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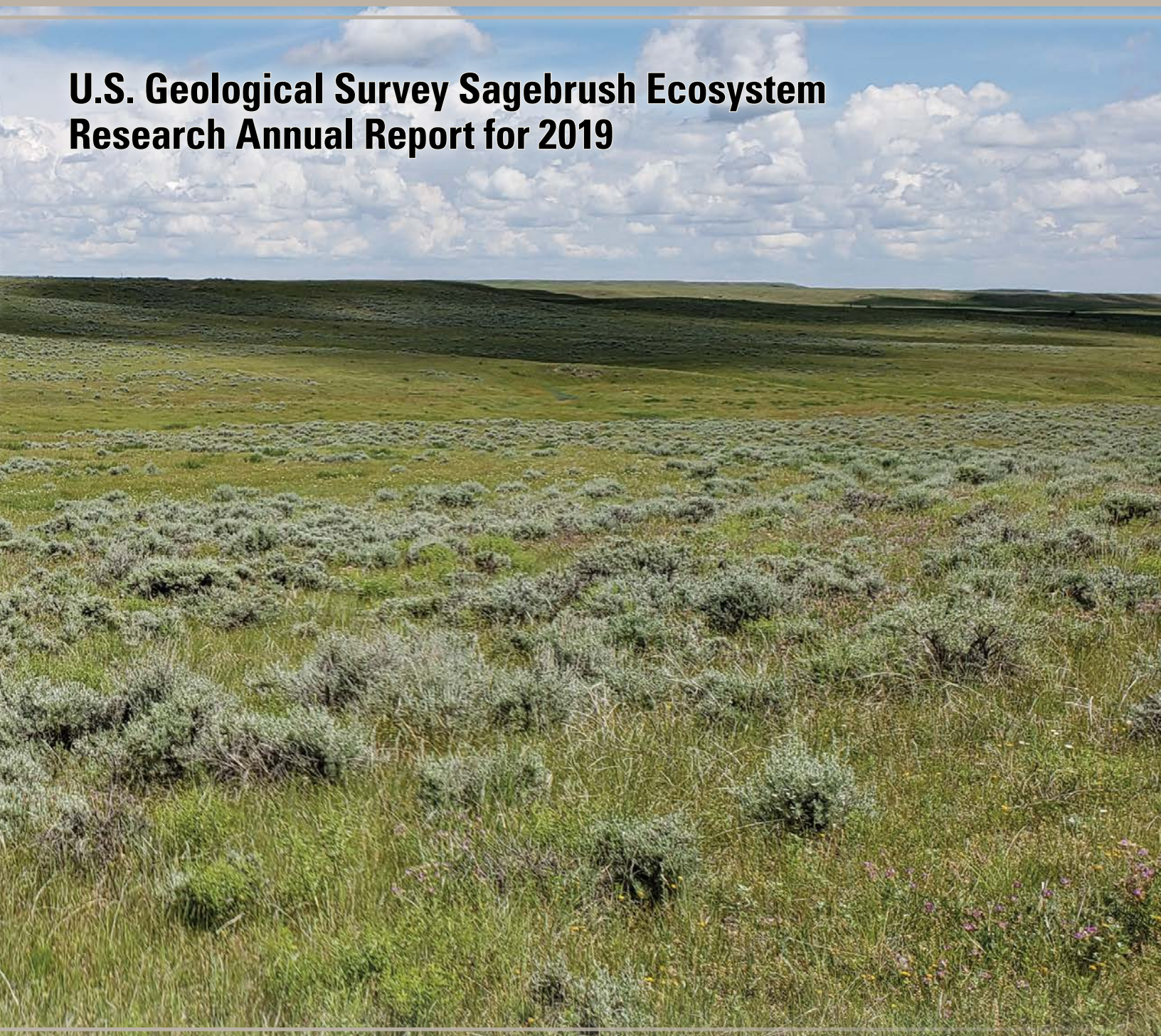
U.S. Geological Survey Sagebrush Ecosystem Research Annual Report for 2019



Circular 1459

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

Cover. Sagebrush in central Montana. Photograph by Steven Hanser, U.S. Geological Survey.

U.S. Geological Survey Sagebrush Ecosystem Research Annual Report for 2019

Edited by Steven E. Hanser

Greater sage-grouse displaying yellow air sacks. Photograph by Tatiana Gettelman, U.S. Geological Survey.

Circular 1459

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

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2019

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Sagebrush in the Great Basin. Photograph by Sasha Reed, U.S. Geological Survey.

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre

Abbreviations

AIM	Assessment, Inventory, and Monitoring
BLM	Bureau of Land Management
CSU	Colorado State University
DART	disturbance automated reference toolset
DOI	U.S. Department of the Interior
DRG	Disturbance Response Group
FIAT	Fire and Invasives Assessment Tool
FWS	U.S. Fish and Wildlife Service
GIS	geographic information system
GPS	Global Positioning System
IPM	integrated population model
LTDL	Land Treatment Digital Library
NCB	northern Columbia Basin
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
PAC	Priority Area for Conservation
SageSTEP	Sagebrush Steppe Treatment Evaluation Project
STM	state-and-transition model
UAS	unmanned aerial systems
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VHF	very high frequency
WLCI	Wyoming Landscape Conservation Initiative
WSB	weed-suppressive bacteria

U.S. Geological Survey Sagebrush Ecosystem Research Annual Report for 2019

Edited by Steven E. Hanser

Research To Support the Management of the Sagebrush Ecosystem

The sagebrush (*Artemisia* spp.) ecosystem extends across a large portion of the Western United States (fig. 1). Affected by multiple stressors, including interactions among fire, exotic plant invasions, and human land uses, this ecosystem has experienced significant loss, fragmentation, and degradation of landscapes once dominated by sagebrush (Knick and Connelly, 2011; Chambers and others, 2017). In turn, wildlife populations have declined following these deleterious conditions. Federal, State, local, and Tribal agencies, nongovernmental organizations, and industry have been galvanized by declining wildlife populations to implement management actions to confront the impacts of these stressors and insure the long-term availability of the sagebrush ecosystem for the broad range of uses critical to stakeholders in the Western United States.

