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Integrated Rangeland Fire Management Strategy Actionable Science Plan Completion Assessment: Sagebrush and Sage-Grouse Topic, 2015–20

Open-File Report 2023–1010

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

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre

Datum

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Abbreviations

BLM	Bureau of Land Management
DOI	U.S. Department of the Interior
GIS	Geographic Information System
IRFMS	Integrated Rangeland Fire Management Strategy
LiDAR	Light Detection and Ranging (remote sensing method)
MZ	WAFWA Sage-grouse Management Zone
NDVI	Normalized Difference Vegetation Index
USGS	U.S. Geological Survey
WAFWA	Western Association of Fish and Wildlife Agencies

Species Names

Big sagebrush	*A. tridentata* spp.
Brewer's sparrow	*Spizella breweri*
Cheatgrass	*Bromus tectorum*
Common raven	*Corvus corax*
Crested wheatgrass	*Agropyron cristatum*
Ferruginous hawk	*Buteo regalis*
Golden eagles	*Aquila chrysaetos*
Greater sage-grouse	*Centrocercus urophasianus*
Greater short-horned lizard	*Phrynosoma hernandesi*
Gunnison sage-grouse	*Centrocercus minimus*
Harvester ant	*Pogonomyrmex* spp.
Jackrabbit	*Lepus* spp.
Juniper	*Juniperus* spp.
Monarch butterfly	*Danaus plexippus*
Northern sagebrush lizard	*Sceloporus graciosus*
Pinyon	*Pinus* spp.
Plateau fence lizard	*Sceloporus undulatus*
Pronghorn	*Antilocapra americana*
Pygmy rabbit	*Brachylagus idahoensis*
Sage thrasher	*Oreoscoptes montanus*
Sagebrush sparrow	*Artemisiospiza nevadensis*
Sagebrush	*Artemisia* spp.
Short-eared owl	*Asio flammeus*
Vesper sparrow	*Pooecetes gramineus*
Wyoming big sagebrush	*A. t. wyomingensis*

Integrated Rangeland Fire Management Strategy Actionable Science Plan Completion Assessment: Sagebrush and Sage-Grouse Topic, 2015–20

By Matthew J. Holloran, Christopher R. Anthony, Mark A. Ricca, Steven E. Hanser, Sue L. Phillips, Paul F. Steblein, and Lief A. Wiechman

Abstract

Loss and degradation of sagebrush rangelands due to an accelerated invasive annual grass-wildfire cycle and other stressors are significant management, conservation, and economic issues in the western United States. These sagebrush rangelands comprise a unique biome spanning 11 states, support over 350 wildlife species, and provide important ecosystem services that include stabilizing the economies of western communities. Impacts to sagebrush ecosystem processes over large areas due to the annual grass-wildfire cycle necessitated the development of a coordinated, science-based strategy for improving efforts to achieve long-term protection, conservation, and restoration of sagebrush rangelands, which was framed in 2015 under the Integrated Rangeland Fire Management Strategy (IRFMS). Central to this effort was the development of an Actionable Science Plan (Plan) that identified 37 priority science needs (Needs) for informing the actions proposed under the 5 topics (Fire, Invasives, Restoration, Sagebrush and Sage-Grouse, Climate and Weather) that were part of the collective focus of the IRFMS. Notable keys to this effort were identification of the Needs co-produced by managers and researchers, and a focus on resulting science being "actionable."

Substantial investments aimed at fulfilling the Needs identified in the Plan have been made since its release in 2016. While the state of the science has advanced considerably, the extent to which knowledge gaps remain relative to identified Needs is relatively unknown. Moreover, new Needs have likely emerged since the original strategy as results from actionable science reveal new questions and possible (yet untested) solutions. A quantifiable assessment of the progress made on the original science Needs can identify unresolved gaps and new information that can help inform prioritization of future research efforts.

This report details a systematic literature review that evaluated how well peer-reviewed journal articles and formal technical reports published between January 1, 2015, and December 31, 2020, addressed nine needs (hereinafter, "Needs") identified under the Sagebrush and Sage-Grouse topic in the Plan. The topic outlined research Needs broadly focused on understanding sagebrush rangelands and population dynamics important for the conservation and management of sage-grouse and other sagebrush-reliant wildlife species. We established the level of progress towards addressing each Need following a standardized set of criteria, and developed summaries detailing how research objectives nested within Needs identified in the Plan ('Next Steps') were either addressed well, partially addressed or remain outstanding (in other words, addressed poorly) in the literature through 2020. Our searches resulted in the inclusion of 333 science products that at least partially addressed a Need identified in the Sagebrush and Sage-Grouse topic. The Needs that were well and partially addressed included:

(1) development of biome-wide mapping techniques that provide regularly updated grassland and shrubland vegetation layers (Need 4);

(2) generation of spatially explicit greater sage-grouse habitat suitability and population models (Need 5);

(3) identification of greater sage-grouse seasonal habitats (Need 6);

(4) identification of thresholds for the extent of threats, especially conifer expansion, above which greater sage-grouse and other sagebrush-obligate species cannot persist (Need 8); and

(5) studies of sagebrush community dynamics as those relate to management and restoration of sagebrush rangelands (Need 9).

Needs addressed poorly included:

(1) investigations of factors conducive and restrictive to greater sage-grouse movement patterns and population connectivity (Need 1);

(2) investigations of livestock and other large ungulate (for example, feral horse) grazing effects on greater sage-grouse populations and habitats (Need 2);

(3) identification of thresholds of disturbance (especially renewable energy developments) below which greater sage-grouse and other sagebrush reliant species are not impacted (Need 3); and

(4) studies of habitat relationships for sagebrush-reliant species other than greater sage-grouse, songbirds, and small mammals (Need 7).

The information provided in this assessment will assist updating the Plan along with other science strategies.

Introduction

Stemming the cumulative loss and degradation of sagebrush (*Artemisia* spp.) rangelands that comprise a unique biome across western North America represents a challenge to land managers and applied researchers in the 21st century. Functioning and viable sagebrush rangelands not only support over 350 plant and animal species of conservation concern (Suring and others, 2005), these landscapes are also essential for agricultural and recreational industries and thereby play a vital role in stabilizing the economies of western communities. This is of particular importance given dramatic fluctuations resulting from the traditional dependence of these communities on energy development (Western Governors' Association, 2017; Bureau of Land Management [BLM], 2020). Approximately 55–60 percent of sagebrush rangelands of the western U.S. have been lost (direct conversion) or degraded (alteration of understory vegetation or fragmentation) since European settlement (Knick and others, 2003; Miller and others, 2011). Sagebrush rangelands are currently distributed across 160 million acres of 14 western states (Remington and others, 2021; fig. 1).

Arresting downward trends in sagebrush ecosystems is complex owing to multiple and often interacting stressors, including conversion to agricultural crops or non-native perennial grasses (for example, crested wheatgrass [*Agropyron cristatum*]), energy development, improper livestock grazing, expansion of native conifers, and other anthropogenic surface disturbing activities (for example, roads, transmission lines, exurban development; Hanser and others, 2018; Shinneman, 2019; BLM, 2020). However, altered wildfire regimes driven largely by positive feedbacks from invasive annual grasses (Miller and Eddleman, 2001; Balch and others, 2013) are perhaps the most immediate and pervasive threat to sagebrush rangelands (U.S. Fish and Wildlife Service, 2013; fig. 2). The proliferation of invasive annual grasses (for example, cheatgrass [*Bromus tectorum*]) and resulting increases in fire frequency and extent can ultimately result in long-term and often permanent loss of fire-intolerant species of sagebrush along with deep rooted bunchgrass and soil microbial communities that normally promote resilience to disturbance and resistance to invasion in sagebrush ecosystems (Chambers and others, 2014; Germino and others, 2016). The threat from the annual grass-wildfire cycle is greatest throughout western portions of the sagebrush biome (that is, Great Basin and Snake River Plain), where trends in proportion of larger fires and fire season length have increased since the mid-1980s and fire frequency has increased substantially compared to historic frequencies (Brooks and others, 2015). Over the next 20 years, median annual total area burned in western states supporting sagebrush is projected to increase (from a 1961–2004 baseline period; Kitzberger and others, 2017), suggesting that increasing trends in sagebrush rangeland fires are likely to continue.

The increasing frequency and impact of wildfires prompted the development of an enhanced strategy for addressing rangeland fire across sagebrush-dominated regions. A significant milestone in this effort was the drafting of the Integrated Rangeland Fire Management Strategy (hereinafter IRFMS; U.S. Department of the Interior [DOI], 2015) following the issuance of Secretarial Order 3336. The IRFMS outlined coordinated, science-based approaches for improving the efficiency and efficacy of actions to better prevent and suppress rangeland fire and to improve efforts to achieve long-term protection, conservation, and restoration of the sagebrush biome. Inherent in the IRFMS was the recognition that a strong science foundation was fundamental to successful rangeland fire prevention and suppression, and to management and restoration of sagebrush rangelands and wildlife populations reliant on those rangelands. Therefore, the IRFMS further called for the development of an Actionable Science Plan (hereinafter, Plan) that identified the priority science needed to inform another generation of management strategies and tools (Integrated Rangeland Fire Management Strategy Actionable Science Plan Team, 2016). Critical elements to the Plan's success were:

(1) the collaborative identification of knowledge gaps by managers and researchers which, when filled, would break down barriers to successful implementation of management actions; and

(2) a focus on the resultant priority science having "actionable" traits by:

(i) immediately filling knowledge gaps;

(ii) directly informing management action aimed at protecting, conserving, or restoring sagebrush ecosystems; and

(iii) facilitating funding mechanisms for effective research and communication of results to management audiences.

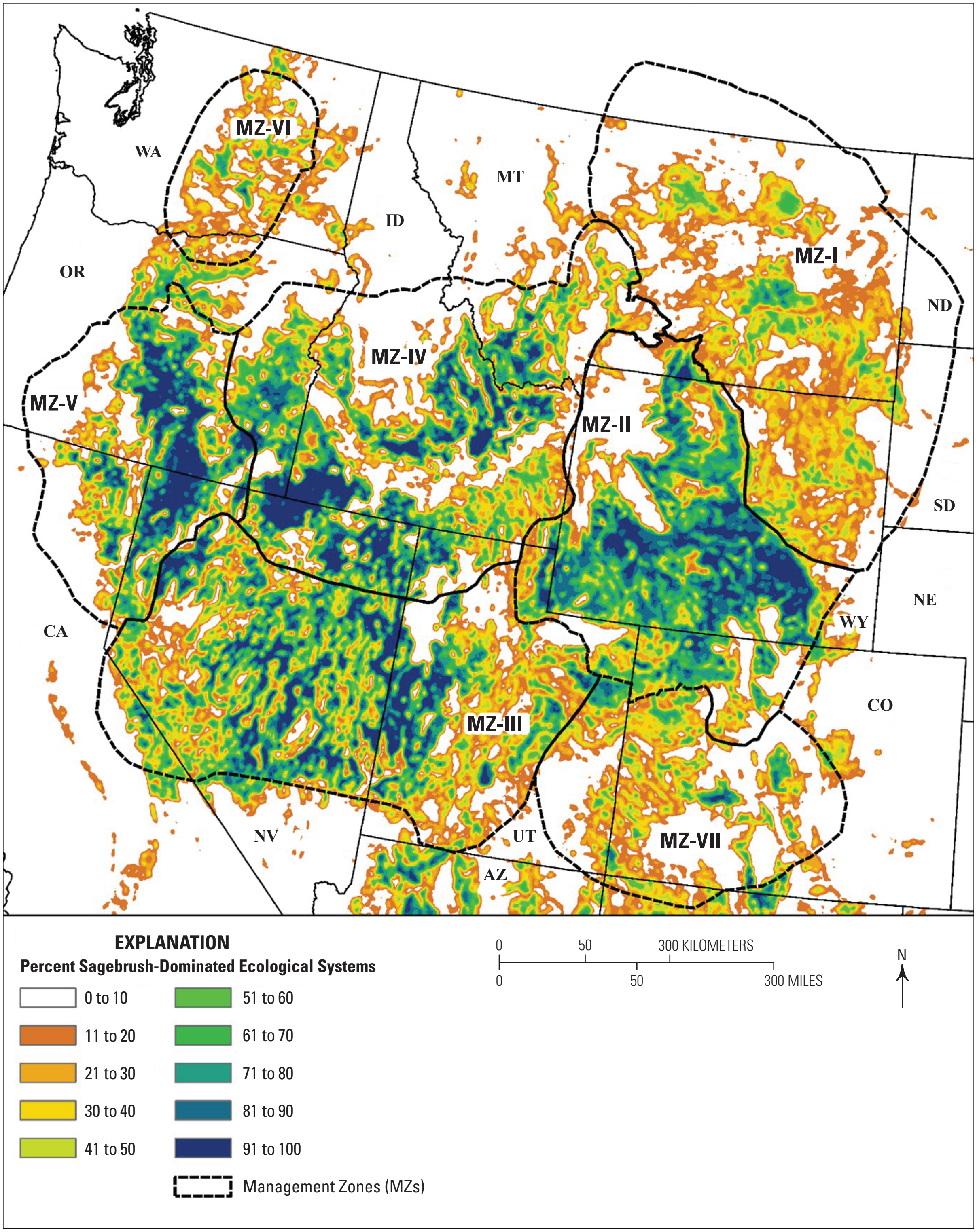

Figure 1. Map showing the landscape cover of sagebrush-dominated ecological systems in the western United States (fig. 28 from Chambers and others, 2017).

