relationship between site fidelity, disturbance, restoration/mitigation, use/behavior and population demography and dynamics.	14
Demographics – Connectivity – Genetics	Better understand the effects of fragmentation, isolation, and landscape barriers on sage-grouse dispersal and population genetics.	17
Demographics – Landscape effects	Relationship between landscape-scale change (land use and development, natural disturbance, etc.) and sage-grouse behavior and population demographics. Consider/differentiate rates of change, types of disturbance, and recovery potential; link landscape conditions to carrying capacity.	13

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Theme/topic	Question or Issue	Citation
Change Agents—Continued		
Demographics – Regional effects	Demographic responses to habitat change: Example: How are populations affected by habitat treatments, grazing disturbance, energy development, fire, etc.?	18
Human footprint	Better understanding of the Human Footprint – especially interactions, accumulation and synergism.	13
Human footprint – Population response	Develop human- footprint models specific to sage-grouse, more effort needs to be undertaken to accurately assess the distribution of human resources throughout the range of sage-grouse.	13
Human footprint – Renewable energy	What the development impacts on sagebrush and sage-grouse – especially new/renewables?	15
Long-term scenarios	What are the long term effects of cumulative human impacts?	10
Roles and impacts	What are the relative roles and effect magnitude of stressors (recognizing variability by region); consider and characterize details of land-use patterns/practices within broad categories. What is the causal relationship? Where are mitigation opportunities?	13
	Model the cumulative effect of human activities on wildland systems in the Western United States including the zones of influence of infrastructure features on sage-grouse behavior and habitat use.	6, 7
	Assessment of different effects (on sage-grouse) of different "types of infrastructure" and different use/visitation/maintenance patterns at industrial sites [e.g., oil and gas (O&G) wells].	17
	Evaluate and publish the effects of wind development, disturbance densities, noise, recreation, mitigation efforts, and rehabilitation and other disturbances on sage-grouse populations (e.g., increases in noxious weeds, predators, infrastructure, etc.).	10
Roles and impacts – Degradation	Role of human disturbance (general, interactions among factors, cumulative, etc.) on habitat degradation.	11
Roles and impacts – Habitat condition	Increased understanding of anthropogenic development/use impact on habitat quality.	11
	Develop a spatially explicit population model that incorporates current estimates (with appropriate estimates of temporal and spatial variation) of demography and movement in order to evaluate the relative effects of changing land-uses on sage-grouse populations.	9
	Evaluate land use that may influence habitat conditions.	6
Roles and impacts – Interactions	Where is the balance between modern disturbance regimes (land use, fire suppression, grazing) with historic/natural regimes and the habitat requirements for sage-grouse and other wildlife, e.g., loss and fragmentation, degradation, invasion, etc.?	13
	Assess, compare and address the relative magnitude, intensity, distribution, accumulation of modern (anthropogenic) disturbances vs. of historic regimes, historical range of variation (HRV) and similar.	13
	Relationship between disturbance type, frequency and intensity and condition of the sagebrush community (including fire, herbivory, treatments).	13
	Elucidate relationships between AUM (grazing), off-highway vehicles (OHV) access, land use and land cover conversion, invasive spp., fire and fire prevention and habitat quality – most are poorly understood.	13
	What are the combinations/interactions among stressors that have the most detrimental effects on sage-grouse populations? What combination of mitigation/reduction of multiple (different) stressors has the most beneficial effect on sage-grouse populations?	13
	Habitat effects of multiple land uses including: urban/exurban development, fire, grazing (livestock, equid and wildlife), fragmentation, roads, structures, invasive species, West Nile virus (WNV)/mosquito habitats, habitat quality and quantity.	13
	Are relatively minor sources of mortality somewhat cumulative and do they combine to have a notable impact on populations?	6
	How to protect quality sage-grouse habitat from wildfire, invasive species, pinyon/juniper succession, improper livestock grazing practices, urban encroachment, roads and transmission lines, tall structures, and energy development.	6
Roles and impacts – Local effects	Improve understanding of the local effects of land uses and how legacies of past actions influence current ecosystem processes – including cumulative effects.	13

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Theme/topic	Question or Issue	Citation
Change Agents—Continued		
Roles and impacts – Methods	What methods/approaches are useful to assess and address cumulative effects (biological and socio-economic) across the range?	6
Roles and impacts – Stress	Well-designed field studies are needed to fully understand impacts of noise and other changes to the ecosystem on stress levels, and further estimate stress effects on population vital rates and seasonal space-use patterns.	18
Scales and interactions – Recovery	Landscape-scale habitat patterns, disturbance-recovery in sagebrush, population response to different disturbance patterns.	17
Scales and interactions	What is/are the scales of effects (local v. regional) of stressors, including invasive plants, over grazing, etc.?	13
	Land use imposes multi-scale effects on a background of natural disturbance, details quantifying amount/level of disturbance with response and differentiation among sagebrush systems (interactions of land use with disturbance and other environmental patterns) in determining system conditions (better determine, elucidate and/or discriminate to improve understanding of causal and predictive relationships).	13
Vulnerability assessment – Habitat condition	What are the future conditions of current sage steppe habitats in relation to a multi-variate picture of climate change, energy development, and agricultural policy?	18
	Explicitly combining information about the vulnerability of landscapes to anthropogenic risk enables conservation planners to consider aspects of urgency as well the probability for success of a given conservation strategy.	13
Change Agents – Anthropogenic Influences		
Agriculture – Easements – CRP	Assess potential for CRP lands to support sage-grouse (including current role/values), include restoration/modifications by planting sagebrush (and other native spp.) – especially nesting and brood-rearing habitat. Prioritize areas, refine seed/planting/composition practices, monitor use along with other environmental variables.	13
	Effectiveness and effective use of Conservation Easements, CRP program, etc. for sage-grouse conservation.	13
	What are the characteristics of CRP (field age, species planted, and configuration with native habitat, field size, and region) that are important for sage-grouse and can be applied over broad regions? What is the impact if expired lands are plowed?	3, 6, 9
	Evaluate the potential impact of (and techniques for) converting CRP to sagebrush habitat on sage-grouse distribution and population viability.	9
	Design, plant, evaluate, and report on field trials for establishing desired vegetation to serve as greater sage-grouse habitat in CRP, cropland, and large monocultural non-native grass plantings.	9
Agriculture – Easements – Policy	Can a national priority area be designated for CRP that prioritizes placement in such a way that there is an increased positive effect on sage-grouse?	6
	What areas are susceptible to agricultural development and which incentives are effective for retention of sagebrush habitats in agricultural areas?	6, 7
	Do farm programs, other than CRP, have a positive impact on sage-grouse and can they be extended and expanded?	6
Agriculture – Habitat condition	Interaction and interplay in impact of agriculture (sagebrush removal, toxins) and potential value during summer (or other seasons), such as CRP or similar.	13
	What agricultural lands are associated with sage-grouse habitat? Are restored croplands or non-native grasslands serving as sage-grouse habitat?	1, 6, 9
	Identify the types of agricultural practices that are beneficial or detrimental to sage-grouse.	6, 9
	What agriculture harvest techniques reduce bird mortality?	6
Agriculture – Land conversion	What are the impacts of agricultural conversion on sage-grouse populations (both short- and long-term)?	16
Dispersed recreation – Lek viewing	Short-term and long-term responses of sage-grouse to human activity at lek sites.	9
	Recreational viewing of sage-grouse at leks or on wintering grounds is also a concern if the number of visits becomes high or the actions of those viewing the birds are not appropriate.	2