The sagebrush ecosystem provides habitat for over 350 species of plants and animals that are dependent on sagebrush for all or part of their annual life history (Wisdom and others, 2005). The greater sage-grouse (*Centrocercus urophasianus*) stands out as the iconic species of this ecosystem. Sage-grouse populations occur in 11 States and require relatively large expanses of sagebrush-dominated habitat to meet all their seasonal habitat needs (fig. 1). Recent management actions to conserve and maintain the sagebrush ecosystem have focused on the protection and restoration of sage-grouse habitat (Chambers and others, 2017). However, each of the 350 species has a unique life history and differing area

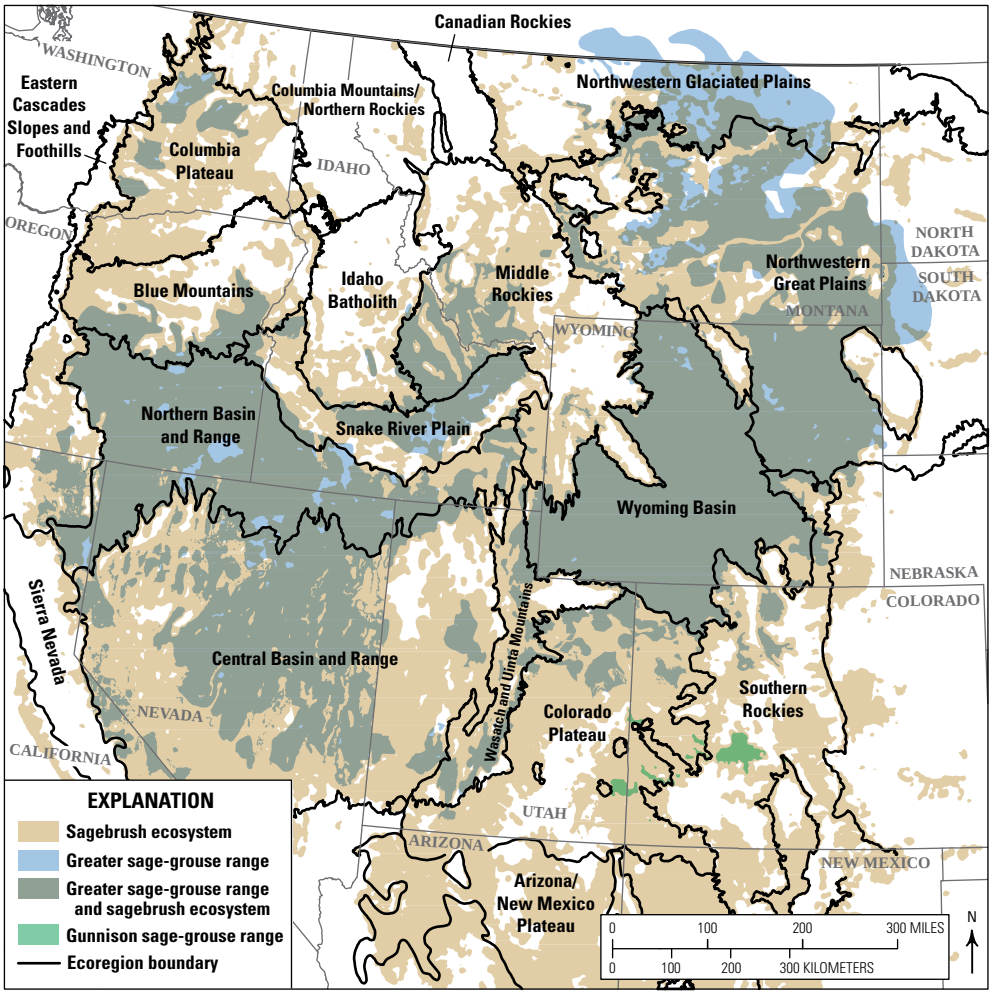

Figure 1. Location of the sagebrush ecosystem and distribution of greater and Gunnison sage-grouse in the Western United States. U.S. Environmental Protection Agency Level III ecoregions are labeled on the map. The Great Basin is composed of the Central Basin and Range, Northern Basin and Range, and Snake River Plain ecoregions. Modified from Integrated Rangeland Fire Management Strategy Actionable Science Plan Team (2016).

requirements (for example, large areas for Mule deer [*Odocoileus hemionus*] and small areas for pygmy rabbit [*Brachylagus idahoensis*]), and some species, such as migratory birds, only rely on the sagebrush ecosystem for part of the year (for example, Brewer's sparrow [*Spizella breweri*]).

The U.S. Geological Survey (USGS) has a broad research program focused on the sagebrush ecosystem and these species and their response to stressors and management actions. The research is tailored specifically to inform and improve strategies for maintaining existing areas of intact sagebrush and restoring degraded landscapes. By providing the science to inform these strategies, the USGS is assisting land and resource managers at the Federal, State, Tribal, and local levels working towards sustainable wildlife populations and restored landscapes.

The USGS provides a foundation of scientific information for use in major land and resource management decisions in the sagebrush ecosystem. These have included such actions as the preclusion of the need to list the greater sage-grouse under the Endangered Species Act and recent revisions to Bureau of Land Management (BLM) and U.S. Department of Agriculture (USDA) Forest Service resource management plans. The USGS continues to build on that foundation to inform science-based decisions within the U.S. Department of the Interior (DOI) and other Federal, State, and local agencies and their continued conservation, management, and restoration of the sagebrush ecosystem to help support local economies.

Structure of the U.S. Geological Survey Sage-Grouse and Sagebrush Ecosystem Research Program

This research program is led out of the USGS National Center, Ecosystems Mission Area with leadership and research scientists located in 11 Western States in the following locations:

Ecosystems Mission Area

National Center

- Ecosystems Mission Area, Reston, Va.

Science Centers

- Forest and Rangeland Ecosystem Science Center, Corvallis, Oreg., and Boise, Idaho
- Fort Collins Science Center, Fort Collins, Colo., and Santa Fe, N. Mex.
- Northern Rocky Mountain Science Center, Bozeman, Mont.
- Southwest Biological Science Center, Flagstaff, Ariz., and Moab, Utah
- Western Ecological Research Center, Sacramento, Dixon, and Oakhurst, Calif.

Cooperative Research Units

- Colorado Cooperative Fish and Wildlife Research Unit, Fort Collins, Colo.
- Idaho Cooperative Fish and Wildlife Research Unit, Moscow, Idaho
- Oregon Cooperative Fish and Wildlife Research Unit, Corvallis, Oreg.
- Montana Cooperative Wildlife Research Unit, Missoula, Mont.
- Utah Cooperative Fish and Wildlife Research Unit, Salt Lake City, Utah
- Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, Wyo.

Land Resources Mission Area

Science Centers

- Earth Resources Observation and Science Center, Sioux Falls, S. Dak., and Boise, Idaho
- Geosciences and Environmental Change Science Center, Denver, Colo.

Climate Adaptation Science Centers

- North Central Climate Adaptation Science Center, Fort Collins, Colo.
- Northwest Climate Adaptation Science Center, Seattle, Wash.
- Southwest Climate Adaptation Science Center, Tucson, Ariz.

Energy and Minerals Mission Area

Science Centers

- Central Energy Resources Science Center, Denver, Colo.
- Science and Decisions Center, Denver, Colo.