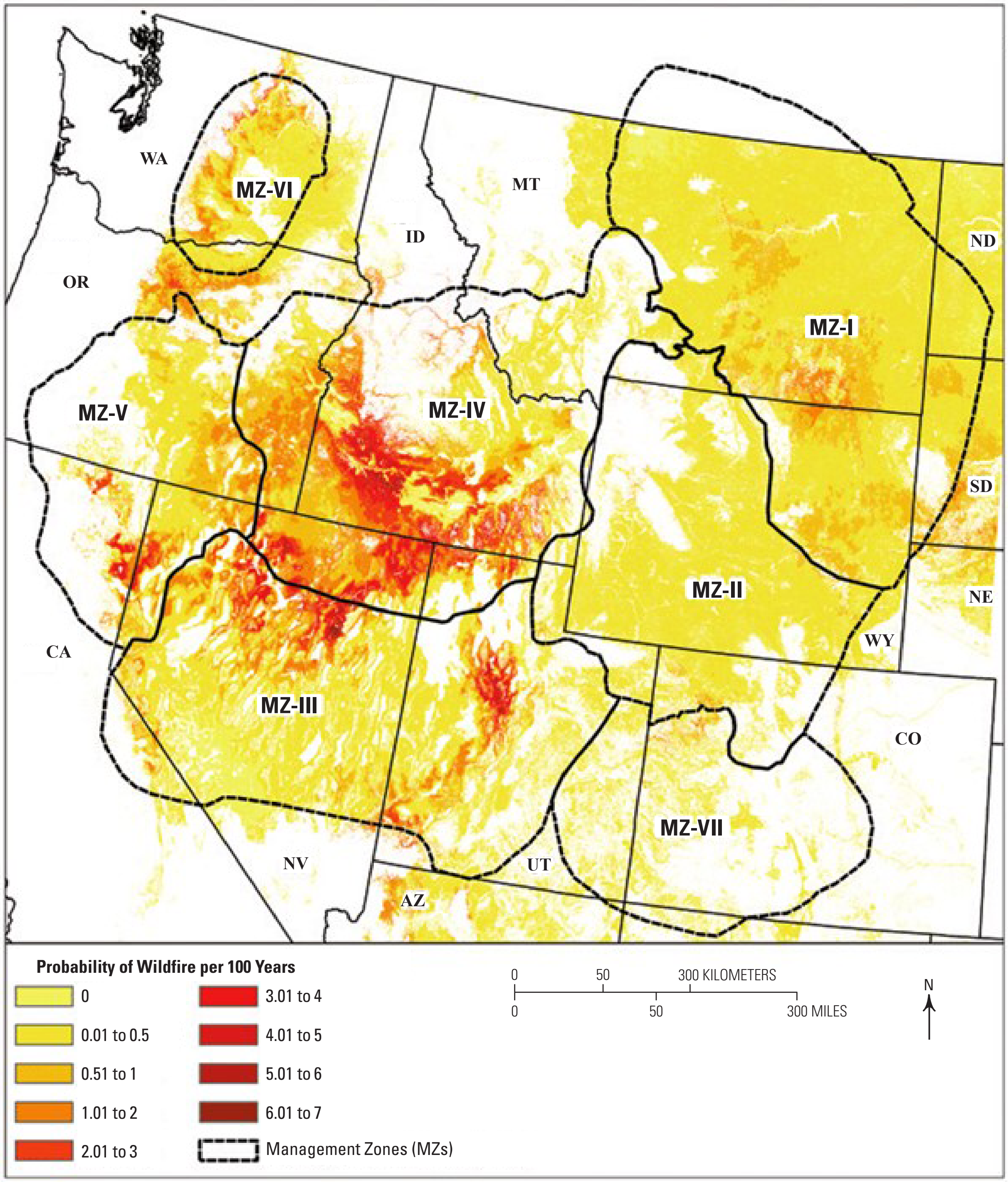

Figure 2. Map showing large fire probability for the sagebrush biome in the western United States (fig. 34 from Chambers and others, 2017).

Accordingly, needed science was identified by considering planning and prioritization efforts conducted in the previous 5 years by Federal and State agencies. The resulting comprehensive list was prioritized with engagement of the broader research and management communities. The 37 highest-priority science needs (hereinafter, Needs) identified through these efforts were then organized under five topics outlined in the IRFMS: (1) Fire, (2) Invasives (plant species), (3) Restoration, (4) Sagebrush and Sage-Grouse, and (5) Climate and Weather. A multi-disciplinary team of experts developed narratives describing these highest-priority Needs and outlined a series of research objectives (hereinafter, Next Steps) to help guide the development of new knowledge, syntheses, and decision-support tools for addressing each Need.

Conservation strategies depend on the consideration and application of the best available science, and on-going efforts to address gaps in that scientific knowledge, to achieve management success. While the state of the science has ostensibly advanced owing to substantial research investments since the Plan's release in 2016, the extent to which knowledge gaps remain relative to identified Needs is largely unknown. Several annotated bibliographies and literature reviews have made strides towards making results from research efforts in the sagebrush biome available and tractable for management audiences (for example, Hanser and others, 2018; Carter and others, 2020; Poor and others, 2021). However, many knowledge gaps likely remain, and an assessment of the progress made on achieving previously identified priorities is needed to help focus the next prioritization on unresolved gaps in the science and new science needs that have arisen since development of the original strategy. A quantifiable and targeted assessment of progress made towards meeting the original Needs under the Plan's five topics can help identify unresolved gaps and prioritize future actionable research efforts for new questions and possible (yet untested) solutions.

The Sagebrush and Sage-Grouse topic in the Plan identified nine Needs focused on understanding components of the sagebrush biome and population dynamics related to the conservation and management of greater sage-grouse (*Centrocercus urophasianus*, hereinafter sage-grouse) and other sagebrush-obligate and sagebrush-reliant wildlife species (fig. 3). The priorities identified across the nine Needs broadly encompassed:

(1) investigations of factors affecting sage-grouse movement patterns and population connectivity;

(2) studies of the effects of ungulate grazing on sagebrush vegetation and sage-grouse populations;

(3) assessments of the response of sage-grouse and other sagebrush-obligate species to surface disturbing activities (for example, energy development, conifer cover, wild fire);

(4) development of enhanced approaches to mapping shrubland vegetation;

(5) development of spatially explicit population models and seasonal habitat suitability models for sage-grouse and other sagebrush-associated species across the sagebrush biome; and

(6) investigations of long-term dynamics of the sagebrush ecosystem as they relate to meeting specific management goals.

This report details a literature review that quantified how well peer-reviewed journal articles and formal technical reports published between January 1, 2015, and December 31, 2020, addressed nine Needs identified under the Sagebrush and Sage-Grouse topic in the Plan. Five years was considered an adequate time period for implementation of science projects that coincided with or were inspired by the Plan and, as such, a suitably defined interval for completing this assessment and updating priority science and management needs. Our objective was to comprehensively summarize the scientific literature generated since the release of the Plan. Leveraging advances in bibliographic search-engine tools, we developed a quantitative "scorecard" to assess progress towards addressing each Need following a standardized set of criteria. The scorecard informed summaries detailing how Next Steps were addressed in the literature as well as those that remain unresolved. The summaries are intended to provide information for stakeholder-driven efforts aimed at identifying the next set of science needs in a forthcoming updated version of the Plan.

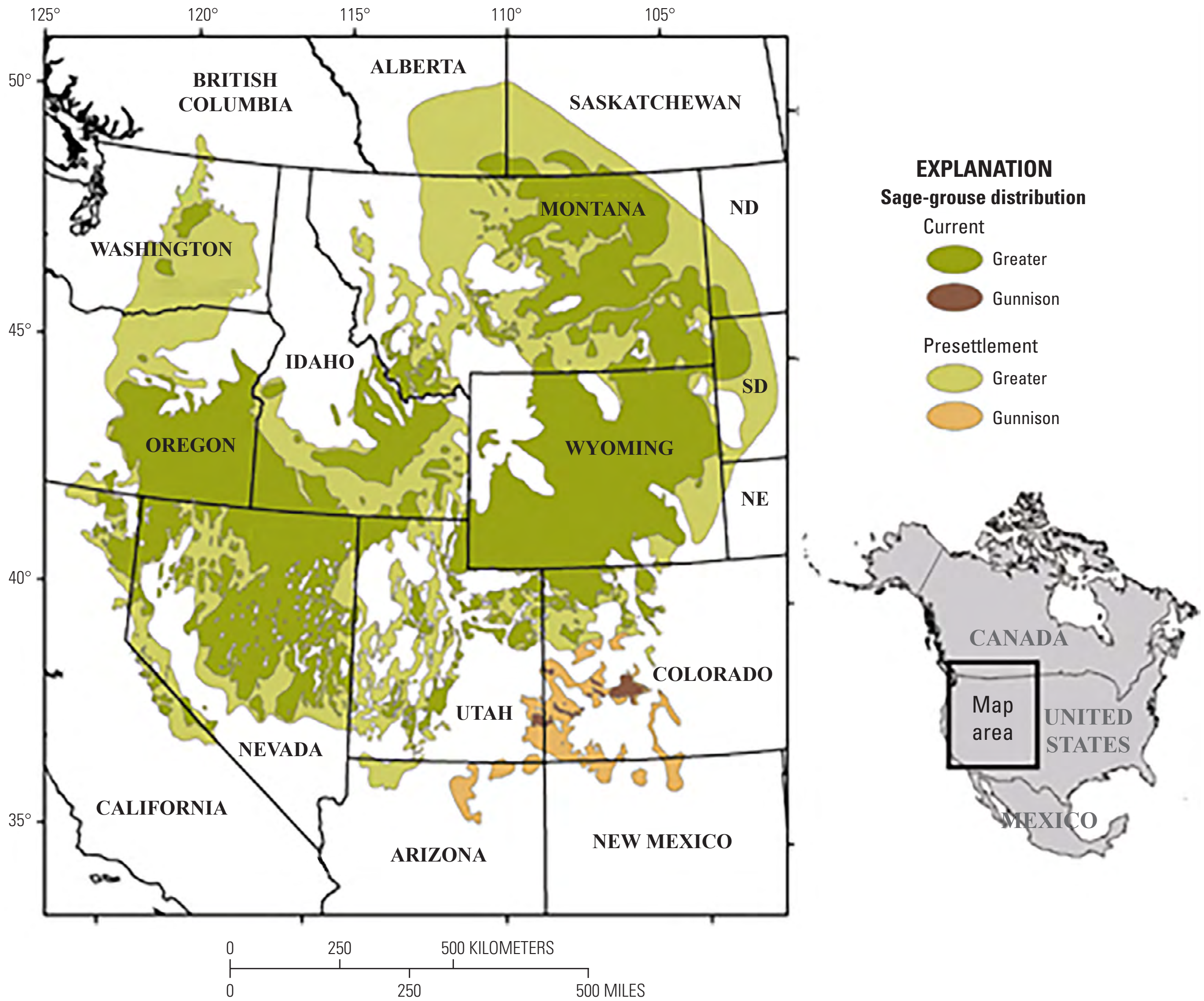

Figure 3. Map showing current and potential pre-settlement distribution of greater sage-grouse (*Centrocercus urophasianus*) and Gunnison sage-grouse (*Centrocercus minimus*) in North America adapted from Schroeder and others (2004; fig. 1 from Aldridge and others, 2008).