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Anthropogenic Influences—Continued		
Dispersed recreation – Management	What management practices can help avoid, reduce or eliminate the disturbance or displacement of sage-grouse by dispersed recreation activities?	6
Dispersed recreation – Mapping	Where are the high-use areas of dispersed recreation in sage-grouse habitat?	6, 9
Dispersed recreation – OHV	Evaluate and publish the effects of OHV use on sage-grouse populations and habitats; evaluate the efficacy of deterrents, penalties, and enforcement of laws and mandates.	7, 10
Dispersed recreation – Population response	Evaluate the effect of recreational activities on sage-grouse mating behavior, nesting and brood-rearing success, and winter flocks.	9
	Evaluate the effect of recreational activities on recruitment and long-term population dynamics of sage-grouse.	9
	Evaluate the effect of recreational activities (e.g., lek viewing, hiking, camping, off-road vehicles, etc.) on the behavior, distribution, demography, and population dynamics of sage-grouse.	9
	Influences of dispersed recreation on nesting chronology and fecundity for a local grouse population.	9
	What are the impacts of dispersed recreation on sage-grouse?	5, 6
	What are the impacts of dog trials, snowmobiles, bird watching, and military training activities on sage-grouse?	6
Energy and Mineral Development	What are the specific effects/stressors associated with renewable energy facilities (wind, solar, geothermal) and how do these activities affect habitat conditions, sage-grouse behavior, population demographics, movement and migration, etc.?	17
Energy and Mineral Development – Corridors	Length of disturbance along buried pipe and power lines. Does continued human use of areas diminish effects of restoration efforts?	9
	What are the effects of existing energy corridors and associated facilities on sage-grouse and sagebrush habitats (e.g., fragmentation, invasive species, and noise disturbance)?	6
	What are the potential effects of proposed energy corridors on sage-grouse and sagebrush habitats (e.g., fragmentation, invasive species, and noise disturbance)?	6
	What are the best criteria and management guidelines for locating energy corridors and the continued operation and maintenance of facilities and corridors that cross sage-grouse habitat in order to minimize impacts of sage-grouse and sagebrush habitat?	6
Energy and Mineral Development – Disturbance footprint	How do individual components of oil and gas development impact sage-grouse?	9
	How do surface disturbance and fragmentation caused by energy development affect quality of sage-grouse habitats?	9
	How do impacts vary by energy type such as coal-bed methane, strip mining, oil wells, and wind turbines – differentiate size of the 'footprint', different 'setbacks', and the sex, life history stage, habitat, and region.	6
	What are the mechanisms for impacts (e.g., indirect avoidance of disturbance such as noise or vertical structures or direct mortality due to collisions or predation)?	6
	Need additional research on tolerance to energy developments – including pad densities, distance, seasonal restrictions, noise limitations and infrastructure – different effects in large populations? In more fragmented habitats and/or populations?	10
Energy and Mineral Development – Disturbance footprint – Buffers	What is the appropriate buffer distance around well pads?	9
	What are the appropriate set-backs or the ramifications of insufficient set-backs?	6
	What are the key sage-grouse habitats in need of buffering?	6
Energy and Mineral Development – Disturbance footprint – Cumulative Effects	What are the cumulative impacts to sage-grouse from energy development? Synergistic effects?	9
	Develop an impacts modeling/assessment for energy and mineral development scenarios that consider (1) reclamation efforts and results; (2) long-term changes; (3) the various stages/intensities of energy development.	9

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Anthropogenic Influences—Continued		
Energy and Mineral Development – Habitat condition – Groundwater	Potential impacts of changes in groundwater levels, due to energy production especially oil shale, on riparian and other mesic habitats with resulting potential for impacts on sage-grouse.	17
Energy and Mineral Development – Infrastructure	Evaluate the impacts of infrastructure, energy, and mineral development (including reclamation efforts following development), on the quality, quantity, and configuration of sage-grouse habitat.	9
	Evaluate the impact of utility corridors, communication towers, wind turbines and other infrastructure on predator effectiveness and resulting effects on sage-grouse populations.	9
Energy and Mineral Development – Minerals	What are the effects of Metallic/Non-metallic Minerals extraction on sage-grouse and sagebrush habitats?	6
	Evaluate the effect of mining development on the behavior, distribution, demography, and population dynamics of sage-grouse.	9
	Better characterize the effects of mining activities on sage-grouse and habitats.	17
	Connect/expand assessment and monitoring of mineral estate leases from local to landscape; local disturbances and restoration activities need to be evaluated locally for effects/impacts AND within a context of landscape scale habitat condition and disturbance.	13
	What are the effects of Surface Coal extraction on sage-grouse and sagebrush habitats?	6
Energy and Mineral Development – Mixed effects	Enhance our understanding of effects of energy development through pre-activity inventory, monitoring over the life of the development, and annual evaluation thereafter.	5
	Further elucidation and differentiation of the effects of energy development, especially traditional oil and gas, oil shales, and cola bed methane, on grouse, in different seasons and habitat conditions (sagebrush type, topography, burn/treats, etc.); searching for thresholds in distance and/or level of use where sage-grouse are minimally affected (as opposed to measurable population declines).	17
	Better elucidate the effects of energy development (e.g., oil and gas) on habitat and sage-grouse behavior, and importantly, with explicit consideration of differences in “biotic potential” among sites and the interaction of potential and disturbance in determining effects, conditions, resilience, etc.	13
Energy and Mineral Development – Monitoring – Methods	What are the most appropriate monitoring techniques for assessing the effects of new facilities and energy corridors?	6
Energy and Mineral Development – Noise	Expand understanding of the effects of anthropogenic/industrial noise on sage-grouse behavior and population demography.	9, 17
	Further investigate evidence that noise, especially intermittent noise, is a key disruptor of sage-grouse behavior.	14
Energy and Mineral Development – Oil Shale	What are the effects of Oil Shale/Tar Sands extraction on sage-grouse and sagebrush habitats?	6
Energy and Mineral Development – Population response	Study, monitor, and attempt to quantify impacts to sage-grouse from oil and gas development and mining operations (e.g., intensity, duration, and timing).	9
	Evaluate the impact of energy development on the behavior, distribution, demography, and population dynamics of sage-grouse. How specific factors affecting population parameters are influenced by energy development; and the relative impact of specific aspects of oil and gas development (e.g., intensity, duration, and timing).	1, 4, 6, 8, 9, 10
	Investigate the specific factors affecting sage-grouse population parameters (e.g., causes of female and chick mortality, effects of noise on sage-grouse habitat use or avoidance, wind direction, and topography influence on noise impacts), and how they are influenced by energy development.	9
	Studies in Pinedale, Wyoming area (Pinedale Anticline O&G development) indicated “sage-grouse declines area explained in part by lower annual survival of females…” – investigate the potential connection between development and female mortality.	14

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Anthropogenic Influences—Continued		
Energy and Mineral Development – Population response – Buffers	Investigate the need/effect/size for buffers around energy development in winter habitats. Are birds more, or less or equally, sensitive to noise disturbance in winter (i.e., compared to nesting)? Do visitation limits (anthropogenic use intensity) and/or development intensity (well pad density) affect response of sage-grouse?	14
Energy and Mineral Development – Population response – Monitor	Develop and implement a valid monitoring plan to assess the impacts of energy and mineral development on sage-grouse.	9
Energy and Mineral Development – Prioritization	Identify important areas for grouse (wintering, nesting, etc.) that require additional protection or conservation during land use planning and leasing of energy reserves.	4, 5
Energy and Mineral Development – Restoration/Mitigation	Determine the effectiveness of energy and mining mitigation actions, stipulations, and BMPs in maintaining sage-grouse populations and/or habitat across the landscape.	9
	Quality, quantity, and/or juxtaposition of mitigated habitat and its compensatory response.	9
	Management experiments that document and evaluate the demographic and population-level response of sage-grouse to habitat creation and/or improvement.	9
	How effective might it be to create new sage-grouse habitats or improve historic habitats?	9
	Need research to understand the efficacy of recommended mitigation (onsite and offsite) to avoid, minimize, or reduce the effects of surface-disturbing activities (onsite), or replace or enhance suitable habitat (offsite).	10
	What are effective mitigation practices (e.g., habitat equivalency, mitigation ratios, mitigation banking) in areas of non-renewable energy development?	6
	Need research on the effectiveness of rehabilitating or restoring sage-grouse habitat following energy development or other surface disturbing activity (this will help determine if off-site mitigation is a viable option).	10
	Provide for long-term monitoring of siting requirements to assess effects of current and future energy development on sage-grouse.	4
	Long-term impacts after oil and gas reclamation are not clearly understood.	4
Energy and Mineral Development – Stipulations	Determine the effectiveness of energy and mining mitigation actions, reclamation, existing stipulations, and BMPs in protecting sage-grouse habitat and populations.	9
	Assess the effects of proposed/implemented buffers and/or development density restrictions on habitat patterns and sage-grouse use and behavior.	14
Energy and Mineral Development – Technology	What technologies and practices can be used to offset, reduce and/or minimize disturbance associated with resource recovery activities?	6
Energy and Mineral Development – Mapping	Identify key sage-grouse areas located within potential energy development areas, to better address cumulative impacts to sage-grouse.	9
	Identify key sage-grouse areas that are not already leased for energy and mineral development.	9
	Map energy development infrastructure within sage-grouse habitat to reflect current and historic development levels, patterns, and conditions.	9
Fences – Population response	What are the direct and indirect impacts of fencing on sage-grouse? What are high risk situations? Local or population level effects?	5, 6, 7, 9, 10, 12
Fences – Structure	What fence design, siting or modifications are best at mitigating the direct and indirect effects of fences on sage-grouse?	1, 6, 7, 9
	Evaluate structural range improvements for effects on sage-grouse habitat – especially fencing.	14
Habitat conditions – Landscape dynamics	Develop monitoring systems that track and predict how changes in land use and cover affect ecosystem function across spatial scales on rangelands.	7
Harvest – Big game	Effects of sage-grouse hunt overlapping with big game season?	10