List of Projects

USGS sage-grouse and sagebrush ecosystem research is aligned with priority needs outlined in the "Integrated Rangeland Fire Management Strategy Actionable Science Plan" (Integrated Rangeland Fire Management Strategy Actionable Science Plan Team, 2016). The list of 116 research projects is organized into five thematic areas: fire (16 projects); invasive species (7 projects); restoration (23 projects); sagebrush, sage-grouse, and other sagebrush-associated species (60 projects); and weather and climate (10 projects). Individual projects often overlap multiple themes (for example, effects of wildfire and invasive annual grasses on greater sage-grouse habitat); therefore, project descriptions are organized according to the main focal theme.

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Sagebrush. Photograph by Justin Welty, U.S. Geological Survey.

Project Descriptions

These descriptions are overviews of projects that are ongoing or were active during 2019. Citations are provided for select products that have resulted from these efforts. Contact information is provided for the primary USGS scientist(s) for each project.

Fire

Fire is a significant threat to maintaining a large contiguous sagebrush ecosystem, and this threat has been intensifying owing to increases in highly flammable invasive annual grasses. USGS scientists are addressing a number of science needs including determining the effects and effectiveness of fuel treatments, understanding historic and potential future fire regimes in the sagebrush ecosystem, evaluating effects of fire on species, and assessing strategies to improve postfire management actions.

Fire in the sagebrush landscape. Photograph by Scott Shaff, U.S. Geological Survey.

Evaluating Effects and Effectiveness of Fuel Breaks

Fuel breaks are intended to reduce fire size, frequency, and the rate at which fire spreads by disrupting fuel continuity, reducing fuel accumulation, or increasing plants with higher moisture content in strips or blocks of land. Land management agencies want better information about the effectiveness of fuel breaks, as well as potential ecological costs and benefits related to fuel breaks. To supply this information, USGS and USDA Forest Service scientists have synthesized available information on the ecological effects and effectiveness of fuel breaks, particularly linear fuel breaks across the Great Basin (fig. 1). By evaluating the extent to which fuel breaks protect existing habitat from wildland fire, as well as how they affect sagebrush habitat, sage-grouse, and other sagebrush-obligate species, this study provides information for managers as they assess tradeoffs between the potential risks and benefits of fuel breaks.

Mowed fuel break in southwestern Idaho. Photograph from U.S. Geological Survey.

Contact

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Publications

Shinneman, D.J., Aldridge, C.L., Coates, P.S., Germino, M.J., Pilliod, D.S., and Vaillant, N.M., 2018, A conservation paradox in the Great Basin—Altering sagebrush landscapes with fuel breaks to reduce habitat loss from wildfire: U.S. Geological Survey Open-File Report 2018–1034, 70 p., https://doi.org/10.3133/ofr20181034.

Shinneman, D.J., Germino, M.J., Pilliod, D.S., Aldridge, C.L., Vaillant, N.M., and Coates, P.S., 2019, The ecological uncertainty of wildfire fuel breaks—Examples from the sagebrush steppe: Frontiers in Ecology and the Environment, v. 17, no. 5, p. 279–288, https://doi.org/10.1002/fee.2045.

Assessing the Effectiveness of Fuel Breaks for Preserving Greater Sage-Grouse in the Great Basin

Fuel breaks have the potential to minimize catastrophic losses of sagebrush habitat and sage-grouse populations by altering fire behavior and facilitating fire suppression. However, they may carry risks to sage-grouse populations—of habitat loss, fragmentation, cheatgrass (*Bromus tectorum*) invasion, and alteration of sage-grouse movements—that have not been quantified. USGS and Colorado State University (CSU) scientists are working with the BLM to (1) quantify sage-grouse response to fuel breaks; (2) use high-resolution data to compare fire sizes and spread among areas with and without fuel breaks; (3) combine data for fuel breaks and past fire behavior, sage-grouse habitat and population dynamics, and sage-grouse responses to fuel breaks and fires within a spatially explicit individual-based model; and (4) model the effects of fuel breaks on sage-grouse populations under alternative scenarios of population responses, altered fire regimes, fuel break designs, and fire management access. Results of this study can help identify the important factors to consider for the strategic placement of fuel breaks to suppress wildfire in sage-grouse habitats and minimize negative impacts on populations.

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Effects of Fuel Breaks on Surrounding Vegetation

Invasive species such as cheatgrass have disrupted the sagebrush fire cycle by increasing the frequency of fires. Invasive grasses dry early in the wildfire season and provide continuous cover for fire to quickly spread. In the wake of fire, restoration attempts are increasingly using fuel breaks to reduce the spread of fire proactively. Although fuel breaks could assist restoration, they are also often created with nonnative species that are persistently green. As part of the Soda Fire Fuel Breaks Project, USGS researchers are assisting the Idaho Office of Species Conservation, BLM, and U.S. Fish and Wildlife Service (FWS) managers by investigating how fuel breaks affect surrounding plant communities across a range of landscape characteristics. Specifically, researchers are studying whether and under what circumstances fuel break plant species invade restoration plots, as well as invasion of the fuel break by other species. Results can inform future restoration efforts in design and implementation of fuel breaks.

Contact

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Evaluating Effects of Woody Fuel Treatments on Native and Nonnative Plants in the Sagebrush Biome

When sagebrush becomes overcrowded, it presents significant wildfire risk. Managers often reduce woody fuels through various techniques that may have undesirable consequences for native vegetation. USGS scientists and collaborators, as part of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP), evaluated a combination of prescribed fire, mowing, and herbicide treatments to reduce woody shrubs to study how treatments affected other plant species and land health indicators. During the SageSTEP project, scientists have completed 10 or more years of research at various sites to provide information on the long-term outcomes of these treatments and support decision making regarding the various methods.

Contact

David A. Pyke, USGS Forest and Rangeland Ecosystem Science Center; david_a_pyke@usgs.gov; 541–750–0989

Publications

Pyke, D.A., Shaff, S.E., Lindgren, A.I., Schupp, E.W., Doescher, P.S., Chambers, J.C., Burnham, J.S., and Huso, M.M., 2014, Region-wide ecological responses of arid Wyoming big sagebrush communities to fuel treatments: Rangeland Ecology & Management, v. 67, no. 5, p. 455–467, https://doi.org/10.2111/REM-D-13-00090.1.

Roundy, B.A., Chambers, J.C., Pyke, D.A., Miller, R.F., Tausch, R.J., Schupp, E.W., Rau, B., and Gruell, T., 2018, Resilience and resistance in sagebrush ecosystems are associated with seasonal soil temperature and water availability: Ecosphere, v. 9, no. 9, article e02417, https://doi.org/10.1002/ecs2.2417.

Sagebrush in central Utah within a treatment area 5 years after conifer removal. Photograph by Steven Hanser, U.S. Geological Survey.

Assessing the Proliferation, Connectivity, and Consequences of Invasive Fine Fuels

Invasive annual grasses (fine fuels) are a significant challenge for land and wildlife management. USGS and CSU scientists are working with the BLM to understand the potential consequences of invasive annual grass proliferation and connectivity on fire behavior and loss of sagebrush in the Great Basin. Landscape disturbances and management activities that create linear features (for example, roads, fuel breaks, transmission lines) often occur adjacent to existing fine fuels and may lead to further spread of invasive annual grasses. The scientists are developing scenarios of future invasion to assess impacts of potential future disturbances and using simulations to compare the effects of disturbance and invasion among current and future landscapes. This project can help develop strategies for managing annual invasive grasses, thus minimizing the potential loss of sage-grouse habitat.