Methods

We organized literature reviews on the five overarching topics included in the Plan (that is, [1] Fire, [2] Invasives (plant species), [3] Restoration, [4] Sagebrush and Sage-Grouse, and [5] Climate and Weather). For the Sagebrush and Sage-Grouse topic, we initially reviewed the sage-grouse literature that was included in broad searches and summarized by Carter and others (2020). We then used the USGS BiblioSearch (Kleist and Enns, 2022) to search the reference databases Web of Science and Scopus using the same search terms as Carter and others (2020) (that is, "greater sage-grouse" and "sage-grouse") for products published between October 2, 2019, and December 31, 2020, to capture the bulk of the relevant literature, that was published after Carter and others (2020). Using the same search tool (Kleist and Enns, 2022), we then conducted a series of literature searches using search terms specific to the Next Steps (for example, sagebrush AND insect species) to capture the science products that may have been excluded by the broad search terms (table 1). We examined all papers included in the resulting lists of literature for relevance to the Needs identified in the Sagebrush and Sage-Grouse topic. Products searched included published literature and peer-reviewed Federal research reports (for example, Open-File Reports released by the U.S. Geological Survey [USGS]). Data releases, popular articles, "gray" literature, and other lower-tier publications were not included in search results (Kleist and Enns, 2022), although some of these types of literature (for example, data releases) were summarized in the annotated bibliographies we accessed (for example, Carter and others, 2020; Poor and others, 2021) and included in our review when pertinent. In situations where a research report was later published in the peer-reviewed literature, we only considered the published manuscript; in situations where the research report included pertinent information not included in the manuscript, we considered both.

We established how well Needs (that is, priority science required to inform the next generation of management strategies) listed in the Plan were addressed in the literature by independently "scoring" each Need from Next Steps (that

Table 1. Search results for the Sagebrush and Sage-Grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan establishing the terms searched, the number of unique articles resulting from that search (Unique Results), and general descriptions of each search (Comment).

[**Search Terms:** We used a search algorithm (Kleist and Enns, 2022) during early stages of tool development, and at that time the entire term between the word AND in the search terms was not searched (for example, "greater" and "sage-grouse" searched, not "greater sage-grouse"). This resulted in broader and more inclusive lists of literature. **Unique Results:** The number of papers associated with each search term represent the number of unique papers resulting from that search but are not necessarily unique to the search (for example, the same paper could be included in the count of both the "greater sage-grouse" and "sage-grouse" searches).**Comments:** Need 4, development of biome-wide mapping techniques that provide regularly updated grassland and shrubland vegetation layers; Need 7, studies of habitat relationships for sagebrush-reliant species other than greater sage-grouse, songbirds, and small mammals; Need 8, identification of thresholds for the extent of threats, especially conifer expansion, above which greater sage-grouse and other sagebrush-obligate species cannot persist; Need 9, studies of sagebrush community dynamics as those relate to management and restoration of sagebrush rangelands]

Search terms	Unique results	Comment
greater sage-grouse	238	2015–October 2019; broad search term captured in Carter and others (2020)
greater sage-grouse	125	October 2019–20; broad search term to capture papers in our timeframe not captured by Carter and others (2020)
sage-grouse	154	October 2019–20; broad search term to capture papers in our timeframe not captured by Carter and others (2020)
sagebrush AND remote sensing AND time series	8	2015–20; Need 4; targeted search term
sagebrush AND remote sensing AND land cover	20	2015–20; Need 4; targeted search term
sagebrush AND remote sensing AND mapping	23	2015–20; Needs 7 and 8; targeted search term
juniper AND wildlife	73	2015–20; Needs 7 and 8; targeted search term
pinyon juniper AND wildlife	33	2015–20; Needs 7 and 8; targeted search term
sagebrush AND ungulate species	17	2015–20; Needs 7 and 8; targeted search term
sagebrush AND insect species	15	2015–20; Needs 7 and 8; targeted search term
sagebrush AND small mammal species	18	2015–20; Needs 7 and 8; targeted search term
sagebrush AND reptile species	7	2015–20; Needs 7 and 8; targeted search term
sagebrush obligate AND habitat suitability	5	2015–20; Needs 7 and 8; targeted search term
sagebrush obligate AND mapping	6	2015–20; Needs 7 and 8; targeted search term
sagebrush habitats AND monitoring	63	2015–20; Need 9; targeted search term

is, science objectives required to address a Need) associated with the Sagebrush and Sage-Grouse topic. Papers that were relevant to a Next Step were considered when scoring that Next Step. Our review approach initially focused on summaries provided in Carter and others (2020) or a paper's abstract. If this information suggested that the research was related to a Next Step, we focused our in-depth examination on research objectives, study area descriptions, and data collection and analysis methods. Because the objective of this project was to assess if Next Steps had been addressed, we did not systematically summarize results although we considered results when necessary to determine if the research addressed a Next Step. A given paper could be relevant to more than one Next Step in a Need, more than one Need, and more than one topic.

Each Next Step was scored based on the relevant literature following a set of criteria (table 2). Scores were scaled from 0.00 to 1.00 with 0.00 indicating that the Next Step had not been considered (in other words, no papers were reviewed that considered the objective[s] detailed in the Next Step) and 1.0 indicating that the Next Step had been considered at the full spatial extent of the issue being investigated. Scores progressively decreased as the applicability of the research associated with a Next Step became more regional or localized. The scale of inference for Next Steps that were pertinent to the entire sagebrush biome was based on Western Association of Fish and Wildlife Agencies Management Zones (WAFWA; MZ) for sage-grouse (Stiver and others, 2006; fig. 1). If studies were distributed in one MZ or less than or equal to three adjoining MZs, the scale of inference was considered local or regional, respectively. 'NA' was assigned when a Next Step could not be evaluated with the literature review approach we used (for example, data releases, online tools), and that Next Step was not scored. A Next Step that could be addressed adequately following our approach but that had no relevant literature identified was scored 0.00 (not NA) and included in the scoring of the Need. Each Need was scored as the proportion of the Next Steps associated with that Need that received a score greater than or equal to (≥) 0.75 (table 2). We categorized each Need based on the scores as addressed well by the literature (scores ≥0.67; that is, a majority of the Next Steps associated with that Need received a score of 0.75 or greater), partially addressed by the literature (scores 0.50–0.66) or addressed poorly by the literature (scores less than or equal to [≤] 0.49). We did not distinguish between Next Steps identified in the Plan as accomplishable within 3 years (short-term) and longer than 3 years (long-term) because 5 years had elapsed between plan formulation and this report.

For each Need, we developed a summary of the Next Steps. Summaries were organized by Need and describe Next Steps or portions of a Next Step that had been 'Addressed' and those that had not (in other words, 'Outstanding') based on the details in the Next Steps rather than each Need in entirety. As such, descriptions of the research related to a given Next Step could be included in both the summaries of the science that had been Addressed as well as what remains Outstanding for a Need. These summaries provide details of how well specific science objectives established in the Plan were addressed and are important for evaluating the scores and informing the next set of science needs in the updated Plan.

Research relevant to the science Needs identified in the Plan continues to be conducted and published. However, because we are not privy to all the research being conducted throughout the sagebrush biome, and we did not want to bias assessments to internal research efforts, products released after 2020 and interim updates of ongoing research were not discussed in this report. As such, the completion scores provided in this assessment are snapshots, and should be augmented with knowledge of newly published and ongoing research programs using the search and scoring methods described in this report when updating the Plan.

Table 2. Criteria used to score Next Steps established for the Needs included in the Sagebrush and Sage-Grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan.

[Sagebrush, *Artemisia tridentata*; Greater sage-grouse, *Centrocercus urophasianus*; NA, not applicable because Next Step not included in scoring of Need]

Scoring description	Score
Next Step addressed across the sagebrush range, or at the full spatial extent of the issue being investigated	1.00
Next Step addressed and was scale independent (for example, literature summaries)	1.00
Next Step partially addressed across the sagebrush range, or at the full spatial extent of the issue being investigated	0.75
Next Step partially addressed and was scale independent	0.75
Next Step addressed at the local or regional level	0.50
Next Step partially addressed at the local or regional level	0.25
Next Step not addressed	0.00
Next Step could not be assessed through literature review approach used (for example, development of databases)	NA

Results and Summary

We reviewed 805 products that were identified by the literature searches conducted for the Sagebrush and Sage-Grouse topic (table 1). Of those, 333 unique products were directly related to at least one of the nine Needs. Most (76 percent) of the 68 Next Steps included in the topic had greater than or equal to one published product that at least partially addressed the science objective(s) of that Next Step. Nine Next Steps could not be effectively assessed with the evaluation approach we used and were not scored (“NA”; table 2). The seven Next Steps that could be effectively assessed but had no related products (that is, were scored as 0.00 not as NA) included:

(1) broad-scale studies of fine-resolution sage-grouse movements to understand how barriers may affect population performance and genetic structure (Need 1);

(2) standardization of data collection protocols associated with studies of the impacts of livestock grazing on sage-grouse vital rates to allow synthetic analyses (Need 2);

(3) investigations of the impacts of anthropogenic noise and the removal of infrastructure on sage-grouse individuals and populations (Need 3); and

(4) development of management applications useful across seasons and the biome from products identifying sage-grouse seasonal habitats (Need 6).

Table 3 provides the completion scores for each Need and summaries of the literature evaluated for Next Steps. Literature citations are provided in appendix 1, organized by Next Step.

The Needs that were addressed well (scores ≥0.67) included the development of biome-wide mapping techniques that can provide regularly updated grassland and shrubland vegetation layers (Need 4); the generation of spatially-explicit sage-grouse population models for use informing local scale management (primarily from lek count data) (Need 5); and studies of sagebrush community dynamics as those relate to management and restoration of sagebrush rangelands (Need 9). Estimates of percent change in biotic attributes of sagebrush rangelands (for example, sagebrush cover, invasive annual grass prevalence), fire perimeters and severity, and variability in mesic area productivity (NDVI) from the 1980s to present have been mapped range wide and techniques for regularly updating these range wide estimates have been established. A substantial number of studies conducted throughout the sagebrush biome have investigated the influence of multiple biotic and abiotic factors, at various spatial scales, on sage-grouse populations, habitat selection and habitat quality (see also Needs 3 and 6). These efforts included spatially-explicit integrated population models and individual-based simulation models that were used to investigate scenarios of locally-relevant management opportunities. Studies investigating relationships between different biotic and abiotic factors and changes in sagebrush vegetation communities have been conducted, and generalized restoration prioritization tools and approaches that are relevant range wide have been developed.

The Needs that were partially addressed (scores 0.50–0.66) included the identification of sage-grouse seasonal habitats (Need 6); and the identification of thresholds for the extent of threats, especially conifer expansion, above which sage-grouse and other sagebrush-obligate species cannot persist (Need 8). A substantial number of studies conducted throughout the sagebrush biome have investigated sage-grouse seasonal habitat selection primarily at local and regional scales (see also Need 5). Numerous studies have investigated the response of sagebrush obligate and associated species, primarily sage-grouse, songbirds, and small mammals, to anthropogenic and natural disturbance factors across the sagebrush biome (see also Need 7).

A number of Needs were addressed poorly (scores ≤0.49) including investigations of factors conducive and restrictive to sage-grouse movement patterns and population connectivity (Need 1); large-scale investigations of livestock and other large ungulate (for example, feral horse) grazing effects on sage-grouse populations and habitats (Need 2); identification of thresholds of disturbance, especially for renewable energy developments, below which sage-grouse and other sagebrush reliant species are not impacted (Need 3); and studies of habitat suitability for sagebrush-reliant species other than sage-grouse, songbirds and small mammals (Need 7). Likely connectivity corridors among sage-grouse population strongholds have been identified, however not in such a way that functional movements among leks and populations can be deduced range wide. Barriers to movement (connectivity constraints) have not been linked to sage-grouse vital rates, population viability, or genetics. Studies investigating the effects of livestock grazing intensity and timing on sage-grouse habitat selection, demographics or population trends have been conducted in eastern portions of the sagebrush biome. However, large-scale, replicated grazing studies that address the effects to sage-grouse habitats and populations of different livestock species, grazing systems, disturbance histories, and other environmental conditions are lacking across most of the sagebrush biome. Studies of sage-grouse response to renewable energy development, industrial noise, compensatory mitigation, and cumulative effects of anthropogenic disturbances have not been done or need to be replicated spatially, and multi-scaled infrastructure siting tools for informing onsite mitigation are limited. Habitat suitability has been modeled for some sagebrush songbird species, golden eagles (*Aquila chrysaetos*), Gunnison sage-grouse (*Centrocercus minimus*), and pygmy rabbits (*Brachylagus idahoensis*), but habitat relationships and information gaps for most wildlife species reliant on sagebrush rangelands remain unknown.