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Anthropogenic Influences—Continued		
Harvest – Demographics	How does the timing of the hunt affect sage-grouse populations and demographics?	10
	Hunting, predation, and additive vs. compensatory mortality? When, and where, can sage-grouse still be hunted? Do slow growth rates and high over-winter survival create a low threshold between additive and compensatory?	17
	Ratio of males – females in population and harvests – does harvest skew population numbers or take more females than males?	17
Harvest – Genetics	Identify genetically isolated subpopulations that could be at risk of overharvest.	4
Harvest – Methods	Links between harvest data and other survey data (leks, broods, etc.).	6
Harvest – Monitoring	Assessment of techniques for conducting harvest surveys. Questionnaires, bag count, wing collection.	6
	How do estimates from hunter questionnaires, bag counts, wing collections relate to/correlate with lek counts and brood surveys? New or complimentary information?	6
Harvest – Monitoring – Methods	Identify and implement more effective techniques to collect sage-grouse hunter statistics,	9
Harvest – Poaching	Are there population impacts from poaching?	2, 10
Harvest – Population response	What are the harvest impacts to sage-grouse relative to season length, bag limits, and sex?	1, 3, 4, 5, 6, 7, 9, 10, 12
	Is harvest additive or compensatory mortality? What are optimal/sustainable/maximum harvest rates?	1, 3, 4, 5, 6, 7, 9, 10, 12
	Implement an intensive monitoring system of sage-grouse population and harvest to refine the adaptive harvest model periodically, to affect season length and bag limit.	9
	Survivorship of sage-grouse in both the presence and absence of hunting.	4
Harvest – Population viability	Define sustainable and huntable populations.	10
	What is the range-wide standard for sustainable sage-grouse populations with sustainable harvest?	6
	Hunting Management – need thresholds (compensatory vs. additive), short-term feedback/adaptive rates.	13
	Potential role (if any) for sport hunting – additive vs. compensatory mortality; effects of variations in harvest season on demographics of mort., breeding, etc.	13
	Differential effects of sport hunting (if any) – season timing, length, bag and possession limits and season limits examined for each population with local biologically informed regulations.	13
	Harvest management (mortality effects, levels, additive vs. compensatory).	13
Mapping	Identify human features relative to existing and potential developments and sage-grouse habitat.	16
Monitoring – Methods	Develop, refine, standardize inventory and methods development for assessment and monitoring of cumulative effects of human activities.	17
Military training – Behavior	Do military "flyovers" have an effect on sage-grouse behavior?	2
Mixed issues – Movement patterns	What are the effects of anthropogenic structures (e.g., power transmission lines) on sage-grouse populations? Do these effects influence movement patterns and seasonal space-use?	18
Mixed issues – Population response	Evaluate the effect of powerlines, fences, roads, and other human infrastructure on the behavior, distribution, demography, and population dynamics of sage-grouse.	9
	Does disturbance associated with infrastructure (powerlines, fences, roads, etc.) have a negative impact on sage-grouse and what is the mechanism of that impact (i.e., visual impacts, collision risk, disturbance intensity, disturbance frequency)?	6
	Can roads, fences, power lines, and pipe lines be built or configured in such a way that the negative impacts to sage-grouse are minimized?	6
Mixed issues – Seasonal habitat	Roles, differences and potential value of seasonal use closures (industrial and recreation use restrictions during lek and nesting) – are they effective? Practical? Useful for management of human effects?	17

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Anthropogenic Influences—Continued		
Mixed issues – Vital rates	Which vital rates are affected by anthropogenic structures (e.g., power transmission lines), and are any negative impacts caused by direct effects (e.g., collision or avoidance) or indirect effects (e.g., subsidized predation), or a combination of both?	18
Renewable Energy Development – Geothermal	Effects of geothermal energy development on sage-grouse ecology.	18
Renewable Energy Development – Solar	Effects of solar energy development on sage-grouse ecology.	12
Renewable Energy Development – Wind	Habitat change: Example: Need to understand the impacts of proposed wind development on habitat loss and alterations of habitat use by grouse – this includes all infrastructure along with all development.	18
	Research and monitoring of the effects of wind energy development in sage-grouse habitats with respect to sage-grouse survival, habitat-use and behavior including: abandonment of leks, nesting, brood rearing or winter habitat and the distance from the wind turbines that effects are experienced.	3, 7, 12
	Not known if birds avoid the vicinity of turbines due to disturbance from noise, motion, or human activity, or if the area is avoided because tall structures are perceived as potential raptor perches.	3, 7
Research – Monitoring	What influence do research activities have on monitored sage-grouse?	18
Residential Development	Identify direct and indirect impacts of urbanization/domestic development on sage-grouse, including habitat quality and behavioral response.	17
	Identify occupied and seasonally important sage-grouse habitats and leks that are at highest risk of urban/suburban/ex-urban development.	6, 7, 9
	Investigate impacts of residential development on sage-grouse behavior, distribution, demography and population dynamics, due to noise, pets, and increased activity.	1, 9
	Identify potential contaminants associated with housing developments (e.g., household chemicals, fertilizers, sediments) that could impact sage-grouse.	9
Surface disturbance – Monitoring	How do we evaluate anthropogenic surface disturbance? What data? What indicators? How measured? What scale(s)?	14
Tall structures – Buffers	How far do elevated structures need to be from sage-grouse to have no effect (behavioral, predation etc.)?	9
Tall structures – Mapping	Identify and map existing utility corridors, wind turbines, communication towers, and designated utility corridors in sage-grouse habitat.	9
	Map and quantify smaller power distribution lines (<138 kv) and telephone lines in sage-grouse priority areas (SGPA). Identify specific potential problem areas.	7
Tall structures – Mixed effects	Link between powerline construction and population-level impacts (predation and direct mortality from collision).	9
	Evaluate the impacts of utility corridors on sage-grouse habitats (i.e., fragmenting effects on habitat).	9
	Evaluate the impacts of communication towers, wind turbines, and associated infrastructure on sage-grouse (both disturbance impacts and habitat fragmentation impacts).	9
	How do powerlines/poles and other tall structures affect sage-grouse populations?	5, 6, 10
Tall structures – Policy	What are the best siting and Operation and Maintenance criteria for tall structures in sage-grouse habitat that minimize negative impacts?	6
Tall structures – Population response	Population dynamics in relation to the distance from the transmission line.	2
Tall structures – Predation	Relationship between tall structures (cellular towers and transmission line poles) and sage-grouse behavior and population dynamics. Should include parallel/simultaneous assessment of predator behaviors with regards to these features and hunting sage-grouse.	13
	How far elevated structures must be from sage-grouse to have no effects on the birds (e.g., behavioral changes, increased predation).	9