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Cheatgrass in southern Idaho. Photograph by Steven Hanser, U.S. Geological Survey.

Long-Term Effects of Treatments on Fuel Loads and Fire Regimes in the Great Basin

The Great Basin is vulnerable to changes in fuels and fire regimes as a result of invasive species and climate change. To address these threats, management agencies are using fuel reduction and seeding treatments designed to reduce fire intensity, spread, and risk. To assess the ecological impacts and long-term effectiveness of these treatments, USGS scientists and university collaborators are evaluating future scenarios of ecosystem dynamics using models that incorporate climate change, fire regimes, and fuel treatments. They are examining potential vegetation response to changing climate, fuel treatments, and postfire seedings and assessing implications for repeated fuels maintenance under several future climate scenarios. Results may be used by land managers and fuels experts engaged in sagebrush ecosystem land use planning and fire management activities, including to design more effective fire suppression strategies.

Contacts

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David S. Pilliod, USGS Forest and Rangeland Ecosystem Science Center; dpilliod@usgs.gov; 208–426–5202

Publication

Pilliod, D.S., Welty, J.L., and Arkle, R.S., 2017, Refining the cheatgrass-fire cycle in the Great Basin—Precipitation timing and fine fuel composition predict wildfire trends: Ecology and Evolution, v. 7, no. 19, p. 8126–8151, https://doi.org/10.1002/ece3.3414.

Future Fire in the Great Basin

Understanding where, when, and why fires occur, how they may change in the future, and what their implications are for land management is fundamental to virtually all aspects of rangeland fire prevention, management, and restoration. USGS scientists are analyzing why fires occur and projecting where and when fire regimes may shift under expected future conditions. The researchers will evaluate some of the assumptions regarding altered fire regimes that are incorporated into the Fire and Invasives Assessment Tool (FIAT). This effort will determine the degree to which recurrent fire and invasive annual grass dominance (evidence of a fire-grass cycle) are associated with warm and dry soils and identify localities that have the strongest evidence for this relationship. This information can help managers prioritize their efforts within the extensive landscapes with warm and dry soils that lead to low resistance to invasion and resilience following disturbance.

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Publications

Brooks, M.L., Matchett, J.R., Shinneman, D.J., and Coates, P.S., 2015, Fire patterns in the range of greater sage-grouse, 1984–2013—Implications for conservation and management: U.S. Geological Survey Open-File Report 2015–1167, 66 p., https://doi.org/10.3133/ofr20151167.

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Fire in big sagebrush. Photograph by Scott Shaff, U.S. Geological Survey.

Identifying the Effects of Reoccurring Fire on Sagebrush Ecosystems in the Northern Columbia Basin

Most sagebrush ecosystems are adapted to relatively long fire return intervals, but frequent fires are becoming common across these landscapes. A decrease in the time between fires may delay ecosystem recovery and enhance the rate of conversion to nonnative species dominance. USGS research is identifying differences in successional trajectories across three burn frequencies in a sagebrush landscape in the northern Columbia Basin (NCB) in Washington State by determining (1) how key ecosystem vegetation characteristics, including fuels, differ across sagebrush sites that have burned once, twice, or three times over a 13-year period; (2) the impact of repeated fire on soil structure and function; and (3) how these characteristics at burned sites compare to nearby unburned sites. Investigating recovery using both vegetation and soils data can provide a comprehensive analysis on the effects of recurring fire on sagebrush ecosystems across the NCB.

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Controlled burn at Hart Mountain National Wildlife Refuge. Photograph by Scott Shaff, U.S. Geological Survey.

Using the Past and the Present To Understand Fire Ecology in the Range of the Gunnison Sage-Grouse

Little is known about the role of fire in the sagebrush ecosystem within the range of the Gunnison sage-grouse (*Centrocercus minimus*; fig. 1), and fire has been mostly absent from these systems in the 20th century, partially owing to active fire suppression. Tree-ring fire scars can provide unique insight into fire regimes prior to fire exclusion and have proven invaluable for managing forests and rangelands. Although fire scars are rare in sagebrush systems in the southwestern United States, USGS and university scientists have identified several sites with fire-scarred ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) trees at sagebrush-forest ecotones in the upper Gunnison Basin. The researchers are using tree-ring fire-scars from these sites to reconstruct historical fire regime components including fire frequency, extent, and seasonality and relationships to climate, over multiple centuries. They are also sampling and characterizing vegetation composition and structure from nearby sagebrush areas that have and have not experienced recent wildfire or prescribed burning. Findings of this study can inform fire and vegetation management on BLM and other lands.

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Effects of Large-Scale Wildfire on Habitat Use and Demography of Female Greater Sage-Grouse in Southeastern Oregon

One of the key stressors for sage-grouse in the Great Basin is the conversion of sagebrush habitat to annual grasses through catastrophic wildfire. In August 2012, the Holloway Fire burned approximately 460,000 acres in highly productive sage-grouse habitat in northern Nevada and southeastern Oregon. USGS Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University, and Oregon Department of Fish and Wildlife scientists initiated a long-term study in 2013 (now in its seventh consecutive year) using the Holloway Fire to address the initial, acute effects as well as the longer term, chronic effects of large-scale wildfire on the habitat use and demographics of female greater sage-grouse. Female survival, reproductive ecology and success, and habitat selection are being monitored continuously to gain key information on the behavioral and demographic responses of female sage-grouse to a large-scale disturbance event and how those responses change relative to time since disturbance. This information can provide managers with information regarding postfire management and help identify potential options for maintaining sage-grouse populations.

Female greater sage-grouse. Photograph by Tatiana Gettelman, U.S. Geological Survey.

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Publications

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Wildfire Effects on Sage-Grouse: A Before and After Case Study

In 2012, the Rush Fire burned more than 300,000 acres of priority sage-grouse habitat in northeastern California and northwestern Nevada. The burned area was considered the core of the remaining sage-grouse population in northern California. Beginning in fall 2014, the USGS implemented a study to compare postfire vital rates, resource utilization, and genetics to the same measures from the same area before the fire. Now in its fifth consecutive year, this ongoing study will increase ecological understanding of how sage-grouse respond demographically and spatially to wildfire and can help land managers better evaluate the efficacy of postfire actions designed to restore sagebrush habitat and ecosystem services.