Table 3. Priority science Needs detailed under the Sagebrush and Sage-grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan establishing the completion score (Score), and a summary of science objectives addressed (Addressed) and not addressed (Outstanding) in the scientific literature published 2015–20.

[Sagebrush, *Artemisia tridentata*; Greater sage-grouse, *Centrocercus urophasianus*]

Need	Score	Summary of 2015–20 literature
Need 1: Investigate sage-grouse movement patterns, the habitat characteristics that are conducive, restrictive, or preventive to those movements, and the genetic structure of populations to help inform management practices to improve or maintain connections.	0.38	***Addressed***: Connectivity corridors among population strongholds have been identified indirectly across the sage-grouse range, and several local-scale studies have been conducted documenting sage-grouse movement patterns or habitat selection during movements among seasonal ranges. Broad-scale and fine-grained genetic structuring of sage-grouse populations across the sagebrush biome have been investigated. Potential barriers to movement have been investigated using genetic data, and broad-scale barriers to movement have been identified using these techniques. Fine-scale biotic barriers to movement (for example, areas influenced by conifer expansion) have been investigated at local scales. ***Outstanding***: Population connectivity, assessed in such a way that functional movements (in other words, population genetic structuring) among leks are deduced, has not been investigated range wide. Studies investigating fine-scale sage-grouse movements either directly (for example, telemetry) or indirectly (for example, genetics) have been conducted in eastern and southwestern portions of the sage-grouse range; studies at these scales in other portions of the sagebrush biome are lacking. Studies linking habitat connectivity or anthropogenic barriers to movement to sage-grouse population metrics (in other words, vital rates), long-term population viability (for example, extirpation risks), or potential genetic consequences have not been conducted. New technologies for documenting sage-grouse movements that reduce impacts to survival have not been described in the literature.
Need 2: Conduct a series of large-scale, replicated grazing studies that address how different livestock species, grazing systems, disturbance histories, and other environmental conditions affect sage-grouse habitat.	0.14	***Addressed***: Studies investigating the effects of grazing intensity, timing, or both on sage-grouse habitat selection, demographics or population trends at local and regional scales have been conducted in eastern portions of the sagebrush biome (MZs 1 and 2). The effects of livestock grazing on sage-grouse habitats have been synthesized and the coordination of geospatial grazing data at the allotment level on BLM land has been addressed. ***Outstanding***: Large-scale, replicated grazing studies that address the effects to sage-grouse habitats and populations of different livestock species, grazing systems, disturbance histories, and other environmental conditions are lacking. Studies linking the timing and intensity of livestock grazing to sage-grouse vital rates, demographics, and population trends have not been replicated outside of MZs 1 and 2. Outside of local-scale studies in western portions of the sagebrush biome examining impacts of herbivory on the performance of Wyoming big sagebrush seedlings and native and non-native perennial bunchgrasses, further studies are needed to determine at what point seedlings or native plants can tolerate grazing by large herbivores. Standardized monitoring and data collection protocols for assessing livestock, feral horse and wildlife grazing effects on sagebrush rangelands and sage-grouse have not been developed.

Table 3. Priority science Needs detailed under the Sagebrush and Sage-grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan establishing the completion score (Score), and a summary of science objectives addressed (Addressed) and not addressed (Outstanding) in the scientific literature published 2015–20.—Continued

[Sagebrush, *Artemisia tridentata*; Greater sage-grouse, *Centrocercus urophasianus*]

Need	Score	Summary of 2015–20 literature
Need 3: Identify thresholds beyond which effects on sage-grouse behavior, population response(s), or habitat use are minimized relative to different types of disturbances and related activities, for example, effects of wildfire, energy development, and other surface-disturbing activities.	0.25	***Addressed***: A large number of local and regional-scale studies distributed across the range included anthropogenic infrastructure, energy infrastructure, conifer cover, habitat treatment, or other disturbance-related covariates in studies of sage-grouse population trends, seasonal habitat selection (including migratory habitats), demographics, and/or functional (in other words, genetic) connectivity. Sage-grouse response to conifer removal treatments has been well studied throughout the range of this issue. A limited number of local-scale studies have investigated sage-grouse population response to the removal of anthropogenic infrastructure or reductions in components of that infrastructure (for example, human activity) impacting the species. Relationships between infrastructure and predator communities have been assessed for ravens. ***Outstanding***: The impacts of renewable energy development on sage-grouse have not been addressed except for a local-scale study of the response of sage-grouse to a wind energy development in MZ 2. Spatially replicated studies of sage-grouse population-level response to industrial noise are lacking, and the impacts of noise on sage-grouse seasonal habitat selection and demographics are unknown. Studies of sage-grouse response to energy development mitigation efforts, including infrastructure removal and reduced human activity, and mine reclamation efforts outside of Wyoming are lacking. Studies assessing development scenarios to improve siting and density of future infrastructure associated with energy developments to decrease impacts to sage-grouse populations at differing spatial scales (for example, informing onsite mitigation) are needed. The spatial arrangements (for example, clustered versus diffuse) of energy infrastructure and the related impacts on sage-grouse seasonal habitat selection and survival and population trends have not been assessed. Cumulative effects of the suite of anthropogenic and natural disturbances on sage-grouse remain largely unknown.

Table 3. Priority science Needs detailed under the Sagebrush and Sage-grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan establishing the completion score (Score), and a summary of science objectives addressed (Addressed) and not addressed (Outstanding) in the scientific literature published 2015–20.—Continued

[Sagebrush, *Artemisia tridentata*; Greater sage-grouse, *Centrocercus urophasianus*]

Need	Score	Summary of 2015–20 literature
Need 4: Develop next-generation mapping techniques to provide regular interval updates and continue to enhance grassland and shrubland vegetation mapping (for example, every 2–5 years).	0.83	***Addressed***: Baseline estimates of biotic attributes of sagebrush rangelands (in other words, fractional percent cover of sagebrush, herbaceous cover, bare ground, etc.) have been quantified and mapped across the biome. Estimates of percent change in biotic attributes of sagebrush systems (for example, sagebrush cover, invasive annual grass cover), fire perimeters and severity, and variability in mesic area productivity (NDVI) from the 1980s to present have been mapped range wide. Techniques for regularly updating these range wide estimates have been established. Several local and regional scale studies throughout the biome have integrated biotic and abiotic changes established from long-term field observation datasets into spatial products, and different approaches to advance monitoring applications of mapping products (for example, invasive annual grass cover estimates, vegetation phenology changes through time, vegetation state changes) have been conducted. Future estimates of climate envelopes, ecosystem dynamics, vegetation distribution (including invasive and conifer species), and resistance and resilience have been modeled for the sagebrush biome at local, regional, and range wide scales. Several studies have investigated the potential response to climate change of different factors (for example, soil water attributes) that could influence biotic attributes of sagebrush rangelands. Regional scale rulesets (thresholds) for estimating the condition of sagebrush rangelands have been developed to assist in predicting future transitions in the sagebrush biome. Several projects have used high resolution imagery and different software packages to map landcover attributes at high spatial resolutions at local and regional scales. Multiple local scale studies have used machine learning extraction techniques, extreme high resolution (for example, sub-centimeter) imagery obtained by Unmanned Aerial Systems (drones), and light detection and ranging (LiDAR) data to classify attributes of sagebrush rangelands. Many sage-grouse and other sagebrush obligate wildlife habitat selection studies include geographic information system based (GIS) modeling of habitat suitability and often quality (for example, resource selection functions, electrical circuit theory); each of these efforts generates new spatial information specific to the sagebrush biome. Energy infrastructure build out has been simulated at local scales in MZ 2. ***Outstanding***: Spatial products integrating temporally-dynamic field data into monitoring tools generated from remotely-sensed data, and higher resolution mapping have not been developed at biome wide scales. Potential changes within sagebrush habitats because of climate change, and changes in fire likelihood or other change agents (for example, anthropogenic development) have not been modeled or projected contiguously across the biome. The mapping of sagebrush to subspecies has not been accomplished, but multiple new technologies and mapping techniques have been explored that may be useful for these efforts.

Table 3. Priority science Needs detailed under the Sagebrush and Sage-grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan establishing the completion score (Score), and a summary of science objectives addressed (Addressed) and not addressed (Outstanding) in the scientific literature published 2015–20.—Continued

[Sagebrush, *Artemisia tridentata*; Greater sage-grouse, *Centrocercus urophasianus*]

Need	Score	Summary of 2015–20 literature
Need 5: Develop spatially explicit sage-grouse population models that incorporate biological processes and habitat dynamics and investigate scenarios that reflect local management possibilities (options, opportunities, and obstacles).	0.75	***Addressed***: Integrated sage-grouse population models have been developed from lek count data at local and regional scales. Several spatially explicit individual-based simulation models have been developed at local scales. A range wide database for lek counts has been created. Substantial numbers of local and regional scale studies have investigated in a spatially explicit manner the influence of multiple biotic and abiotic factors, at various spatial scales, on sage-grouse populations, habitat selection and demographics (see also Sagebrush and Sage-grouse topic Needs 3 and 6 summaries). ***Outstanding***: Biome wide integrated population models, individual-based simulation models, and management-related simulations are lacking. A range wide, coordinated assessment of sage-grouse seasonal habitat selection and demographic data has not been accomplished. Sage-grouse seasonal habitat selection and demographic data are not standardized across the numerous studies conducted throughout the sagebrush biome
Need 6: Identify seasonal habitats for sage-grouse across their entire range	0.57	***Addressed:*** Substantial numbers of local and regional scale studies have investigated the influence of multiple biotic and abiotic factors, at various spatial scales, on sage-grouse populations, habitat selection and habitat quality (in other words, demographics; see also Sagebrush and Sage-Grouse topic Needs 3 and 5 summaries). Habitat objectives established in either the sage-grouse habitat guidelines or the Habitat Assessment Framework (HAF) have been compared to vegetation measures collected at sage-grouse nests or within sagebrush-dominated rangelands considered suitable for sage-grouse at local and regional scales. The utility of broadly applied habitat objectives given variability in sage-grouse selected habitats across the sagebrush biome has been assessed. ***Outstanding***: Models of sage-grouse seasonal habitat suitability or quality from fine-grained habitat selection and demographic information employing consistent analytical techniques and covariate groupings have not been developed range wide. Studies linking data-driven estimates of sage-grouse seasonal habitat suitability and quality to population viability have not been conducted across the biome. Sage-grouse seasonal habitat thresholds relative to habitat objectives and linked to geospatial layers have not been identified.
Need 7: Develop sagebrush ecosystem-wide models identifying conditions necessary to support sagebrush-associated species, other than sage-grouse, using an individual species approach or species groups when necessary.	0.25	***Addressed***: Range wide habitat suitability has been modeled for some sagebrush obligate and associated songbird species (primarily Brewer's sparrow, sagebrush sparrow, sage thrasher, and vesper sparrow), golden eagles, Gunnison sage-grouse, and pygmy rabbits. Several local and regional scale studies have modeled habitat suitability for common ravens. Habitat relationships of sagebrush associated raptor species (ferruginous hawk, short eared owl), small mammals, reptiles (northern sagebrush lizard, plateau fence lizard, greater short-horned lizard), pronghorn, bats, and insects (harvester ants, gall insect communities) have been investigated locally. General literature has been summarized for bird species (relative to response to renewable energy projects), pinyon/juniper associated species, reptiles, monarch butterflies and pollinator insects (relative to food requirements), and jackrabbits. ***Outstanding***: Spatially explicit habitat suitability estimates (either empirically or deductively derived), and the identification of modeling data needs and information gaps for most wildlife species reliant on sagebrush habitats are lacking. Standardized monitoring strategies, literature summaries, and the identification of information necessary to inform management actions for the bulk of sagebrush associated priority species have not been developed.