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Anthropogenic Influences—Continued		
Tall structures – Predation	Evaluate sage-grouse response to new and existing power lines as associated with habitat conditions and avian predator densities.	7
	Evaluate the impact of utility corridors, communication towers, wind turbines and other infrastructure on predator effectiveness and behavior effects on sage-grouse populations.	9
Tall structures – Structure	Does modification of poles to limit perching prevent electrocution of raptors and decrease predation on sage-grouse?	4
Transportation – Collisions	Influence of collisions with vehicles, fences, and transmission lines on survival.	6
	Are there population level impacts of road collision mortality?	9
	What are the impacts of vehicle mortality/collisions (leks near roads/travel corridors crossing roads)?	10
Transportation – Fire – Invasives	Identify utility, railroad, road rights of way where invasive plants increase fire risk.	7
Transportation – Habitat condition	What are the net effects of roads, trails and OHV use on the condition/value of sagebrush habitats? including habitat loss, fragmentation, invasive plants.	17
	Elucidate and differentiate road effects, including size of road, road use/traffic levels, proximity of roads to habitat and nature of disturbance to birds (noise, dust, sight; infrastructure vs. activities).	17
	What are the effects of existing roads, trails and railroad corridors and associated facilities on sage-grouse and sagebrush habitat?	6
Transportation – Mapping	Identify, categorize (e.g., 2-track, gravel, unpaved, paved), and map roads in sage-grouse range.	9
	Identify, map, quantify, and evaluate impacts of existing roads, including 2-tracks, in relation to known lek locations and sage-grouse winter ranges.	5
	Identify, map, quantify, and evaluate impacts of existing roads, including 2-tracks, in relation to known lek locations and sage-grouse winter ranges.	4
	Accurate local, regional and range-wide Inventory of roads.	13
	Map and quantify secondary and other roads (e.g., paved county, gravel, two tracks) in SGPAs. Identify specific potential problem areas.	7
Transportation – Monitoring – Methods	What are the best monitoring plans to measure effectiveness of BMPs and mitigation measures in minimizing effects of roads and railroads on sage-grouse and sagebrush habitats?	6
Transportation – Population response	Evaluate the effects of road placement and traffic levels on sage-grouse and sage-grouse habitat.	9
	The biological meaning of particular linear density values to sage-grouse is unknown – what are the effects of different road-densities (land-use intensity) on sage-grouse distributions?	7
	What are the net effects of roads, trails and OHV use on sage-grouse behavior/populations? including displacement and avoidance behavior, noise, direct encounters.	17
	Elucidate and differentiate road effects, including size of road, road use/traffic levels, and nature of disturbance to birds (noise, dust, sight; infrastructure vs. activities)	17
Transportation – Prioritization	Identify and prioritize areas for road buffers, removal, realignment, or seasonal closures where appropriate to avoid degradation of habitat.	5
	What are the best criteria and management guidelines to locate, construct, maintain, or close roads and railroads, to minimize impacts to sage-grouse and sagebrush habitat?	6
	Travel management should evaluate the need for permanent or seasonal road and/or area closures for sage-grouse.	14
Transportation – Seasonal habitat	Evaluate impacts of existing roads, including 2-tracks, in relation to known lek locations and sage-grouse wintering areas.	4

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Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes		
Conifer encroachment – Other wildlife	What are the habitat relationships of wildlife associated with pinyon-juniper and other conifers (all phases) which have invaded sagebrush habitats, plant and animal species of concern (e.g., ferruginous hawk, gray vireo, juniper titmouse, pinyon jay) in particular?	6
Disease – Interactions	Distribution, disease ecology, effects on sage-grouse, risk assessment for WNV.	13
	Understanding long-term impacts of WNV will require intensive monitoring of radio-marked populations. Population models suggest that, except during severe outbreaks (Walker and others, 2004), natural geographic and temporal fluctuation in vital rates that drive population growth can mask impacts of WNV in any given year.	13
	Long-term response of different sage-grouse populations to WNV is expected to vary markedly depending on factors that influence susceptibility, including: (1) annual and seasonal temperature precipitation profiles, (2) land uses that influence the distribution of surface water, (3) population size, (4) genetic diversity, and (5) connectivity with other populations. Small, isolated, or genetically depauperate populations.	13
Disease – Monitoring	Implement range-wide disease monitoring – risk assessment, prediction, and make explicit connections to sage-grouse demographics.	13
	Systematic, or opportunistic, range-wide infectious disease surveillance for sage-grouse – requires protocol development, training and equipment.	13
Disease – Other diseases	What are the effects of bacterial, fungal, viral and parasitic diseases including Tularemia, Aspergillosis, hermatozoa, WNV, Avian Pox, Avian Malaria, Cestodes, coccidian, and other viral and bacterial pathogens on sage-grouse populations? When do outbreaks occur?	1, 2, 4, 6, 9, 10
	Elucidate understanding of coccidiosis, including connections with landscape patterns, habitat use, and concentrations of animals/population distributions.	17
	Disease Management – population level effects of parasites, infectious disease, reactions to toxins are rare; WNV effects, environmental triggers, risk.	13
	Potential interactions among disease, parasites, sage-grouse and climate change, anthropogenic disturbance, stress, etc.	13
	Focus on WNV – but the long-term impacts of most macro- and microparasites and their associated infectious diseases on greater sage-grouse populations remain largely unknown. We recommend that avian infectious bronchitis virus and other avian corona viruses, avian retroviruses, Mycoplasma spp., and the Eimeria coccidians and associated enteric bacteria be evaluated or at least monitored more closely in addition to WNV.	13
	What are the effects of disease on sage-grouse (especially WNV)?	11
Disease – West Nile Virus	How do agricultural water management and infrastructure contribute to the threat of WNV?	6
	WNV impact on population trends and the role of the virus in terms of observed mortality rates in subsequent years.	1, 2, 3, 4, 5, 8, 9, 10
	Determine the impact of wet conditions on mosquito production as it relates to the potential for catastrophic disease in sage-grouse. Determine the risk factors and potential of catastrophic disease in sage-grouse populations.	9
	Determine the level of susceptibility to WNV and survival patterns of each sage-grouse age and sex class. Examine whether sage-grouse can develop immunity to WNV and whether the immune response can be inherited.	2, 9
	Examine the spatial interaction of mosquito species that are the main vectors of the virus (e.g., *Culex tarsalis* and *C. pipiens*) with seasonal habitat use by sage-grouse (e.g., evaluate whether sage-grouse are more likely to be exposed to the virus in relatively wetter brood-rearing habitat than in lekking and nesting habitats).	9
	WNV exposure risk, survival potential, habitat and seasonal covariates.	17
	Research and testing of potential conservation measures for WNV.	7
	Determine alternate hosts for WNV in greater sage-grouse habitats.	2
	Effects of land management activities on WNV and its vectors.	12