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Effects of Wildfire and Climate on Persistence of Greater Sage-Grouse

Wildfire and climate change are frequently identified as important factors contributing to the decline of sage-grouse populations, yet fire regimes and climate patterns can vary substantially across broad geographic ranges. Using three decades of sage-grouse population counts, wildfire information, and climate data, USGS scientists linked long-term declines of sage-grouse to chronic effects of wildfire across the Great Basin. The analysis indicated that projected declines may be slowed or halted through fire suppression targeted at remaining areas of intact sagebrush with high densities of breeding sage-grouse. Ongoing research is determining how wildfire affects long-term sage-grouse population dynamics across their entire range and how variation in postfire recovery of sagebrush ecosystems modulates impacts of wildfire on sage-grouse population growth. Researchers are also using simulation analysis to better understand tradeoffs between restoration and suppression efforts in reducing long-term impacts to sage-grouse populations.

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Perennial Grass Response to Postfire Grazing Management in the Great Basin

Perennial grasses are a vital component of a functioning sagebrush ecosystem and an important source of food for grazing cattle. In the event of a wildfire, burned perennial grasses need time to recover—but when are perennial grasses stable enough to accommodate grazing again? USGS scientists are investigating seasonal timing of grazing after fires and the length of grazing rest after fire to determine how these factors affect perennial grass recovery. In addition, this study is examining the length of grazing rest after postfire seeding to determine any impacts on seedling establishment and growth. Results can inform managers' recommendations for postfire livestock grazing when rehabilitation of sagebrush steppe habitat is the focus. Findings could also guide postfire grazing management on lands that provide critical sage-grouse habitat.

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How Fire and Postfire Seeding Alter Pollinators in Sagebrush Habitat

Wildfire and subsequent postfire restoration are common in western North America, yet information on how these events alter animal communities is generally lacking, especially for insect pollinators. USGS scientists compared insect pollinator assemblages in locations that burned 1 to 20 years prior to nearby unburned locations in sagebrush steppe habitats in southwestern Idaho. In some locations they also compared the diversity and abundance of pollinators in burned areas that were seeded after wildfire relative to burned areas that were not seeded. Other investigations examined the visitation of pollinators to small forb "islands" planted within burned areas to test this as an alternative strategy or supplement to

Drill seeding after the Soda Wildfire in southwestern Idaho. Photograph from Bureau of Land Management.

drill seeding. This combination of studies can reveal important information about forb-pollinator interactions and the effectiveness of restoring forbs to burned areas.

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Publication

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Pollinator Use of Forbs in the Soda Wildfire Area

Pollinating insects are in serious decline across the United States, affecting native plants. USGS scientists are examining insect pollinator communities and forb-pollinator relationships at treatments across the area burned by the 2015 Soda Wildfire in southwestern Idaho and southeastern Oregon. Researchers are comparing pollinators in seeded burned areas to unburned areas outside the Soda Wildfire. Researchers are also comparing pollinator use of seeded forbs versus nonseeded forbs, as well as native versus nonnative forbs. This research will contribute to the understanding of pollinators on public lands and inform pollinator conservation planning efforts.

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Butterfly using habitat recovering after the Soda Wildfire in southwestern Idaho. Photograph by Justin Welty, U.S. Geological Survey.

Environmental and Fire Interactions in Northern Great Basin Vegetation Communities

Management of sagebrush communities is complicated by varied responses to the intensity and location of disturbances. USGS scientists, in collaboration with the BLM Assessment Inventory and Monitoring Program, are examining sites within sagebrush communities of the northern Great Basin to identify how the cover of native shrubs and grasses and invasive plants responds to disturbances, while also considering the influence of climate factors. BLM monitoring plots are found within landscapes of varying overall surface disturbance and within burned and unburned areas. Burned plots represent a range of fire severities and years since fire, allowing an examination of foliar cover, community composition, and recovery times following fires of mixed severity and overlap with the cumulative physical footprint of transportation, energy, and other surface disturbances. Identifying the factors leading to increased sagebrush community resistance and resilience can help managers prioritize actions and identify sound management options.

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Controlled burn at Hart Mountain National Wildlife Refuge. Photograph by Scott Shaff, U.S. Geological Survey.

Invasive Species

Invasive plant species, primarily cheatgrass, are a significant threat to the sagebrush ecosystem by increasing fire frequency and competition with native plant species. USGS scientists are (1) addressing the need to develop and assess prevention, eradication, and control measures for invasive plant species; (2) determining the factors that influence invasive plant species distributions; and (3) developing maps to inform early detection and other control measures.

Landscape invaded by cheatgrass in southern Idaho. Photograph by Steven Hanser, U.S. Geological Survey.

Near-Real-Time Cheatgrass Mapping

Mapping the invasion of sagebrush shrubland by cheatgrass in near realtime can help land managers understand the current distribution of cheatgrass and the potential risk for fire in the current year. USGS scientists have developed techniques that enable annual mapping of cheatgrass distributions. Maps have been made for the Great Basin and across Wyoming to provide a time series back to 2000. Researchers are now producing 250-meter-resolution cheatgrass distribution maps by late May for a current year to inform fire suppression activities and other management activities, such as application of weed suppressive bacteria, targeted grazing, and other cheatgrass control measures. Map products at a higher resolution (30 meters) are under development and can help inform local-scale management efforts.

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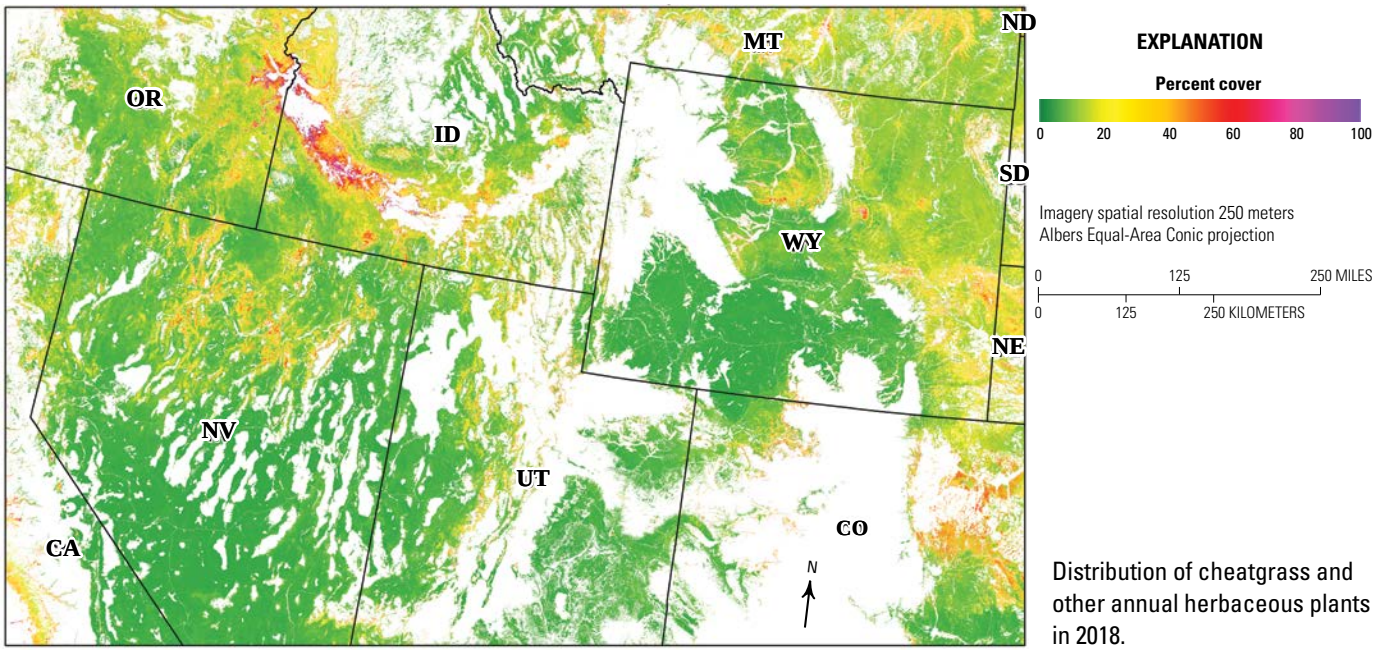