Table 3. Priority science Needs detailed under the Sagebrush and Sage-grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan establishing the completion score (Score), and a summary of science objectives addressed (Addressed) and not addressed (Outstanding) in the scientific literature published 2015–20.—Continued

[Sagebrush, *Artemisia tridentata*; Greater sage-grouse, *Centrocercus urophasianus*]

Need	Score	Summary of 2015–20 literature
Need 8: Develop thresholds for the extent and magnitude of a threat (for example, cover of pinyon and juniper, density of oil and gas wells, road density, etc.) above which the habitat can no longer support sagebrush-obligate species.	0.50	***Addressed***: Numerous local and regional scale studies have investigated the response of sagebrush obligate and associated wildlife species, primarily songbirds and small mammals, to anthropogenic and natural disturbance factors across the sagebrush biome (see also Sagebrush and Sage-Grouse topic Need 7 summary). The overlap between sage-grouse habitat protections and several other sagebrush obligate or associated species or groups of species has been investigated at local, regional and range wide scales. The umbrella effectiveness of sage-grouse for sagebrush obligate and associated songbirds has been more formally assessed (population trend or fine-scale habitat selection consistency among species) in several local scale studies. Responses of songbirds, small mammals, bats, and general wildlife to conifer treatments have been assessed by multiple local and regional scale studies in western and southern portions of the sagebrush biome. An extensive pinyon-juniper wildlife and management literature review has been completed. ***Outstanding***: Thresholds for the extent and magnitude of threats or disturbances to habitats above which habitat suitability is eliminated for sagebrush obligate wildlife have not been identified. Thresholds of conifer treatments (for example, identification of treatment levels resulting in irreversible impacts) and effects on pinyon-juniper associated species have not been identified. Efficacy of species-specific management strategies for sagebrush obligate or associated species other than in relation to strategies implemented for sage-grouse have not been assessed. Underlying causal mechanisms for sagebrush obligate species response to anthropogenic disturbance have not been thoroughly investigated across the sagebrush biome. Standardized monitoring strategies and literature summaries for most sagebrush associated priority species have not been developed.

Table 3. Priority science Needs detailed under the Sagebrush and Sage-grouse topic in the Integrated Rangeland Fire Management Strategy Actionable Science Plan establishing the completion score (Score), and a summary of science objectives addressed (Addressed) and not addressed (Outstanding) in the scientific literature published 2015–20.—Continued

[Sagebrush, *Artemisia tridentata*; Greater sage-grouse, *Centrocercus urophasianus*]

Need	Score	Summary of 2015–20 literature
Need 9: Conduct long-term monitoring to assess development of community structure, community function, dynamics in native seedings, as well as suitability of resulting communities in meeting specific management goals, such as sage-grouse habitat restoration.	0.75	***Addressed***: Multiple local and regional scale studies have been conducted investigating relationships between different biotic and abiotic factors and changes in sagebrush cover, invasive annual grass cover, and mesic area productivity from 1984 (see also Sagebrush and Sage-Grouse topic Need 4 summary). Generalized regional and local scale restoration prioritization tools and approaches that are relevant range wide have been developed. Several regional scale decision support tools for prioritizing proactive management of sagebrush systems (conifer treatments and conservation easements) including economic and ecological potential considerations have been developed. Numerous studies investigating sage-grouse lek count protocols and data to establish approaches and covariates to estimating population trends locally, regionally and range wide have been conducted. Soil climate conditions (for example, temperature and moisture) and conifer cover have been mapped across the biome; and several aspects of invasive annual grass and fire attributes have been mapped range wide (see also Invasives topic Need 1 and Fire topic Need 3 summaries). Multiple approaches to collecting data important for monitoring sagebrush rangelands and wildlife have been investigated across the sagebrush biome (see also Sagebrush and Sage-Grouse topic Needs 7 and 8 summaries). Range wide studies have been completed that estimate resistance and resilience of sagebrush rangelands based on soils data. ***Outstanding***: Unified metrics linked to sage-grouse population or demographic trends that can be used to quantify sagebrush habitat suitability and quality for sage-grouse have not been developed, limiting the ability to evaluate habitat conservation and restoration success. Fine grained geospatial estimates of human disturbance, most specifically infrastructure, have not been mapped consistently across the sagebrush biome. Simulation models of sage-grouse gains and losses in response to alternative sagebrush restoration efforts are geographically limited. Decision-support tools explicitly integrating ecosystem response to different proactive sagebrush management options have not been developed. Fine-grained soils information has not consistently been incorporated into assessments of the response of rangelands to different sagebrush restoration activities across treatment options.

There were several Next Steps identified under the Sagebrush and Sage-Grouse topic that were addressed poorly, even when the overall Need was well or partially addressed. Underlying causal mechanisms explaining population-level response of sage-grouse and other sagebrush-dependent species to anthropogenic infrastructure remain largely unknown (Needs 3 and 8). A range wide, coordinated assessment of sage-grouse seasonal habitat selection and demographic data with links to population viability has not been accomplished (Needs 5 and 6). Unified metrics suitable for quantifying sagebrush habitat suitability and quality for sage-grouse and other sagebrush-dependent species have not been developed, limiting the ability to evaluate the success of habitat conservation and restoration activities (Need 9).

The completion scores and summaries in this report provide the basis to identify new actionable science priorities that are needed to address the issues continuing to drive the loss, degradation, restoration, and fragmentation of sagebrush habitats in the western United States. The resulting information can directly inform an update to the Plan, as well as other highly relevant science planning documents including, but not limited to: Parts 1 and 2 of the Science Framework (Chambers and others, 2017; Crist and others, 2019), the WAFWA Sagebrush Conservation Strategy (Remington and others, 2021), and online science portals for managers in various stages of development. Because actionable science production continues to move forward quickly, Needs and Next Steps likely to be addressed by science released after 2020 will require consideration in Plan updates.

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Glossary

Addressed Objective detailed in a Next Step that was addressed in the literature published between January 1, 2015, and December 31, 2020

Fire frequency The recurrence of fire in a given area over time

Need A shared vision among researchers and managers of priority science required to fill knowledge gaps and inform the next generation of management strategies and tools

Next step Science objectives (in other words, new research, syntheses, and tools) required to address a Need

Objective Science or research goals detailed as Next Steps in the Plan

Outstanding Objective detailed in a Next Step that was not addressed in the literature published between January 1, 2015, and December 31, 2020

Plan IRFMS Actionable Science Plan (Integrated Rangeland Fire Management Strategy Actionable Science Plan Team, 2016)

Score Relative measure of the level of progress towards addressing the Next Steps established in a Need

Topic One of five science themes identified in the Plan relevant to the management of sagebrush ecosystems

Appendix 1. Literature included in scoring Next Steps for the Sagebrush and Sage-grouse topic in the Actionable Science Plan

The literature in this appendix is organized by Need and Next Step. Needs are defined as a shared vision among researchers and managers of priority science required to fill knowledge gaps and inform the next generation of management strategies and tools. Next Steps are defined as science objectives (that is, new research, syntheses, and tools) required to address a Need. Next Steps scored as 0.00 in table 2 are described as "Not addressed." Next Steps that could not be assessed through literature review approach used (for example, development of databases) are described as "NA."

Sagebrush and Sage-Grouse Science Need 1

Investigate sage-grouse movement patterns, the habitat characteristics that are conducive, restrictive, or preventive to those movements, and the genetic structure of populations to help inform management practices to improve or maintain connections.

Next Step 1a

Compile and integrate disparate GPS tracking datasets to relate fine-scale movement patterns of sage-grouse relative to landscape characteristics, and identify variation in environmental resistance and barriers between seasonal habitats and between populations across the sage-grouse range.

Crist, M.R., Knick, S.T., and Hanser, S.E., 2017, Range-wide connectivity of priority areas for greater sage-grouse—Implications for long-term conservation from graph theory: The Condor, v. 119, no. 1, p. 44–57.

Next Step 1b

Initiate studies using high-frequency, fine-resolution GPS data to link sage-grouse movement processes to habitat conditions and anthropogenic features across the landscape.

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Tack, J.D., Jakes, A.F., Jones, P.F., Smith, J.T., Newton, R.E., Martin, B.H., Hebblewhite, M., and Naugle, D.E., 2019, Beyond protected areas—Private lands and public policy anchor intact pathways for multi-species wildlife migration: Biological Conservation, v. 234, p. 18–27.

Next Step 1c

Expand studies done with genetic data collected from lek sites that provide broad-scale patterns of range-wide population connectivity, including use of single nucleotide polymorphisms and other advanced genetic and genomic techniques.

Cross, T.B., Naugle, D.E., Carlson, J.C., and Schwartz, M.K., 2017, Genetic recapture identifies long-distance breeding dispersal in greater sage-grouse (*Centrocercus urophasianus*): The Condor, v. 119, no. 1, p. 155–166.

Hanks, E.M., Hooten, M.B., Knick, S.T., Oyler-McCance, S.J., Fike, J.A., Cross, T.B., and Schwartz, M.K., 2016, Latent spatial models and sampling design for landscape genetics: The Annals of Applied Statistics, v. 10, no. 2, p. 1041–1062.

Fike, J.A., Oyler-McCance, S.J., Zimmerman, S.J., and Castoe, T.A., 2015, Development of 13 microsatellites for Gunnison sage-grouse (*Centrocercus minimus*) using next-generation shotgun sequencing and their utility in greater sage-grouse (*Centrocercus urophasianus*): Conservation Genetics Resources, v. 7, no. 1, p. 211–214.

Oyler-McCance, S.J., Cornman, R.S., Jones, K.L., and Fike, J.A., 2015a, Genomic single-nucleotide polymorphisms confirm that Gunnison and greater sage-grouse are genetically well differentiated and that the Bi-State population is distinct: The Condor, v. 117, no. 2, p. 217–227.

Oyler-McCance, S.J., Cornman, R.S., Jones, K.L., and Fike, J.A., 2015b, Z chromosome divergence, polymorphism and relative effective population size in a genus of lekking birds: Heredity, v. 115, no. 5, p. 452–459.

Row, J.R., Knick, S.T., Oyler-McCance, S.J., Lougheed, S.C., and Fedy, B.C., 2017, Developing approaches for linear mixed modeling in landscape genetics through landscape-directed dispersal simulations: Ecology and Evolution, v. 7, no. 11, p. 3751–3761.

Shirk, A.J., Schroeder, M.A., Robb, L.A., and Cushman, S.A., 2015, Empirical validation of landscape resistance models—Insights from the greater sage-grouse (*Centrocercus urophasianus*): Landscape Ecology, v. 30, no. 10, p. 1837–1850.

Next Step 1d

Use fine-scale genetic data from individual sage-grouse to investigate how movement barriers impact population performance and genetic structure at local scales.

Cross, T.B., Naugle, D.E., Carlson, J.C., and Schwartz, M.K., 2016, Hierarchical population structure in greater sage-grouse provides insight into management boundary delineation: Conservation Genetics, v. 17, no. 6, p. 1417–1433.

Davis, D.M., Reese, K.P., Gardner, S.C., and Bird, K.L., 2015, Genetic structure of greater sage-grouse (*Centrocercus urophasianus*) in a declining, peripheral population: The Condor, v. 117, no. 4, p. 530–544.

Jahner, J.P., Gibson, D., Weitzman, C.L., Blomberg, E.J., Sedinger, J.S., and Parchman, T.L., 2016, Fine-scale genetic structure among greater sage-grouse leks in central Nevada: BMC Evolutionary Biology, v. 16, article 127, 13 p.

Fedy, B.C., Row, J.R., and Oyler-McCance, S.J., 2017, Integration of genetic and demographic data to assess population risk in a continuously distributed species: Conservation Genetics, v. 18, no. 1, p. 89–104.

Row, J.R., Oyler-McCance, S.J., Fike, J.A., O'Donnell, M.S., Doherty, K.E., Aldridge, C.L., Bowen, Z.H., and Fedy, B.C., 2015, Landscape characteristics influencing the genetic structure of greater sage-grouse within the stronghold of their range—A holistic modeling approach: Ecology and Evolution, v. 5, no. 10, p. 1955–1969.

Row, J.R., Oyler-McCance, S.J., and Fedy, B.C., 2016, Differential influences of local subpopulations on regional diversity and differentiation for greater sage-grouse (*Centrocercus urophasianus*): Molecular Ecology, v. 25, no. 18, p. 4424–4437.

Next Step 1e

Complete a range-wide genetic analysis to provide the first comprehensive assessment of sage-grouse genetic connectivity.