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Disease – West Nile Virus	Risk mapping to predict the potential for WNV epizootics in greater sage-grouse.	18
	Continue to develop and test methods for vaccination of sage-grouse to protect against WNV infection for populations identified as high risk through risk mapping and that are particularly susceptible to stochastic events (small, isolated/endangered).	18
	Develop and evaluate management techniques designed to reduce WNV transmission especially in populations at risk.	18
	Evaluate the relative impacts of WNV versus other stressors and design mitigation strategies that will reduce the risks of the greatest threats to long-term population viability.	18
	Determine the risk of WNV in agricultural sage habitats vs. more pristine sage habitat. Where does WNV amplification occur in sage-grouse habitat?	18
Fire and fuels management – Effects/recovery	Recovery time required to reestablish sagebrush after fire, by site condition, species composition, and size/intensity of fire.	7, 9
	Where do uncharacteristic wildfires result in adverse impacts (e.g., invasive species, reduced fire return intervals)?	3, 6
	What are the effects of size of burn or treatment on response of sage-grouse individuals and populations?	17
Fire and fuels management – Landscape dynamics	Improve understanding of spatial variability in ecosystem conditions, fire history, fire regimes, recovery rates and landscape scale patch and matrix dynamics. What is the appropriate/desirable ratio of early, mid and late seral communities to provide habitat values and maintain productive ecosystems and landscapes?	14
	Test this statement (fire history, HRV, etc.): “Disturbance in some form has been an integral component of sagebrush systems throughout their evolutionary history.”	13
	Better understanding of the relationship between natural disturbances, especially fire, and the sagebrush ecosystem, including return intervals, recovery rates, historic fire behavior vs. current observations, fuel accumulation, ignition sources and frequency, seasonal patterns, variability among regions...with an eye towards informing and improving range conditions through better understanding of dynamics.	17
	Better understanding of the relationship between fire and vegetation conditions (pre and post fire) in sagebrush ecosystems – historic, desired and current/likely responses.	17
	Sagebrush fire recovery rates, eco/bio limitations, historic regimes, environmental and condition covariates.	13
	Characterize sage-grouse habitat degradation due to fire suppression, fuels management, and/or decreased fire-return intervals.	11
	Identify/describe/characterize (balance in) the role of fire in protecting and maintaining healthy sagebrush communities and loss of intact sagebrush required for habitat.	17
Fire and fuels management – Mapping	Map all burns and fuel treatments in sage-grouse habitat. Assessment of pre-burn plant species composition and diversity.	6, 7, 9
Fire and fuels management – Methods	What are the best methods for area-specific fire suppression for sage-grouse habitat? Location of fire camps, staging areas, and helibases?	4, 6
	How should habitat mosaics and fuels be managed to improve and reduce possibility of damaging wildfires?	6
	Are green strips and/or fire breaks within and adjacent to sage-grouse habitat effective at slowing or stopping wildfires? Potential fragmentation impacts?	6
	Develop criteria for managing fuels and other risks to sage-grouse habitat.	4, 5
	What are the most effective means for wildfire suppression?	6
Fire and fuels management – Monitoring	What protocols are best for long-term monitoring of the response of habitat to wildfire, prescribed burns, and mechanical fuel reduction treatments?	6
Fire and fuels management – Planning	Develop firefighting plan to protect important seasonal sage-grouse habitats.	16

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Fire and fuels management – Planning	Identify strategic locations for fire lines.	16
Fire and fuels management – Prioritization	Where and how should wildfire be managed and utilized to improve sage-grouse habitat?	6
	Where and how should wildfire be contained and suppressed in important sage-grouse habitat? What are the priorities for protection of sage-grouse habitat versus structures and other developments?	1, 2, 3, 4, 5, 6, 7, 10
	Identify and prioritize specific areas for habitat restoration and fuels modification (e.g., cheatgrass) and areas bordering roads, railroads, farmlands or other areas where cheatgrass or other vegetation poses a high fire risk.	7
Fire and fuels management – Regime	Influence of fine fuel continuity (cheatgrass) and woodland encroachment on temporal and spatial variability of fire return intervals.	13
	Expand and re-assess estimates of historic fire regimes, HRV and similar attributes, to improve perspectives on long-term trends, and regional and local return intervals.	14
	Several theories/applications regarding the role of fire and disturbance need better examination and testing – e.g., historic disturbance regime and HRV; disturbance interval vs. recovery rates (including climate, herbivory, etc.); effects of changed (shortened or lengthened) return interval on plants and animals.	13
Fire and fuels management – Restoration/Mitigation	Large-scale wildfires are likely to continue throughout the Western United States, and a better understanding of effective habitat rehabilitation following these events is needed to reduce threats of long-term conversion to exotic grassland is needed.	18
	Improve understanding of spatial variability in ecosystem conditions, fuel profiles, fire history and response of systems (post-fire) – and importantly link to sage-grouse populations and sagebrush habitat conservation.	14
	Develop more effective habitat restoration techniques for sage-grouse habitat to improve success of rehabilitation efforts after wildfire. What are the priority habitat conditions for post-fire rehab and restoration objectives when restoring sagebrush/sage-grouse habitats?	6, 10
	Develop post-fire Emergency Stabilization and Rehab. Approaches/methods/designs that maintain, improve, or minimally affect habitat distribution and quality.	14
	Develop fuels management approaches/methods/designs that reduce wildfire threats and maintain, improve, or minimally affect habitat distribution and quality.	14
Fire and fuels management – Vulnerability	Identify a process to identify fire vulnerable sagebrush habitats and spatially delineate these habitats.	16
Herbivory Effects – Domestic livestock – Economics	Conduct a cost-benefit analysis of the economic impact of different grazing management options that benefit sage-grouse	9
	Identify critical sage-grouse areas, and adjust grazing to minimize conflict between production of commodities and protection of societal values.	5
Herbivory Effects – Domestic livestock – Habitat condition	Browsing impacts on nutritional quality of plants, production, standing biomass.	9
	Link between grazing and increased big sagebrush cover.	3
	Expand our limited understanding of livestock grazing impacts on vegetation at large time and spatial scales.	7
	Can livestock management be used to improve range condition for sage-grouse?	6
	Determine land management practices, particularly grazing management, that result in optimum forb and insect density, diversity, and abundance.	1, 6
	Interactions between livestock, stocking levels, grazing seasons and seasonal habitat requirements, habitat quality, sage-grouse use, predator success.	13
Herbivory Effects – Domestic livestock – Habitat condition – Environment	Assess the effects of grazing intensity (grazing system) on habitat condition across environmental gradients – evaluate capacity and potential compared to demands, consider environmental covariates; directly assess impacts on sage-grouse habitat condition and behavior/use of those areas.	13
Herbivory Effects – Domestic livestock – Habitat condition – Fire	Evaluate and describe interactions between fire and grazing and effects on habitat diversity, distribution and condition – consider local and landscape perspectives.	1

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Herbivory Effects – Domestic livestock – Habitat condition – Interactions	Separation of drought and grazing impacts on forb abundance and sage-grouse populations.	9
	Experimentally manipulated studies to separate grazing impacts from other confounding factors.	9
Herbivory Effects – Domestic livestock – Habitat condition – Practices	Can/could/should grazing systems, BMPs and related practices, be revised/improved to reduce negative effects and improve system functions (including primary production – forage – and habitat values – food and cover)?	17
	Review and evaluate different grazing systems and their effects on the vegetation parameters (habitat conditions) important to sage-grouse.	9
	Investigate the effects and effectiveness of grazing management to meet seasonal sage-grouse habitat requirements – season/timing of grazing and grouse use; numbers of livestock, distribution of livestock, intensity of use, type of livestock.	14
	What grazing management systems (season of use, grazing duration, kind of livestock, and stocking intensity) are conducive to meeting sage-grouse habitat conditions (i.e., changes in species composition, residual cover, and forb production) and sage-grouse populations within similar Ecological Sites?	1, 6, 7, 9, 10
	Regional differences in vegetation response depending on grazing system (rotation, season, stocking rate etc.). Northern latitudes and higher elevation sites with high moisture vs. dry, lower elevation sites.	9
	What are the influences of livestock species, habitat type, region, weather, and past management practices?	6
	Design and implement grazing management systems that maintain or enhance herbaceous understory cover, height, and species diversity that occurs during the spring nesting season.	12
	Identify and evaluate effects of various grazing management plans on the interaction of sage-grouse, commodity production, and societal values.	4, 5
	Design and implement livestock grazing management practices (riparian pastures, seasonal grazing, development of off-stream water facilities, etc.) to achieve riparian management objectives.	4
	The importance of grazing pressure, rest, and rotation on the condition of sagebrush-dominated habitats and the capability of sagebrush-dominated habitats to support sage-grouse.	6
	Large replicated livestock grazing study that could focus on how different grazing systems impact sage-grouse habitat.	18
	What would be the short (1–3 years) vs. longer-term (3–10 year) impacts of livestock removal in comparison to best grazing practices for sage-grouse on fire risk (fuels) and sage-grouse habitat?	18
Herbivory Effects – Domestic livestock – Habitat condition – Trampling	What is the potential for livestock to trample nests and are there differences between grazing systems?	6
Herbivory Effects – Domestic livestock – Habitat condition – Utilization	Improve the understanding of relationship between condition of habitat, grazing and management practices using long-term productivity, composition, structure. Look for balance between agriculture and habitat to achieve system management and habitat goals.	17
Herbivory Effects – Domestic livestock – Historic impacts	What are the lasting impacts of historic overgrazing? Separate current grazing from historic impact.	9, 17
	Analyze whether the historic shift from sheep to cattle has resulted in vegetative changes.	1
Herbivory Effects – Domestic livestock – Mapping	Identify and map areas where potential conflicts may be occurring with human activities related to sheep bedding and leks.	7