Distribution of cheatgrass and other annual herbaceous plants in 2018.

Sagebrush Ecosystem Management in Light of Sage-Grouse, Fire, and Invasive Species

Scientists from the USGS, with Federal and State agency collaborators, have produced a strategic approach to help management agencies prioritize regional-scale management actions while maximizing conservation effectiveness. This approach was developed for conservation and restoration of sagebrush ecosystems and sage-grouse and focuses specifically on habitat threats caused by invasive annual grasses and altered fire regimes. The team used information about (1) factors that influence sagebrush ecosystem resilience to disturbance and resistance to invasive annual grasses and (2) the distribution, relative abundance, and persistence of sage-grouse populations to inform the development of management strategies at both landscape and site scales. This approach and associated technical reports and publications may help managers determine the most effective management strategies based on an area's resilience to disturbance and resistance to nonnative invasive plants, particularly invasive annual grasses.

Cheatgrass. Photograph by Scott Shaff, U.S. Geological Survey.

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Spatial Variation in the Role of Climatic Extremes in Shaping Plant Invasions

A broad-scale perspective is needed to link geographic variation in climate and disturbance to decisions on the ground regarding where to apply treatments aimed at limiting the impacts of invasions and restoring native plant composition. USGS scientists are conducting analyses to link the abundance of major plant invaders to climatic extremes, land use, and fire history. The researchers are determining how the drivers and limits of invader abundance vary among invasive species and across the Great Basin and Mojave Desert. For example, they will examine if cheatgrass is likely to be limited by drought and temperature extremes, and whether those areas are vulnerable to red brome (*Bromus rubens*) invasion. The work can inform management by providing a nuanced spatial perspective on invasion risk for current and potential invaders.

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Landscape invaded by cheatgrass in southern Idaho. Photograph by Steven Hanser, U.S. Geological Survey.

Exotic Forbs in Disturbed Sagebrush Steppe

Invasion by exotic tap-rooted forbs, such as spotted knapweed (*Centaurea stoebe*), leafy spurge (*Euphorbia esula*), thistles, or skeletonweed (*Chondrilla juncea*), stresses big sagebrush communities, especially at higher elevations. USGS scientists have completed nearly a decade of evaluation of plant community patterns that reveal inverse relationships of exotic forbs (or deep-rooted native herbs) and big sagebrush. They are also examining the ecophysiological and hydrological mechanisms underlying the competition between these exotic and native species. These exotic forbs are often secondary invaders of areas already overtaken by exotic annual grasses. When present in the landscape, exotic forbs may increase appreciably following herbicide treatments aimed at controlling annual grasses. Studies are underway to evaluate the response of exotic forbs to postfire herbicide and other land treatments. This information is intended to help managers as they work to develop alternative control strategies for exotic forbs.

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Landscape-Scale Assessment of Emerging Techniques for Controlling Exotic Annual Grasses

Invasive annual grasses such as cheatgrass and medusahead (*Taeniatherum caput-medusae*) lead to increased fire frequency and loss of sagebrush steppe habitat and impede restoration of desirable perennials. Weed-suppressive bacteria (WSB) are an emerging tool for selectively reducing annual grasses, but this use has not been tested well in the field. USGS scientists and collaborators are comparing commercially available sources of WSB with and without herbicides and other common postfire plant and soil treatments following fires that spanned southwestern Idaho in 2016. This research will determine if WSB are effective on target (exotic) and nontarget (native) species and will describe how to best apply WSB to help outreach specialists and land managers be best informed about the potential benefits and risks of WSB.

Medusahead. Photograph from U.S. Department of Agriculture.

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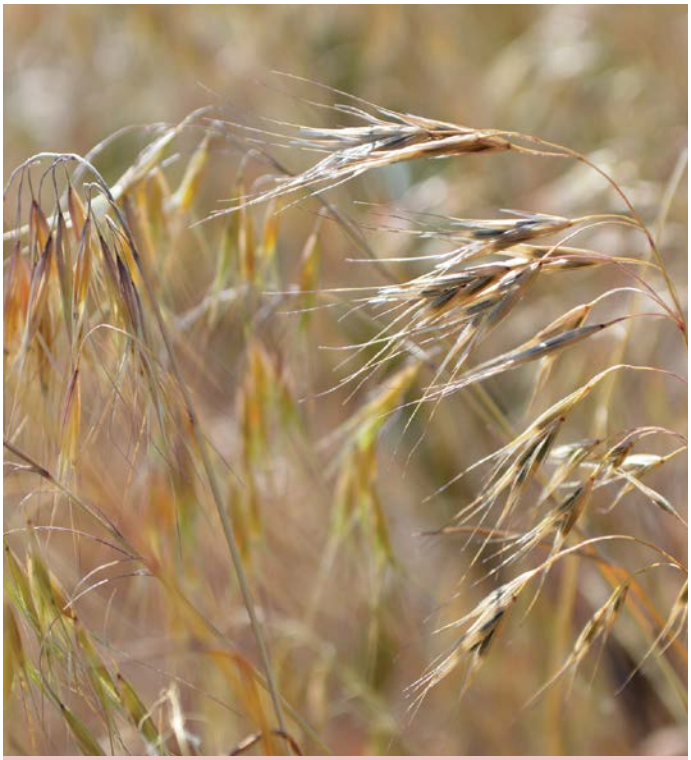
Publication

Lazarus, B.E., and Germino, M.J., 2019, An experimental test of weed-suppressive bacteria effectiveness in rangelands in southwestern Idaho, 2016–18: U.S. Geological Survey Open-File Report 2019–1050, 19 p., https://doi.org/10.3133/ofr20191050.