Cross, T.B., Schwartz, M.K., Naugle, D.E., Fedy, B.C., Row, J.R., and Oyler-McCance, S.J., 2018, The genetic network of greater sage-grouse—Range-wide identification of keystone hubs of connectivity: Ecology and Evolution, v. 8, no. 11, p. 5394–5412.

Oh, K.P., Aldridge, C.L., Forbey, J.S., Dadabay, C.Y., and Oyler-McCance, S.J., 2019, Conservation genomics in the sagebrush sea—Population divergence, demographic history, and local adaptation in sage-grouse (*Centrocercus* spp.): Genome Biology and Evolution, v. 11, no. 7, p. 2023–2034.

Row, J.R., Doherty, K.E., Cross, T.B., Schwartz, M.K., Oyler-McCance, S.J., Naugle, D.E., Knick, S.T., and Fedy, B.C., 2018, Quantifying functional connectivity—The role of breeding habitat, abundance, and landscape features on range-wide gene flow in sage-grouse: Evolutionary Applications, v. 11, no. 8, p. 1305–1321.

Next Step 1f

Develop new technology that allows for acquisition of movement data with increased frequency and resolution and reduced sage-grouse mortality.

Not addressed.

Next Step 1g

Investigate landscape factors that explain regional variation in movement patterns across different spatial scales using genetic and telemetry data.

Not addressed.

Next Step 1h

Complete studies of sage-grouse movements relative to habitat conditions and human features across the landscape using high-frequency, fine-resolution GPS data to understand how movement barriers affect population performance and genetic structure.

Not addressed.

Studies Related to Need 1, But Not Any of the Next Steps

Burkhalter, C., Holloran, M.J., Fedy, B.C., Copeland, H.E., Crabtree, R.L., Michel, N.L., Jay, S.C., Rutledge, B.A., and Holloran, A.G., 2018, Landscape-scale habitat assessment for an imperiled avian species: Animal Conservation, v. 21, no. 3, p. 241–251.

Cardinal, C.J., and Messmer, T.A., 2016, Ecology of greater sage-grouse populations inhabiting the northwestern Wyoming Basin: Human-Wildlife Interactions, v. 10, no. 2, p. 188–204.

Forbey, J.S., Patricelli, G.L., Delparte, D.M., Krakauer, A.H., Olsoy, P.J., Fremgen, M.R., Nobler, J.D., Spaete, L.P., Shipley, L.A., Rachlow, J.L., Dirksen, A.K., Perry, A., Richardson, B.A., and Glenn, N.F., 2017, Emerging technology to measure habitat quality and behavior of grouse—Examples from studies of greater sage-grouse: Wildlife Biology, 10 p.

Gibson, D., Blomberg, E.J., Atamian, M.T., Espinosa, S.P., and Sedinger, J.S., 2018, Effects of power lines on habitat use and demography of greater sage-grouse (*Centrocercus urophasianus*): Wildlife Monographs, v. 200, no. 1, p. 1–41.

Heinrichs, J.A., Aldridge, C.L., O'Donnell, M.S., and Schumaker, N.H., 2017, Using dynamic population simulations to extend resource selection analyses and prioritize habitats for conservation: Ecological Modelling, v. 359, p. 449–459.

O'Donnell, M.S., Edmunds, D.R., Aldridge, C.L., Heinrichs, J.A., Coates, P.S., Prochazka, B.G., and Hanser, S.E., 2019, Designing multi-scale hierarchical monitoring frameworks for wildlife to support management—A sage-grouse case study: Ecosphere, v. 10, no. 9, p. 1–34.

Reinhardt, J.R., Naugle, D.E., Maestas, J.D., Allred, B., Evans, J., and Falkowski, M., 2017, Next-generation restoration for sage-grouse—A framework for visualizing local conifer cuts within a landscape context: Ecosphere, v. 8, no. 7, article e01888, 18 p.

Sagebrush and Sage-Grouse Science Need 2

Conduct a series of large-scale, replicated grazing studies that address how different livestock species, grazing systems, disturbance histories, and other environmental conditions affect sage-grouse habitat.

Next Step 2a

Identify numerous study sites and initiate monitoring within pastures and plots at those sites that have different and explicit grazing treatments, documenting the past grazing regime at those study pastures and plots to experimentally link the timing and intensity of livestock grazing to sage-grouse demographics and population trends.

Monroe, A.P., Aldridge, C.L., Assal, T.J., Veblen, K.E., Pyke, D.A., and Casazza, M.L., 2017, Patterns in greater sage-grouse population dynamics correspond with public grazing records at broad scales: Ecological Applications, v. 27, no. 4, p. 1096–1107.

Smith, J.T., Tack, J.D., Berkeley, L.I., Szczypinski, M., and Naugle, D.E., 2018a, Effects of livestock grazing on nesting sage-grouse in central Montana: The Journal of Wildlife Management, v. 82, no. 7, p. 1503–1515.

Smith, J.T., Tack, J.D., Berkeley, L.I., Szczypinski, M., and Naugle, D.E., 2018b, Effects of rotational grazing management on nesting greater sage-grouse: The Journal of Wildlife Management, v. 82, no. 1, p. 103–112.

Next Step 2b

Identify or refine detailed protocols for monitoring sage-grouse vital rates and estimating local grazing intensity that would be used at replicate study sites so that data from numerous sites and States can contribute to synthetic analyses.

Not addressed.

Next Step 2c

Conduct an assessment of feral horse and burro impacts on local vegetation and sage-grouse habitat selection, vital rates, and population trends. If done in conjunction with analysis of effects of livestock grazing, this would facilitate analyses of interactive effects.

Baur, L.E., Schoenecker, K.A., and Smith, M.D., 2018, Effects of feral horse herds on rangeland plant communities across a precipitation gradient: Western North American Naturalist, v. 77, no. 4, p. 526–539.

Boyd, C.S., Davies, K.W., and Collins, G.H., 2017, Impacts of feral horse use on herbaceous riparian vegetation within a sagebrush steppe ecosystem: Rangeland Ecology and Management, v. 70, no. 4, p. 411–417.

Davies, K.W., and Boyd, C.S., 2019, Ecological effects of free-roaming horses in North American Rangelands: Bioscience, v. 69, no. 7, p. 558–565.

Next Step 2d

Develop a synthesis of grazing effects on sage-grouse habitat condition.

Chambers, J.C., Beck, J.L., Bradford, J.B., Bybee, J., Campbell, S., Carlson, J., Christiansen, T.J., Clause, K.J., Collins, G., Crist, M.R., Dinkins, J.B., Doherty, K.E., Edwards, F., Espinosa, S., Griffin, K.A., Griffin, P., Haas, J.R., Hanser, S.E., Havlina, D.W., Henke, K.F., Hennig, J.D., Joyce, L.A., Kilkenny, F.M., Kulpa, S.M., Kurth, L.L., Maestas, J.D., Manning, M., Mayer, K.E., Mealor, B.A., McCarthy, C., Pellant, M., Perea, M.A., Prentice, K.L., Pyke, D.A., Wiechman, L.A., and Wuenschel, A., 2017, Science framework for conservation and restoration of the sagebrush biome—Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions—Part 1. Science basis and applications: Fort Collins, Colorado, U.S Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR360. p. 213.

Chambers, J.C., Beck, J.L., Campbell, S., Carlson, J., Christiansen, T.J., Clause, K.J., Dinkins, J.B., Doherty, K.E., Griffin, K.A., Havlina, D.W., Mayer, K.F., Hennig, J.D., Kurth, L.L., Maestas, J.D., Manning, M., Mealor, B.A., McCarthy, C., Perea, M.A., and Pyke, D.A., 2016, Using resilience and resistance concepts to manage threats to sagebrush ecosystems, Gunnison sage-grouse, and greater sage-grouse in their eastern range—A strategic multi-scale approach: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-356, 143 p.

Crist, M.R., Chambers, J.C., Phillips, S.L., Prentice, K.L., and Wiechman, L.A., eds., 2019, Science framework for conservation and restoration of the sagebrush biome—Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions—Part 2. Management applications: Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-389, 237 p.

Elwell, S.L., Griswold, T., and Elle, E., 2016, Habitat type plays a greater role than livestock grazing in structuring shrubsteppe plant-pollinator communities: Journal of Insect Conservation, v. 20, no. 3, p. 515–525.

Hanser, S.E., Deibert, P.A., Tull, J.C., Carr, N.B., Aldridge, C.L., Bargsten, T.D., Christiansen, T.J., Coates, P.S., Crist, M.R., Doherty, K.E., Ellsworth, E.A., Foster, L.J., Herren, V.A., Miller, K.H., Moser, A., Naeve, R.M., Prentice, K.L., Remington, T.E., Ricca, M.A., Shinneman, D.J., Truex, R.L., Wiechman, L.A., Wilson, D.C., and Bowen, Z.H., 2018, Greater sage-grouse science (2015–17)–Synthesis and potential management implications: U.S. Geological Survey, Open-File Report 2018–1017, p. 1–46.

Hunter, H.E., Husby, P.O., Fidel, J., and Mosley, J.C., 2018, Ecological health of grasslands and sagebrush steppe on the Northern Yellowstone Range: Rangelands, v. 40, no. 6, p. 212–223.

Rowland, M.M., 2019, The effects of management practices on grassland birds—Greater Sage-Grouse (*Centrocercus urophasianus*), chap. B *in* Johnson, D.H., Igl, L.D., Shaffer, J.A., and DeLong, J.P., eds., The effects of management practices on grassland birds: U.S. Geological Survey Professional Paper 1842, p. 50.

Next Step 2e

Coordinate the collection of consistent range-wide geospatial information documenting grazing timing and intensity at the allotment and pasture level to facilitate large-scale analyses of grazing information.

NA.

Next Step 2f

Develop long-term replicated grazing studies across the sagebrush ecosystem and within different ecological sites across the range of sage-grouse to better understand the different effects of grazing on sage-grouse habitat selection, vital rates, and population trends.

Smith, J.T., Tack, J.D., Berkeley, L.I., Szczypinski, M., and Naugle, D.E., 2018a, Effects of livestock grazing on nesting sage-grouse in central Montana: The Journal of Wildlife Management, v. 82, no. 7, p. 1503–1515.

Smith, J.T., Tack, J.D., Berkeley, L.I., Szczypinski, M., and Naugle, D.E., 2018b, Effects of rotational grazing management on nesting greater sage-grouse: The Journal of Wildlife Management, v. 82, no. 1, p. 103–112.

Next Step 2g

Implement consistent sampling at many sites in multiple states to ensure that results are rigorous and applicable throughout the sage-grouse range.

Not addressed.

Next Step 2h

Evaluate effect of extended rest from grazing after a restoration seeding (beyond the typical 2 years) on restoration success, including root growth development and at what point plants are established to the point of tolerating grazing by livestock or feral horses and burros.

Davies, K.W., Bates, J.D., and Boyd, C.S., 2020, Response of planted sagebrush seedlings to cattle grazing applied to decrease fire probability: Rangeland Ecology and Management, v. 73, no. 5, p. 629–635.

Denton, E.M., Smith, B.S., Hamerlynck, E.P., and Sheley, R.L., 2018, Seedling defoliation and drought stress—Variation in intensity and frequency affect performance and survival: Rangeland Ecology and Management, v. 71, no. 1, p. 25–34.

Studies Related to Need 2, But Not Any of the Next Steps

Clark, P.E., Williams, C.J., Kormos, P.R., and Pierson, F.B., 2018, Postfire grazing management effects on mesic sagebrush-steppe vegetation—Mid-summer grazing: Journal of Arid Environments, v. 151, p. 104–112.

Clark, P.E., Williams, C.J., Pierson, F.B., and Hardegree, S.P., 2016, Postfire grazing management effects on mesic sagebrush-steppe vegetation—Spring grazing: Journal of Arid Environments, v. 132, p. 49–59.

Coates, P.S., Brussee, B.E., Howe, K.B., Gustafson, K.B., Casazza, M.L., and Delehanty, D.J., 2016, Landscape characteristics and livestock presence influence common ravens—Relevance to greater sage-grouse conservation: Ecosphere, v. 7, no. 2, article e01203, 20 p.

Connell, L.C., Scasta, J.D., and Porensky, L.M., 2018, Prairie dogs and wildfires shape vegetation structure in a sagebrush grassland more than does rest from ungulate grazing: Ecosphere, v. 9, no. 8, article e02390, 19 p.

Conover, M.R., and Roberts, A.J., 2016, Declining populations of greater sage-grouse—Where and why: Human-Wildlife Interactions, v. 10, no. 2, p. 217–229.