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Herbivory Effects – Domestic livestock – Monitoring	Monitor the response of forbs (kinds, vigor, and production), and the compositional diversity of native species with respect to livestock grazing.	4
	Monitor the response of forbs (kinds, vigor, and production) and the compositional diversity of native species with respect to livestock grazing.	5
	What are the best standardized monitoring protocols for addressing the effects of grazing management systems to detect trends in vegetation response (vigor, production, diversity) and similarity to condition outlined in the sage-grouse habitat guidelines?	6
Herbivory Effects – Domestic livestock – Monitoring – Methods	Identify monitoring methods that are best suited to the type of grazing management being incorporated at a site. Note: proper use will vary with the type of grazing system, e.g., rest rotation vs. deferred.	4
Herbivory Effects – Domestic livestock – Population response	Identify and evaluate how domestic grazing directly affects sage-grouse – consider different life stages also – e.g., nestlings, juveniles, lekking, nesting females, etc.	2, 6, 9, 10
	What are the direct impacts of grazing on sage-grouse?	3
	Identify differential effects of grazing (location, timing, and system) and sage-grouse use/response?	13
Herbivory Effects – Domestic livestock – Seasonal habitat	How do grazing regimes affect seasonal grouse distributions from year to year on a landscape level?	18
	Identify and evaluate how domestic grazing indirectly affects sage-grouse – evaluate all seasons and seasonal habitats (nesting, brood rearing, and winter).	2, 6, 9, 10
Herbivory Effects – Domestic livestock – Water and other infrastructure	Effects of fencing and stock tanks on grazing pressure and habitat condition.	9
	Consider effects of livestock and wildlife distribution on sage-grouse prior to developing additional water sources.	5
	How do water developments affect sage-grouse and their habitat (directly and indirectly)?	10
	Impacts of infrastructure and rangeland 'improvements' associated with livestock, including fences, water provision and the removal of sagebrush (either mechanically or with fire or chemicals).	6
	Role of natural and artificial water sources (in arid environments) in providing mosquito habitats and therefore probability of WNV infection.	17
	What is the current extent of conifer species (stand age, canopy cover, snag density, soil site potential, stand density, overstory species) within greater sage-grouse habitats?	4, 6
	Where are areas of future threat from encroachment of conifer species within greater sage-grouse habitats?	4, 6
	Prioritize areas where removal of piñon-juniper to enhance sage-grouse habitat is needed.	9
Herbivory Effects – Horses and burros – Habitat condition	How is sage-grouse habitat affected by free-ranging horses and burros? Mechanisms of alteration, and which (if any) most strongly affect sage-grouse and other sage-dwelling birds.	18
	Much remains to be learned of the synecology of free-ranging horses, and how their effects on other ecosystem components vary across ecological contexts and key environmental gradients (e.g., rainfall, elevation, seasonality, temperature).	18
Herbivory Effects – Horses and burros – Habitat condition – Other wildlife	What are impacts of introduced, free-ranging equids on habitat conditions for sagebrush obligates, and habitat specialists? – invertebrates (ants and other sage-grouse foods), small mammals, passerines, etc.	13
Herbivory Effects – Horses and burros – Habitat condition – Population control	Determine effects of management, culling and population control on equids; determine effects/response on ecosystem of equid control; determine effects/response of equids on sage-grouse populations/behavior/etc.	13
Herbivory Effects – Horses and burros – Habitat condition – Rangeland health	Impacts of wild/feral equids, and removal (gathers), on rangeland health and sage-grouse habitat conditions.	12, 13, 14, 17

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Herbivory Effects – Horses and burros – Habitat condition – Wet/mesic	Understand the effects of horses on habitat value of springs and seeps for sage-grouse and other sagebrush-obligate species; highlight equid relationships with mesic areas, research from outside the region, potential interactions (e.g., Mosquito/WNV habitats) vulnerability of different systems...	13
Invasive Species – Cheatgrass	Climate induced patterns, climate change, adaptation and plasticity of cheatgrass – potential effects on ecosystem values, fire return intervals, etc.	13
	What is the risk of increased fire and loss of existing sagebrush communities due to extensive distribution of cheatgrass, combined with its aggressiveness in replacing sagebrush?	13
Invasive Species – Control and Containment	Locations and methods (soil bacteria, chemical) to control cheatgrass and restore (seed, re-treat, etc.) the native communities.	17
	What methods can be used for early detection of new patches of invasive species before they spread?	4, 5, 6
	Develop and implement management techniques that minimize the risk of invasive plant infestation.	4, 5
	What are the best integrated invasive species control methods (e.g., grazing, mowing, seeding, herbicides) that minimize negative impacts on greater sage-grouse population and their habitats?	6
	What methods are effective for containment of existing infestations (e.g., border spraying, planting barriers of aggressive plants, grazing to minimize seed production)?	6
	What are the practices that will minimize the spread of invasive species by domestic livestock and wildlife?	6
	What are the practices that will minimize the spread of invasive species by vehicles and equipment?	6
	Cheatgrass control and restoration of valuable sagebrush-grassland ecosystem.	17
Invasive Species – Habitat condition – Ecosystem function	Ecological processes affected by/affecting weeds and range degradation – e.g., altered vegetation, nutrient cycles, topsoil, biotic crusts.	15
	Which species is the biggest problem (widespread plus negative effects)? How to effectively combat (treatment development/effectiveness)? How to strategically attack widespread distributions? How to best combat re-occurrence, including seed banks, recruitment, native health, etc.?	13
	How will annual/biennial grasses such as Japanese brome affect Northern habitats in the long run? How will fire intervene in conjunction with climate change?	18
Invasive Species – Habitat condition – Fire	Interactions between cheatgrass, disturbance (history), range condition and prob. of wildfire need better characterization, understanding of causal relationships, etc.	13
Invasive Species – Habitat condition – Food availability	Effects of noxious and invasive weeds on insect communities, which are an important food source for young sage-grouse.	9
	Which, if any, exotic invasive plants do Sage-grouse use as food?	9
Invasive Species – Habitat condition – Prioritization	Identify significant annual grass infestations in relation to SGPAs – prioritize for treatment.	16
	Conduct analyses to identify intact landscapes at high risk of conversion.	16
Invasive Species – Habitat condition	Separate and define cause-effect with regard to invasive plants, disturbance, ecosystem function and services, degradation and resilience – for improved management of sage-grouse habitats.	13
	What invasive plant species pose the greatest risk to sage-grouse and their habitats?	1, 5, 6, 10, 11, 13, 17, 18
	Establish functional links between invasive species and habitat degradation.	11, 13