Use of Cheatgrass-Suppressive Bacteria To Restore Sagebrush Steppe

USGS scientists and colleagues are using WSB (*Pseudomonas fluorescens*, strain D7) in two case studies at the Hanford Reach National Monument to examine the potential for using successful WSB to attack invasive annual grasses (particularly cheatgrass) and leave native perennial plants intact. WSB was applied proactively to remaining sagebrush habitats that also have cheatgrass to potentially halt invasion and increase resistance to further invasion while retaining existing native sagebrush steppe plant communities. WSB was also applied to sagebrush understories, to help reduce cheatgrass fuel loads, which would result in reduced fire risk and rate of spread. If successful, WSB could be a cost-effective means to modify the seeding environment, boosting success in postfire rehabilitation projects through reducing annual grass competition with native seedlings while also minimizing the negative impacts to native plants that have been observed with the use of herbicides.



Cheatgrass. Photograph by Jennifer Strickland, U.S. Fish and Wildlife Service.

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Evaluating a Novel Biopesticide for Controlling Exotic Annual Grasses Following Rangeland Wildfire

Invasions by exotic annual grasses, most notably cheatgrass and medusahead, are unambiguous threats to rangelands in the Western United States, diminishing livestock productivity and increasing wildfire activity. In a new study, USGS scientists will test the effectiveness of a novel WSB known as MB906 combined with the herbicide imazapic on target weeds and nontarget native plants on over 1,000 acres in the Boise River Wildlife Management Area, Idaho. Study plots burned in the summer of 2016, and researchers will compare untreated, control areas to areas treated with WSB, imazapic, or the combination of WSB and imazapic. The objective is to determine if, when, and where spraying is effective for controlling exotic annual grasses.

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Publication

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Sagebrush in the Sawtooth Valley, Idaho. Photograph by Steven Hanser, U.S. Geological Survey.

Restoration

Restoration of the sagebrush vegetation community following effects from stressors, including wildfire, invasive species, and numerous disturbance types, is important for maintaining the sagebrush ecosystem for wildlife and as healthy rangeland for grazing, recreation, and other uses by local communities. USGS scientists are conducting a range of studies including assessing the efficiency and effectiveness of restoration actions and determining factors that increase their success.

Postfire seeding following the Soda Wildfire in southwestern Idaho. Photograph from Bureau of Land Management.

Field of Sagebrush Dreams: Sage-Grouse Responses to Burns and Sagebrush Restoration in Fire-Affected Landscapes

Fire can reduce sage-grouse habitat, diminish local and regional population sizes, and result in the fragmentation of sage-grouse populations. Research is needed to identify the best ways to restore sagebrush to support sage-grouse demography, persistence, and space use. To evaluate the efficacy of sagebrush restoration approaches that may create functional sage-grouse habitat in postfire landscapes, USGS and CSU scientists are (1) planting sagebrush in burned areas previously occupied by sage-grouse, (2) measuring sagebrush regrowth, (3) evaluating the use of revegetated areas by sage-grouse, and (4) predicting the success of sage-grouse using revegetated habitat. Using experiments with patch size, configuration, and proximity to edge of burn, the project aims to identify sage-grouse-focused sagebrush restoration approaches. This research also will evaluate sagebrush restoration approaches and predict times to sagebrush and sage-grouse recovery to help inform land and resource management decisions.

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Field crew planting sagebrush seedlings in northeastern California. Photograph by David Pyke, U.S. Geological Survey.

Restoration of Native Understory Plants in Degraded Sagebrush Steppe Ecosystems

Sagebrush steppe that is resistant to annual grasses typically has herbaceous perennials between and under sagebrush and other shrubs. When fires burn these resistant communities, they may eliminate sagebrush temporarily, but understory plants may survive and compete with cheatgrass and shortly regain their codominance in the community. However, large expanses of sagebrush lands are now missing their herbaceous understory, owing to several factors including inappropriate grazing, and are at risk of being dominated by annual grasses following fire. Current practice is to wait for fires to eliminate sagebrush before attempting restoration, but transplanting herbaceous understory plants into vacant gaps before the next fire may successfully increase resistance of these communities. USGS scientists are evaluating transplants and seeding for reintroducing native grasses and forbs into interspaces between shrubs to help inform future management efforts to improve sage-grouse habitat in sagebrush lands that are lacking native herbaceous plants.

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Selecting the Right Seed for Restoration Success

Sagebrush ecosystems are threatened by an increasing number of large wildfires because sagebrush cannot re-sprout after a burn, and natural seedling establishment is limited. Land managers attempt to recolonize sagebrush by aerial or drill seeding burned areas. Seeds used in sagebrush ecosystem restoration and rehabilitation projects often are transferred across climate zones and hundreds of miles. USGS scientists are examining how seeds from different climates and with different genetic characteristics grow in variable climates and respond to traditional seeding treatments. They are determining how seeds of sagebrush and key native perennial species from different sources grow, survive, and respond to different temperature and precipitation patterns and to the planting methods managers traditionally employ. This information can help inform agency seed procurement and provide postfire rehabilitation specialists with the basic information needed to use "the right seed in the right place at the right time."

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Sagebrush common garden in Idaho. Photograph by Matthew Germino, U.S. Geological Survey.

SageSuccess Project: Sagebrush Restoration for Sage-Grouse

The SageSuccess Project is a joint effort among the USGS, BLM, and FWS to examine the factors that contribute to establishment of big sagebrush across the range of sage-grouse and whether seeding and planting sagebrush ultimately creates high-quality sage-grouse habitat. Scientists will examine seedings and plantings completed between 1990 and 2013 to assess factors including seed subspecies and source, climate, soil type and moisture, fire history, land use, and treatment implementation method. Where seed sources are known, researchers will assess the effects of seed transfer across geographic, elevation, and climate zones on seeding outcomes. This research is informing site-level management activities and continues to provide insights to help managers develop new practices or improvements of existing methods to restore sagebrush.

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Assessing the Influence of Microsite Soil Characteristics on Sagebrush Restoration Success

Fertile “islands” are important for germination, growth, and establishment of sagebrush and other plants in arid and semi-arid environments because of the unique soil nutrients and microclimates they provide. In recently burned areas, these microsites are often associated with locations of former sagebrush plants. USGS scientists have observed big sagebrush seedling establishment in these fertile islands 1 year after fire, and sometimes these were the only locations where young sagebrush was thriving. The researchers are currently broadening the inference of these observations by sampling additional recently burned sites across the Great Basin to determine (1) whether this pattern holds, (2) what soil characteristics lead to this pattern, and (3) whether these soil characteristics could be reproduced by manipulating postfire soils in areas that have no prefire sagebrush. This work could help inform future big sagebrush seeding efforts.