Cutting K.A., Rotella J.J., Schroff S.R., Frisina M.R., Waxe J.A., Nunlist E., and Sowell B.F., 2019, Maladaptive nest-site selection by a sagebrush dependent species in a grazing-modified landscape: Journal of Environmental Management, v. 236, no. epub 2019, p. 622–630.

Davies, K.W., Bates, J.D., and Boyd, C.S., 2016, Effects of intermediate-term grazing rest on sagebrush communities with depleted understories—Evidence of a threshold: Rangeland Ecology and Management, v. 69, no. 3, p. 173–178.

Davies, K.W., Boyd, C.S., and Bates, J.D., 2018, Eighty years of grazing by cattle modifies sagebrush and bunchgrass structure: Rangeland Ecology and Management, v. 71, no. 3, p. 275–280.

Dittel, J.W., Sanchez, D.M., Ellsworth, L.M., Morozumi, C.N., and Mata-Gonzalez, R., 2018, Vegetation response to juniper reduction and grazing exclusion in sagebrush-steppe habitat in eastern Oregon: Rangeland Ecology and Management, v. 71, no. 2, p. 213–219.

Goosey, H.B., Smith, J.T., O’Neill, K.M., and Naugle, D.E., 2019, Ground-dwelling arthropod community response to livestock grazing—Implications for avian conservation: Environmental Entomology, v. 48, no. 4, p. 856–866.

Gosselin, E.N., Holbrook, J.D., Huggler, K., Brown, E., Vierling, K.T., Arkle, R.S., and Pilliod, D.S., 2016, Ecosystem engineering of harvester ants—Effects on vegetation in a sagebrush-steppe ecosystem: Western North American Naturalist, v. 76, no. 1, p. 82–89.

Mitchell, R.M., Bakker, J.D., Vincent, J.B., and Davies, G.M., 2017, Relative importance of abiotic, biotic, and disturbance drivers of plant community structure in the sagebrush steppe: Ecological Applications, v. 27, no. 3, p. 756–768.

Veblen, K.E., Nehring, K.C., McGlone, C.M., and Ritchie, M.E., 2015, Contrasting effects of different mammalian herbivores on sagebrush plant communities: PLoS ONE, v. 10, no. 2, article e0118016, 19 p.

Sagebrush and Sage-Grouse Science Need 3

Identify thresholds beyond which effects on sage-grouse behavior, population response(s), or habitat use are minimized relative to different types of disturbances and related activities, for example, effects of wildfire, energy development, and other surface-disturbing activities.

Next Step 3a

Assess the relative influence of predators and infrastructure on sage-grouse behaviors and population dynamics, including distinction of altered sage-grouse behavior (avoidance) from direct impacts (mortality).

Coates, P.S., O’Neil, S.T., Brussee, B.E., Ricca, M.A., Jackson, P.J., Dinkins, J.B., Howe, K.B., Moser, A.M., Foster, L.J., and Delehanty, D.J., 2020, Broad-scale impacts of an invasive native predator on a sensitive native prey species within the shifting avian community of the North American Great Basin: Biological Conservation, v. 243, 10 p.

Gibson, D., Blomberg, E.J., Atamian, M.T., Espinosa, S.P., and Sedinger, J.S., 2018, Effects of power lines on habitat use and demography of greater sage-grouse (*Centrocercus urophasianus*): Wildlife Monographs, v. 200, no. 1, p. 1–41.

Next Step 3b

Expand on the work of Blickley and others (2012) by building into study designs assessments of effects of different types of noise (industrial, recreational, and road noises in sagebrush landscapes) and by including variations in volume and distance across large geographic areas and over multiple sage-grouse populations.

Not addressed.

Next Step 3c

Investigate the impacts of noise on sage-grouse nesting females, nest success, and brood and chick survival.

Not addressed.

Next Step 3d

Evaluate impacts of wind turbines and associated infrastructure on sage-grouse habitat use, seasonal survival, nesting, and brood-rearing success rates.

Cardinal, C.J., and Messmer, T.A., 2016, Ecology of greater sage-grouse populations inhabiting the northwestern Wyoming Basin: Human-Wildlife Interactions, v. 10, no. 2, p. 188–204.

Hansen, E.P., Stewart, A.C., and Frey, S.N., 2016, Influence of transmission line construction on winter sage-grouse habitat use in southern Utah: Human-Wildlife Interactions, v. 10, no. 2, p. 169–187.

Kohl, M.T., Messmer, T.A., Crabb, B.A., Guttery, M.R., Dahlgren, D.K., Larsen, R.T., Frey, S.N., Liguori, S., and Baxter, R.J., 2019, The effects of electric power lines on the breeding ecology of greater sage-grouse: PloS ONE, v. 14, no. 1, article E0209968, 25 p.

LeBeau, C.W., Beck, J.L., Johnson, G.D., Nielson, R.M., Holloran, M.J., Gerow, K.G., and McDonald, T.L., 2017a, Greater sage-grouse male lek counts relative to a wind energy development: Wildlife Society Bulletin, v. 41, no. 1, p. 17–26.

LeBeau, C.W., Johnson, G.D., Holloran, M.J., Beck, J.L., Nielson, R.M., Kauffman, M.E., Rodemaker, E.J., and McDonald, T.L., 2017b, Greater sage-grouse habitat selection, survival, and wind energy infrastructure: The Journal of Wildlife Management, v. 81, no. 4, p. 690–711.

LeBeau, C.W., Smith, K.T., Holloran, M.J., Beck, J.L., Kauffman, M.E., and Johnson, G.D., 2019, Greater sage-grouse habitat function relative to 230-kV transmission lines: The Journal of Wildlife Management, v. 83, no. 8, p. 1773–1786.

Next Step 3e

Determine the effects of conifer removal relative to removal of anthropogenic tall structures, considering demonstrable effects on habitat use. Address in these studies how predators respond to treatments, including raptors, canids, corvids, and rodents.

Coates, P.S., Andrle, K.M., Ziegler, P.T., and Casazza, M.L., 2016, Monitoring and research on the Bi-State distinct population segment of greater sage-grouse (*Centrocercus urophasianus*) in the Pine Nut Mountains, California and Nevada—Study progress report, 2011–15: U.S. Geological Survey Open-File Report 2015–1222, 40 p.

Coates, P.S., Prochazka, B.G., Ricca, M.A., Gustafson, K.B., Ziegler, P., and Casazza, M.L., 2017, Pinyon and juniper encroachment into sagebrush ecosystems impacts distribution and survival of greater sage-grouse: Rangeland Ecology and Management, v. 70, no. 1, p. 25–38.

Cook, A.A., Messmer, T.A., and Guttery, M.R., 2017, Greater sage-grouse use of mechanical conifer reduction treatments in northwest Utah: Wildlife Society Bulletin, v. 41, no. 1, p. 27–33.

Mathews, S.R., Coates, P.S., Prochazka, B.G., Ricca, M.A., Meyerpeter, M.B., Espinosa, S.P., Lisius, S., Gardner, S.C., and Delehanty, D.J., 2018, An integrated population model for Greater Sage-grouse (*Centrocercus urophasianus*) in the Bi-State Distinct Population Segment, California and Nevada, 2003–17: US Geological Survey Open-File Report 2018–1177, 89 p.

Sandford, C.P., Kohl, M.T., Messmer, T.A., Dahlgren, D.K., Cook, A., and Wing, B.R., 2017, Greater sage-grouse resource selection drives reproductive fitness under a conifer removal strategy: Rangeland Ecology and Management, v. 70, no. 1, p. 59–67.

Severson, J.P., Hagen, C.A., Maestas, J.D., Naugle, D.E., Forbes, J.T., and Reese, K.P., 2017a, Short-term response of sage-grouse nesting to conifer removal in the northern Great Basin: Rangeland Ecology and Management, v. 70, no. 1, p. 50–58.

Severson, J.P., Hagen, C.A., Maestas, J.D., Naugle, D.E., Forbes, J.T., and Reese, K.P., 2017b, Effects of conifer expansion on greater sage-grouse nesting habitat selection: The Journal of Wildlife Management, v. 81, no. 1, p. 86–95.

Severson, J.P., Hagen, C.A., Tack, J.D., Maestas, J.D., Naugle, D.E., Forbes, J.T., and Reese, K.P., 2017, Better living through conifer removal—A demographic analysis of sage-grouse vital rates: PLoS ONE, v. 12, no. 3, article e0174347, 17 p.

Next Step 3f

Determine the response of sage-grouse to removal of infrastructure, including sage-grouse demography, population size of sage-grouse, and habitat characteristics.

Fedy, B.C., Kirol, C.P., Sutphin, A.L., and Maechtle, T.L., 2015, The influence of mitigation on sage-grouse habitat selection within an energy development field: PLoS ONE, v. 10, no. 4, article e0121603, 19 p.

Holloran, M.J., Fedy, B.C., and Dahlke, J., 2015, Habitat use of greater sage-grouse relative to activity levels at natural gas well pads: The Journal of Wildlife Management, v. 79, no. 4, p. 630–640.

Kirol, C.P., Sutphin, A.L., Bond, L., Fuller, M.R., and Maechtle, T.L., 2015, Mitigation effectiveness for improving nesting success of greater sage-grouse influenced by energy development: Wildlife Biology, v. 21, no. 2, p. 98–109.

Pratt, A.C., and Beck, J.L., 2019, Greater sage-grouse response to bentonite mining: The Journal of Wildlife Management, v. 84, no. 4, p. 866–879.

Van Lanen, N.J., Green, A.W., Gorman, T.R., Quattrini, L.A., and Pavlacky, D.C., Jr., 2017, Evaluating efficacy of fence markers in reducing greater sage-grouse collisions with fencing: Biological Conservation, v. 213, p. 70–83.

Next Step 3g

Assess development scenarios to improve siting and density of future project development to decrease impacts of sage-grouse populations (for example, concentrated and clustered development versus diffuse development).

Garman, S.L., 2017, A simulation framework for assessing physical and wildlife impacts of oil and gas development scenarios in southwestern Wyoming: Environmental Modeling and Assessment, v. 23, no. 1, p. 39–56.

Heinrichs, J.A., O'Donnell, M.S., Aldridge, C.L., Garman, S.L., and Homer C.G., 2019, Influences of potential oil and gas development and future climate on sage-grouse declines and redistribution: Ecological Applications, v. 29, no. 6, article e01912, p. 1–16.

Juliusson, L.M., and Doherty, K.E., 2017, Oil and gas development exposure and conservation scenarios for greater sage-grouse—Combining spatially explicit modeling with GIS visualization provides critical information for management decisions: Sevenoaks, England, Applied Geography, v. 80, p. 98–111.

Next Step 3h

Assess the indirect effects of land use activities (density and distribution) and potential covariates on sagebrush habitats.

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Sagebrush and Sage-Grouse Science Need 4

Develop next-generation mapping techniques to provide regular interval updates and continue to enhance grassland and shrubland vegetation mapping (for example, every 2–5 years).

Next Step 4a

Complete a baseline sagebrush ecosystem-wide characterization of shrub and grass components for the entire sagebrush ecosystem.

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Next Step 4b

Conduct an ecosystem-wide analysis of sagebrush change back in time to 1983 from the baseline using the Landsat archive and ancillary data (for example, fire data).

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Next Step 4c

Further explore how to integrate ground sampling and monitoring using remote sensing to synergistically advance monitoring applications (for example, machine learning and approaches using big data).

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Next Step 4d

Using Landsat change trends, develop scenario maps of the future showing how sagebrush ecosystem could change based on expected climate, fire, and other change agents.

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Next Step 4e

Explore new mapping technologies that synergistically merge multiple new technologies and data to provide higher spatial, structural, and thematic resolution maps than now possible and that cover larger areas.

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Next Step 4f

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Sagebrush and Sage-Grouse Science Need 5

Develop spatially explicit sage-grouse population models that incorporate biological processes and habitat dynamics and investigate scenarios that reflect local management possibilities (options, opportunities, and obstacles).

Next Step 5a

Coordinate and establish sage-grouse telemetry study sites across the species' range to collect consistent sage-grouse demographic rate information for use in development of a range-wide integrated population model and scenario modeling. This information will also help establish links between sage-grouse population change, protective measures, conservation efforts, restoration actions, and effectiveness of metrics for habitat monitoring.

Not addressed. See Needs 3 and 6 for local and regional habitat selection and demographic studies.