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Invasive Species – Mapping	Map areas of exotic plant occurrence and effect zones.	13
	Inventory and map existing invasive, introduced, and noxious weed populations within and adjacent to occupied sage-grouse habitat or suspected range.	1, 4, 5, 6, 10
	Risk mapping of annual grass invasion potential and annual-induced/triggered fire potential.	17
Invasive Species – Restoration/ Mitigation	After treatment in invaded areas what are the optimal seed mixtures appropriate for the soils, climate, and landform of the area to ensure recovery of the ecological processes and habitat features of the potential natural vegetation, and to prevent the re-invasion of undesirable species?	6, 12
	Research and develop effective prevention, control, and restoration techniques for invaded landscapes.	16
	How can exotic plant invasion following fire be mitigated, and what are reasonable strategies for reducing threats of sagebrush conversion to exotic grasslands? Are there unintended negative risks to sage-grouse from management activities to reduce risk?	18
Invasive Species – Weather/ Climate	Interaction between cheatgrass and perennial species, seed banks, stability and resilience to changes in weather and climate (effects on long-term ecosystem condition and stability).	13
Mixed issues – Herbivory	Evaluate the effects of herbivores (wild and domestic) on greater sage-grouse (e.g., nest trampling, changes in behavior, also positive effects).	9
	Review effects of herbivores (wild and domestic) on sage-grouse; evaluate effects of trampling; evaluate effects on sage-grouse behavior; evaluate positive effects on habitat, predation rates, behavior.	9
	Impacts of mule deer, white-tailed deer, elk, pronghorn, bison, and free-roaming horses and burros on sage-grouse and habitats?	6
	Evaluate the effect of herbivores on the quality of sagebrush habitat (e.g., grass and forb abundance, diversity, and vegetative structure).	9
	What are the compounding and interactive effects of livestock, feral horses and other ungulates under different range conditions, fire risk and regimes, invasive species, etc.?	17
Weather/Climate – Interactions	Role of “stochastic events” in risks to sage-grouse habitats – especially wildfire, drought – as well as interactions of these factors with other management activities/goals.	13
Other wildlife – Birds	Does the stocking of pen-reared birds, such as ring-necked pheasants have potential to adversely impact wild populations of sage-grouse?	6
Other wildlife – Colocation	Which regional species are positively correlated with the abundance of sage-grouse and which are negatively correlated and how do these negative and positive correlations relate to potential management?	6
	If other species such as mule deer or elk are treated as umbrella species for sage-grouse, how are sage-grouse effected and is this effect dependent on region, habitat, or other factors?	6
	Identify how and where sage-grouse management may affect other species, i.e., Utah prairie dog, burrowing owl, sage thrasher, mule deer, pygmy rabbit, etc.	10
	Continue, expand and improve evaluation of sage-grouse and associated management of sagebrush ecosystems, as a suitable “conservation umbrella” for a variety/multitude of sagebrush obligates/inhabitants.	13
Other wildlife – Competition	What is the influence of wild ungulates on sage-grouse and their habitat?	9
Other wildlife – Guzzlers	What are the effects of gallinaceous guzzlers built to supply free water in normally arid habitats? Are benefits offset by increased competition with other species, WNV from mosquitos, or increased predation risk?	6
Other wildlife – Monitoring	Establish an inventory and vegetative monitoring schedule to quantitatively determine the extent of the effects of other wildlife in key areas.	4, 5
Other wildlife – Restoration/ Mitigation	Assess how proposed habitat improvement projects geared toward other species could impact sage-grouse.	1

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Predation – Behavior	Research, monitoring and evaluation activities to investigate: the behavior of predator species, the intra- and inter-specific relationships of predator populations, the impact of predators and other mortality factors on specific sage-grouse populations of concern, and on sex/age classes.	7
Predation – Control	What are the functional and/or numerical responses by predators following control programs?	9
	Experimentally implement and evaluate predator control measures in areas where predation is suspected to be limiting sage-grouse, to gain a greater understanding of the effects of this management approach on sage-grouse, specific predators, and the relationship between predator species. Both short- and long-term consequences.	1, 5, 7, 9, 10
	How do different species of predators interact with each other and how is this inter-relationship influenced by predator control?	2, 6
	Evaluate whether predator management aimed at a specific predator species is an effective management tool that increases production and recruitment of sage-grouse in local populations.	9
	Predator management has been tried within the range of sage-grouse, but sufficient evidence has not been provided to support implementing control programs over broad geographic or temporal scales.	13
	The long-term biological consequences of predator control are poorly understood and may actually be counterproductive under some circumstances.	4
	Predation Management – need to characterize levels and species (better characterize risk); determine if/when needed and effective; determine predator behaviors, e.g., foraging distances.	13
Predation – Demographics	What are the effects of current levels of predation on annual survival?	18
Predation – Effects	Effect of predation on the fluctuations and viability of sage-grouse populations.	9
	Effect of predation on the demographic structure and population fluctuations.	9
	Determine age-specific mortality and identify relative risks from avian and mammalian predation within local sage-grouse populations.	9
	Information is needed to determine the presence and possible effects of non-indigenous predators or abnormally high levels of predators on sage-grouse populations, regardless of habitat quality.	7
	How do predators impact sage-grouse populations (by life history stage)?	9, 10, 15
	How do native predators (at un-naturally high population levels) (e.g., ravens) impact sage-grouse population?	10
	Assessment of predation to determine if predation is a limiting factor.	2
	Determination of the time of day and period of incubation in which nests are most vulnerable to predation.	2
	Detection of links between female time budgets and types of successful predator encounter.	2
	Does predation impact survival in a compensatory or density-independent way?	6
	What is the level of predation of snakes on sage-grouse (and/or eggs); and is this a significant source of mortality?	17
Predation – Habitat	Does reduction in canopy cover increase predation risk?	9
	Investigate the influence of sage-grouse habitat on predation rates.	9
	Investigate how predation rates on sage-grouse are influenced by the natural temporal and spatial variability in sagebrush ecosystems (e.g., plant age class, fire intervals).	9
	Investigate the influence of habitat quality (e.g., nutrition, forb/insect quality and quantity) on sage-grouse chick vulnerability to predation.	9
	Determine the factors that affect habitat quality as it relates to the level of predation.	7
	Predator population structure * predation rates * habitat variables * landscape context (relationships and interactions).	13

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Predation – Habitat	Relationship between habitat management, connectivity of suitable habitats and long-term predation rates.	13
	Research methods for increasing the populations of sage-grouse, such as reducing predation through manipulation of habitat features.	3
	Review the relationship between predation and sage-grouse populations and habitat conditions, variations due to seasons, ecosystem pattern and processes, disturbance, etc.	9
	To what extent can intact habitat mitigate the effects of increasing predators?	18
	The influence of predation, interaction with habitat features, and the role of anthropogenic disturbance are not well-understood for nesting sage-grouse and information on other vital rates such as adult or juvenile survival are lacking.	18
Predation – Habitat – Human footprint	Effectiveness of removing den sites, such as abandoned farmsteads, and nesting or perching structures, such as powerlines and fences to reduce predation.	9
	Initiate studies to determine the relationships between predation, habitat fragmentation, and habitat condition.	4, 5
	Determine the effect of habitat fragmentation as it relates to the level of predation.	7
	Does the human footprint, especially infrastructure, increase predation by common ravens? Does raven control have a substantial and/or lasting effect on sage-grouse reproductive rates?	13
	Test and compare in different regions/SMZs: The human footprint can influence sage-grouse population regulation via top-down and/or bottom-up regulatory processes. Top-down human footprint effects increase the spread of synanthropic predators into areas in which they do not occur or are present only at low densities in the absence of human features.	13
Predation – Identification	Develop better methodologies to assist in identification of predator species linked to sage-grouse predation.	7
	What is the predator community influencing sage-grouse? – distributions, behavior/foraging, interactions?	13
Predation – Infrastructure	Evaluate the impact of infrastructure, powerlines, roads, and fences on predation rates in sage-grouse populations.	9
	Document the incidence and extent of avian predation on sage-grouse nest success, juvenile and adult survival in areas with extensive infrastructure and areas without extensive infrastructure.	7
	To what extent does predation from human subsidized predators limit individual sage-grouse vital rates, and overall population growth?	18
	The overall role of subsidized predation in changing landscapes regulating sage-grouse populations remains unclear.	18
Predation – Invasive Species	Investigate how invasive weed species impact predation rates on sage-grouse.	9
Predation – Methods	Identification of nest predators and their depredation sign.	2
Predation – Monitoring	Develop an effective and consistent monitoring program to determine if predation management actions are achieving desired results in sage-grouse populations.	9
Predation – Non-native	How do non-native predators impact individual sage-grouse populations?	10
Predation – Populations	Document and monitor current predator population levels in sage-grouse habitat.	9
	Investigate and evaluate the natural variability in sage-grouse predator populations.	9
	Assess population status and trends of important predator species (both native and invasive).	4, 5
Predation – Restoration/ Mitigation	Can the effects of predation be mitigated by habitat management, and would this approach be more efficient or effective than controlling predators?	6
Predation – Species interactions	Behavioral and spatial interactions of predators with sage-grouse and with other predator species.	9
	Evaluate relationships among sage-grouse predator species, including how sage-grouse predator species population levels change relative to each other.	9