Next Step 5b

Synthesize existing data and literature about population ecology of sage-grouse, as well as habitat associations related to demographic rates. This synthesis should include information about specific sage-grouse life stages (for example, nesting, brood-rearing, wintering) while assessing vital rates and specific habitat needs across different ecoregions that sage-grouse inhabit.

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Next Step 5c

Convene a multi-agency working group to develop the metrics and process for completing a range-wide framework for an integrated population model that can predict or explain sage-grouse population performance relative to management decisions.

NA.

Next Step 5d

Develop a range-wide integrated population model that incorporates landscape-scale environmental, disturbance, and climate information to provide reliable estimates of sage-grouse population size, population performance, and models that can explain variation in population size and performance across multiple spatial scales.

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Coates, P.S., Casazza, M.L., Ricca, M.A., Brussee, B.E., Blomberg, E.J., Gustafson, K.B., Overton, C.T., Davis, D.M., Niell, L.E., Espinosa, S.P., Gardner, S.C., and Delehanty, D.J., 2016, Integrating spatially explicit indices of abundance and habitat quality—An applied example for greater sage-grouse management: Journal of Applied Ecology, v. 53, no. 1, p. 83–95.

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Next Step 5e

Use a spatially explicit simulation modeling environment to link data and models with vital rate and movement information. These models will allow for the evaluation of how multiple interacting management actions and changes in land use and resource condition affect local and regional populations. This biologically realistic and mechanistic approach to evaluating the population responses across life stages will aid in identifying effective alternative management actions impacting sage-grouse distribution, abundance, and persistence.

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Next Step 5f

Develop an online interface to facilitate access by State and Federal agencies to the range-wide integrated population model to inform sage-grouse management actions.

NA.

Studies Related to Need 5, But Not Any of the Next Steps

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Coates, P.S., Prochazka, B.G., Ricca, M.A., Wann, G.T., Aldridge, C.L., Hanser, S.E., Doherty, K.E., O'Donnell, M.S., Edmunds, D.R., and Espinosa, S.P., 2017, Hierarchical population monitoring of greater sage-grouse (*Centrocercus urophasianus*) in Nevada and California—Identifying populations for management at the appropriate spatial scale: U.S. Geological Survey Open-File Report 2017–1089, 49 p.

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Row, J.R., Oyler-McCance, S.J., and Fedy, B.C., 2016, Differential influences of local subpopulations on regional diversity and differentiation for greater sage-grouse (*Centrocercus urophasianus*): Molecular Ecology, v. 25, no. 18, p. 4424–4437.

Sagebrush and Sage-Grouse Science Need 6

Identify seasonal habitats for sage-grouse across their entire range.

Next Step 6a

Compile and summarize habitat objectives from land use plans across the range of sage-grouse, and summarize literature to develop regional functional responses that link site-scale habitat objectives to fine- or mid-scale shrub map products, which will be used for seasonal habitat models range-wide.

Bates, J.D., and Davies, K.W., 2019, Characteristics of intact Wyoming big sagebrush associations in southeastern Oregon: Rangeland Ecology and Management, v. 72, no. 1, p. 36–46.

Dahlgren, D.K., Messmer, T.A., Crabb, B.A., Kohl, M.T., Frey, S.N., Thacker, E.T., Larsen, R.T., and Baxter, R.J., 2019, Sage-grouse breeding and late brood-rearing habitat guidelines in Utah: Wildlife Society Bulletin, v. 43, no. 4, p. 576–589.

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Next Step 6b

Collect existing telemetry data throughout the sage-grouse range and evaluate threshold-based seasonal habitat maps to evaluate sage-grouse resource selection models.

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Next Step 6c

Develop empirically based seasonal habitat models for sage-grouse range-wide using existing telemetry data and new data collected as part of a multi-partner population and habitat monitoring framework.

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Hansen, E.P., Stewart, A.C., and Frey, S.N., 2016, Influence of transmission line construction on winter sage-grouse habitat use in southern Utah: Human-Wildlife Interactions, v. 10, no. 2, p. 169–187.

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Kirol, C.P., Beck, J.L., Huzurbazar, S.V., Holloran, M.J., and Miller, S.N., 2015, Identifying greater sage-grouse source and sink habitats for conservation planning in an energy development landscape: Ecological Applications, v. 25, no. 4, p. 968–990.

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Stonehouse, K.F., Shipley, L.A., Lowe, J., Atamian, M.T., Swanson, M.E., and Schroeder, M.A., 2015, Habitat selection and use by sympatric, translocated greater sage-grouse and Columbian sharp-tailed grouse: The Journal of Wildlife Management, v. 79, no. 8, p. 1308–1326.

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Next Step 6d

Develop approaches to apply habitat objectives to shrub map products that allow the development of thresholded seasonal habitat models (several methods being pursued).

Henderson, E.B., Bell, D.M., and Gregory, M.J., 2019, Vegetation mapping to support greater sage-grouse habitat monitoring and management—Multi- or univariate approach?: Ecosphere, v. 10, no. 8, p. 1–22.

Next Step 6e

Integrate seasonal habitat models into a large spatially explicit population-viability modeling approach that encompasses the range of sage-grouse.

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Next Step 6f

Develop spatially explicit simulations to evaluate the effects of land use change (energy development, climate-induced habitat changes, fires, restoration, etc.) on sage-grouse seasonal habitat, and thus population viability.

Heinrichs, J.A., Aldridge, C.L., Gummer, D.L., Monroe, A.P., and Schumaker, N.H., 2018, Prioritizing actions for the recovery of endangered species—Emergent insights from greater sage-grouse simulation modeling: Biological Conservation, v. 218, p. 134–143.

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Next Step 6g

Use results from studies in Next Step 6f to support multiple management applications across spatial and management hierarchies.

NA.

Next Step 6h

Develop a modeling process to enable frequent updates of seasonal models to account for habitat lost due to fire and other disturbance, and gained through conservation and restoration actions.

NA.

Studies Related to Need 6, But Not Any of the Next Steps

Coates, P.S., Brussee, B.E., Ricca, M.A., Dudko, J.E., Prochazka, B.G., Espinosa, S.P., Casazza, M.L., and Delehanty, D.J., 2017, Greater sage-grouse (*Centrocercus urophasianus*) nesting and brood-rearing microhabitat in Nevada and California—Spatial variation in selection and survival patterns: U.S. Geological Survey Open-File Report 2017–1087, 79 p.

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Dudko, J.E., Coates, P.S., and Delehanty, D.J., 2019, Movements of female sage grouse Centrocercus urophasianus during incubation recess: The Ibis, v. 161, no. 1, p. 222–229.

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Sagebrush and Sage-Grouse Science Need 7

Develop sagebrush ecosystem-wide models identifying conditions necessary to support sagebrush-associated species, other than sage-grouse, using an individual species approach or species groups when necessary.

Next Step 7a

Update existing expert opinion and habitat suitability models using current land-cover and human-disturbance mapping products.

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Next Step 7b

Develop empirically based models for those species where suitable and sufficient data exist.

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Miller, R.A., Paprocki, N., Stuber, M.J., Moulton, C.E., and Carlisle, J.D., 2016, Short-eared Owl (*Asio flammeus*) surveys in the North American Intermountain West—Utilizing citizen scientists to conduct monitoring across a broad geographic scale: Avian Conservation and Ecology, v. 11, no. 1, article 3, 9 p.

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Next Step 7c

Initiate data collection to develop the information necessary to model those sagebrush-associated species that lack sufficient existing data to develop models.

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Next Step 7d

Conduct a comprehensive review and synthesis of available information for sagebrush-obligate and associated species to identify information that can inform modeling efforts.

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Next Step 7e

Develop standard monitoring strategies and protocols for priority species lacking current baseline habitat information.

Barnard, D.M., Germino, M.J., Pilliod, D.S., Arkle, R.S., Applestein, C., Davidson, B.E., and Fisk, M.R., 2019, Cannot see the random forest for the decision trees—Selecting predictive models for restoration ecology: Restoration Ecology, v. 27, no. 5, p. 1053–1063.

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Next Step 7f

Identify and resolve information gaps for sagebrush-obligates and ecosystem management.

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Next Step 7g

Develop empirical models for sagebrush-associated species as data become available.

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Next Step 7h

Develop decision-support tools to inform management actions for individual or groups of sagebrush-associated species.

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Sagebrush and Sage-Grouse Science Need 8

Develop thresholds for the extent and magnitude of a threat (for example, cover of pinyon and juniper, density of oil and gas wells, road density, etc.) above which the habitat can no longer support sagebrush-obligate species.

Next Step 8a

Assess efficacy of current management strategies for conservation of sagebrush-obligates, and identify recommended changes using this information.

Barlow, N.L., Kirol, C.P., Doherty, K.E., and Fedy, B.C., 2020, Evaluation of the umbrella species concept at fine spatial scales: The Journal of Wildlife Management, v. 84, no. 2, p. 237–248.

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Next Step 8b

Initiate additional research on the effects of habitat management and modification on pinyon-juniper associated species, such as the juniper titmouse (*Baeolophus ridgwayi*) and the pinyon jay (*Gymnorhinus cyanocephalus*), to identify potential irreversible impacts to these species resulting from habitat management geared towards the restoration of sagebrush-steppe and sagebrush-obligates.

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Next Step 8c

Develop or refine monitoring protocols and initiate systematic monitoring for sagebrush-obligates and other sagebrush-associated species to develop data necessary for evaluation of thresholds established for sage-grouse conservation.

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Next Step 8d

Conduct a comprehensive review of data and literature for sagebrush-obligate species to identify types of responses to various disturbance factors and habitat change, the magnitude of those responses, and the underlying mechanisms.

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Next Step 8e

Evaluate the responses of sagebrush-obligate species relative to various disturbance factors and habitat change and the magnitude of those responses, and determine the underlying causal mechanisms for those responses.

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Next Step 8f

Continue research to identify habitat needs, connectivity, vital rates, etc. of sagebrush-obligate and sagebrush associated species.

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Studies Related to Need 8, But Not Any of the Next Steps

NA.

Sagebrush and Sage-Grouse Science Need 9

Conduct long-term monitoring to assess development of community structure, community function, dynamics in native seedings, as well as suitability of resulting communities in meeting specific management goals, such as sage-grouse habitat restoration.

Next Step 9a

Identify and assess a standardized set of monitoring indicators and protocols, and evaluate their success for measuring efforts to meet habitat conservation and restoration goals.

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Next Step 9b

Develop high-quality geospatial information for environmental and human disturbance metrics including soil characteristics, temperature, precipitation, and infrastructure.

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Next Step 9c

Develop and assess new monitoring methods to improve monitoring efficiency (for example, use of tablets and other devices, photo points, remote sensing, and LiDAR).

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Next Step 9d

Use radio-telemetry and spatially explicit simulation (population) modeling to evaluate the potential gains and losses of sage-grouse associated with alternative sagebrush restoration approaches.

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Next Step 9e

Use long-term temporally stamped sagebrush mapping products currently being developed (See Sagebrush and Sage-Grouse Science Need 4) to construct temporal data series of changes in sagebrush vegetation components (1984–2016) for evaluation of the time to recovery of sagebrush vegetation given the various treatments, disturbances, and restoration practices.

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Next Step 9f

Develop decision-support tools to enable managers to evaluate potential outcomes of planned treatments using information about similar treatments conducted under equivalent environmental conditions, including pre-treatment vegetation, ecological site, weather, and disturbance.

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Next Step 9g

Complete evaluation of monitoring indicators and adopt those that provide clear information to detect community structure and function, evaluate success of management treatments, and detect habitat changes critical to sage-grouse and other sagebrush-obligate species.

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Next Step 9h

Use improved soil maps, maps and models of topography and climate, and information about post-disturbance vegetation response to refine and describe community responses to treatments across environmental gradients.

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Next Step 9i

Develop a set of long-term monitoring sites across the sagebrush ecosystem, stratified by ecological site conditions, resistance and resilience, and other environmental characteristics to facilitate evaluation of long-term community dynamics.

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Next Step 9j

Work with the Natural Resources Conservation Service to complete and improve soil surveys and maps for public lands across the West.

NA.

Studies Related to Need 9, But Not Any of the Next Steps

Balzotti, C.S., Kitchen, S.G., and McCarthy, C., 2016, Beyond the single species climate envelope—A multifaceted approach to mapping climate change vulnerability: Ecosphere, v. 7, no. 9, article e01444, 23 p.

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