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Predation – Species interactions	Investigate the roles of and relationships between native and nonnative predators in the sagebrush ecosystem.	9
	Determine if changing predator species (e.g., increased red fox, raven, raccoon, etc.) impacts sage-grouse productivity.	1
	Evaluate relationships among sage-grouse predator species, including how sage-grouse predator species population levels change relative to each other, and different effects in different life stages and seasons.	9
	Influence of predator trophic interactions and behavior on predation rates.	9
	Correlate changes between alternate prey species abundance and sage-grouse abundance.	1
Weather/Climate – Cycles/Trends	What are the effects of drought cycles, ENSO-PDO-NAO, and long-term warming?	11
Weather/Climate – Demographics	How does weather at peak of hatch affect Fall populations? What is the associated prediction for climate change affecting weather at peak of hatch? Can multiple years of good/poor conditions affect long term (20 year) population numbers?	18
Weather/Climate – Fire	Examine the relationship between climate change and fire frequency in sagebrush ecosystems; will wildfire severity and frequency increase?	13
Weather/Climate – Future scenarios	What influence will climate change have on long-term conservation of sagebrush and sage-grouse?	10, 15
	Reduce uncertainty in climate projections and assess impacts of climate variability.	15
Weather/Climate – Habitat condition	Develop a system that identifies the effects of global change in the very early stages and identifies appropriate management responses.	7
	Develop new concepts of landscape scale management of rangelands to provide for adaptive management in response to climate change.	7
	Quantify possible effects of climate change on sagebrush and associated understory plant composition and distribution.	1
	Is there a relationship with the recent historic climate record and highly functional or degraded habitat areas, or population density?	18
	Which habitat characteristics or landscape features buffer populations against periodic drought and/or climate change?	18
Weather/Climate – Habitat condition – Interactions	Effects of climate (and changing climate) on composition, structure and productivity (incl. sage-grouse) of the sagebrush ecosystem; interactions of drought-grazing, drought-invasives, drought-invertebrates, etc.	17
	Correlate historical and present weather data with historical and present sage-grouse population data to determine weather impacts to sage-grouse populations and habitat.	1
	How do climate patterns/trends (esp. drought) affect sagebrush ecosystem conditions (productivity, composition, invasions…) and how are/might cycles be tied to cycles (and vulnerabilities) of vegetation and wildlife?	13
	Characterize the potential influence of climate change on sagebrush species, communities and landscape patterns – e.g., increasing temperature, atmospheric CO_2, severe weather events.	13
	Characterize the role and effects of interactions between climate and changing climate with woody expansion, drought, invasive spp., wildfire threats – and implications for sagebrush ecosystems.	13
Weather/Climate – Population	How does drought affect sage-grouse over the short- and long-term?	10, 15
	Evaluate the effects of drought and water developments on sage-grouse populations.	10
	Correlate climate data with sage-grouse population distribution.	1
Weather/Climate – Population response	Correlate, on a local level, historical and present weather data with historical and present sage-grouse population data to determine weather impacts to sage-grouse populations and habitat.	1, 10
	What are the predicted consequences of climate change to sage-grouse populations, and how does this risk vary across the species' range?	18

Appendix A. Research questions identified from a review of Federal and State sage-grouse conservation document, peer-reviewed papers, and input from the scientific community. Questions have been categorized into a hierarchical organizational structure by theme and topics addressed—Continued.

Theme/topic	Question or Issue	Citation
Change Agents – Natural Processes—Continued		
Weather/Climate – Population response	Recent evidence from the Great Basin demonstrates that sage-grouse populations may be extremely sensitive to annual climatic variation. Does this pattern hold true range-wide, and what are the implications of these results, given future climate change?	18
Weather/Climate – Seasonal habitat	Relationship between winter and spring conditions (esp. weather/climate) and the timing/ location of lek use/appearance, breeding, nesting, etc. (linear time-line, variable amongst years? Populations? Individuals?)	17
	What habitat or landscape features allow small segments of sage-grouse populations reproduce successfully during years of extreme drought? How can managers protect or improve these habitat features.	18
Socio-economics		
Coordination – Management and policy	Mechanisms for integration and coordination across range and jurisdictions.	6
Coordination – Monitoring	Encourage, inform and support (WAFWA, others) efforts to better estimate sage-grouse distributions, abundance, and trends – and importantly, link and integrate monitoring of populations with monitoring of habitat conditions, environmental patterns, etc.	14
Data Management – Monitoring	Standardization of field data collection protocols and/or the establishment of a centralized data storage system would facilitate analyses and foster closer coordination.	7
Economics – Management and policy	It is also possible that there is an economical and biological tradeoff between the uses of habitat management or harvest management for the purpose of improving populations of sage-grouse; which is more approach is more efficient or should they both be used?	6
	What are the costs and benefits of status quo, habitat loss, or habitat restoration for rangeland use and rural/urban rangeland towns, cities, and counties?	6
	What are the social and economic factors that influence human actions and decisions and their role in the persistence of sage-grouse and habitat?	6, 12
	What do we know about socioeconomic conditions of ranching that will affect sage steppe habitats? How can working landscapes and local economies, especially ranching, be integrated across a landscape to foster sage-grouse?	18
Information/Data – Management and policy	How can assembling a common database (e.g., LCMAP) be fostered across the range?	18
	Science, data and information (development and distribution).	6
Integrated management – Adaptive management – Management and policy	Develop an effective adaptive management framework for sage-grouse conservation.	14
	What long term Adaptive Management experiments can be established across the range of the Greater Sage-Grouse to foster science and management collaboration and test conceptual models about how grouse respond to climate change and habitat management?	18
Integrated management – Management and policy	Translate quantified habitat and population objectives to management objectives (practical, meaningful, attainable, etc.)	14
	What management actions (annual decisions) are being made by state and federal land managers that affect grouse? What are the local and landscape level social networks that informally implement such things?	18
	Address (numerous/all) threats and constraints rigorously and objectively to inform practices and decisions that perpetuate sage-grouse populations...	13
	Are regulatory mechanisms sufficient for long-term sage-grouse conservation?	6
Landscape planning – Management and policy	Policy and planning frameworks need science based objectives, measures and decision process for RMPs.	17
	Policy and planning frameworks need common data and regional perspectives for local and regional cumulative impacts analyses.	17
	Policy and planning frameworks need consistent measures/evaluations across jurisdictions.	17
	Policy and planning frameworks need: habitat mapping and “parcel prioritization” for connectivity, seasonal habitat value, restoration potential.	17

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Theme/topic	Question or Issue	Citation
Socio-economics—Continued		
Landscape planning – Prioritization – Management and policy	Prioritizations for proactive, efficient allocation of limited resources (maximize biological return).	6
	Habitat Protection – need inventory, priorities; ID and protect "existing sagebrush habitat" via plans.	13
	Relative Importance (values) of landscape units for habitat(s) and uses; Landscape Scale Risk-Opportunity Assessment; Cumulative Effects Assessment; Vulnerability assessment.	13
	How can science-based research be best used to prioritize management actions and ensure efficient use of limited resources?	18
Landscape planning – Regional planning – Management and policy	How to balance wildlife and human use/needs (across the landscape and mutually desirable habitats/areas) to provide for local economies and protect public resources? (landscape conservation planning).	17
	Development of information, outlines, approaches for broad-scale, long-term conservation plans that address development including rate/level of disturbance, impact area, recovery, turn-over and accumulation of effects.	13
	Research aimed at developing decision support tools that map habitat, guide management decisions, and assess management actions would substantially benefit range-wide sage-grouse populations.	18
Social trends – Management and policy	What are the characteristics of early-adopters of good grazing and grouse management practices in different SMZs?	18

Citation Reference

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2 Nevada Sage-Grouse Conservation Team (2004)
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