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Soda Wildfire Response: Integrating Science Into Adaptive Management

The "Integrated Rangeland Fire Management Strategy" provides a comprehensive, science-based approach to enhance the conservation and restoration of the sagebrush steppe and to meet important economic, cultural, and social goals. The management response to the 2015 Soda Wildfire, which burned 285,000 acres of mostly sagebrush steppe in the northern Great Basin, is the first test of new guidelines outlined in the strategy. Managers used herbicide applications and planted or seeded desirable species to restore site resistance and resilience and habitats of sagebrush-obligate species. The USGS is leading the effort to monitor these vegetation treatments to (1) inform retreatment decisions, (2) determine when to allow resumption of grazing, (3) report on site recovery and treatment effectiveness, and (4) provide a comprehensive assessment of a major fire rehabilitation project in sagebrush steppe. Resulting data can be useful for testing theories about resistance and resilience, the role of bunchgrasses, exotic annual grass responses, sagebrush seed source effects, soil stability effects, and how management actions—particularly iterative treatments—impact these variables.

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Sagebrush. Photograph by Steven Hanser, U.S. Geological Survey.

Postfire Sagebrush Growth

Establishment and growth of big sagebrush after fire are critical components of restoration efforts in the Great Basin; however, these ecological processes often occur over several decades and thus are difficult to document. In the northern Great Basin, a number of postfire restoration vegetation surveys conducted between 5 and 25 years ago provide an opportunity to revisit and measure these vegetation characteristics. The goal of these remeasurement surveys is to quantify how growth of big sagebrush after fire influences habitat of greater sage-grouse through changes in density, cover, and height. USGS researchers are also assessing how sagebrush growth influences cover of exotic annuals, especially cheatgrass, and native forbs. Comparisons between growth rates of seeded and planted (that is, nursery-raised seedlings) will be made. Results may assist managers in determining the length of time and environmental conditions required for sagebrush establishment to meet sage-grouse habitat guidelines.

USGS biologists in the area burned by the Soda Wildfire in 2015. Photograph by Justin Welty, U.S. Geological Survey.

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Land Treatment Digital Library

The BLM actively manages vegetation on millions of acres of public rangelands in the United States. The USGS and BLM compiled over 75 years of records of those vegetation management actions—or land treatments—into a centralized, spatially explicit database called the Land Treatment Digital Library (LTDL), which can be accessed at https://ltdl.wr.usgs.gov. In a recently published paper, researchers summarized data from over 9,000 treatments in the Great Basin to highlight the scope and scale of information in the LTDL. The authors discussed how this information can be used for adaptive management and ecological research, including evaluating responses of communities and ecosystems to natural and human caused disturbance. Information in the LTDL can help land managers evaluate past treatments and improve future restoration actions.

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Land Treatment Exploration Tool

The LTDL houses information on nearly 40,000 land treatments in the Western United States. The BLM and the USGS have developed a decision support and planning tool (https://chsapps.usgs.gov/apps/land-treatment-exploration-tool/) that enables users to upload a proposed treatment area during the planning phase of a project to identify past treatments that have occurred in the surrounding area or that share similar characteristics, such as treatment types, ecological sites, seed mixes, or other factors. When queried, the tool returns both nearby treatments and treatments within a larger range that match one or more specific search attributes specified by the user. Users can then tap into this information to assess what worked where and why, and potentially network with other personnel who implemented these treatments. Ultimately, this tool aids in planning future land treatments and implementing adaptive management strategies for improved likelihood of success for future treatments.

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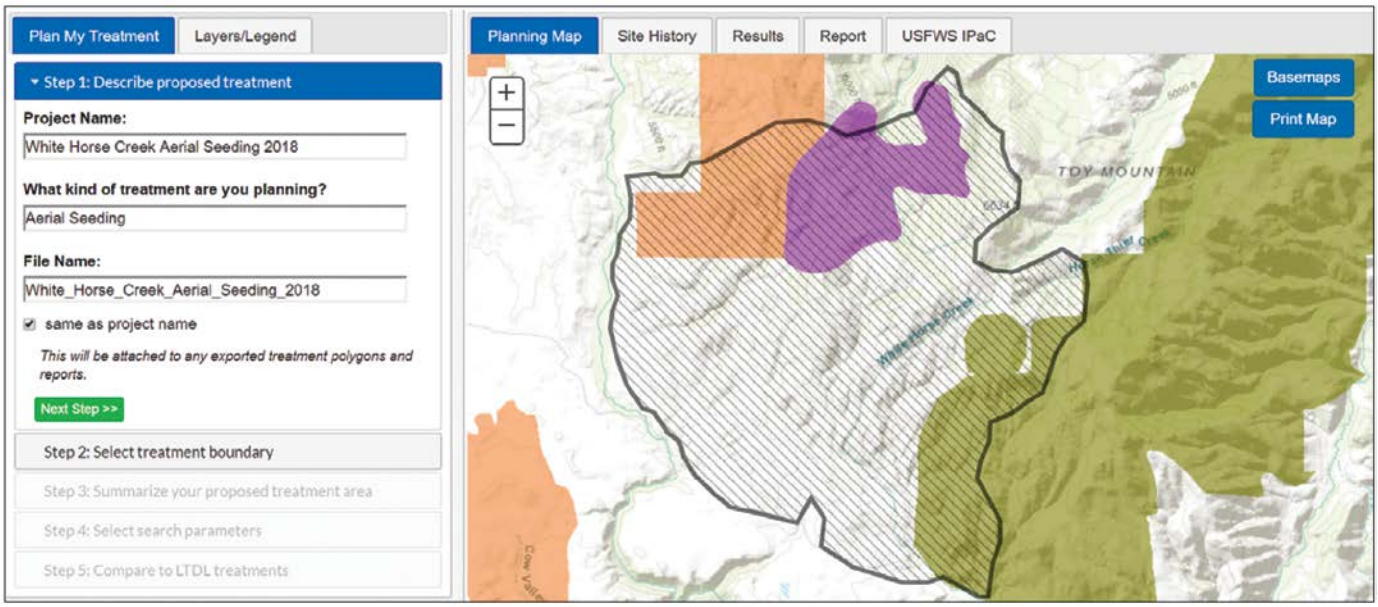

Example of the interactive map interface in the land treatment planning tool.

Decision Support for Conservation and Restoration Efforts in the Sagebrush Biome

The DOI, USDA, and State agencies share common management goals for sagebrush ecosystems, including improving the capacity to manage for resistance to invasive species or resilience to disturbance to achieve long-term conservation and restoration objectives. USGS scientists along with Federal and State partners have developed a core set of data and models that provide an analytical backbone to support planning needs in the sagebrush biome. These data and models have been added to a web-based tool that make the data and derived products associated with the "Science Framework for Conservation and Restoration of the Sagebrush Biome" (Chambers and others, 2017) available and usable by a wide audience. This "Conservation and Restoration Strategy Tool" is now available and can be accessed at https://doi.sciencebase.gov/cnr/. Key functions of the web tool include (1) spatial data discovery and exploration; (2) summarization and reporting of data by predefined geographic units at different scales; and (3) summarization and reporting of data by user-defined areas of interest. This work is capitalizing on previous and ongoing research projects that are focused on large landscape conservation.

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Interpreting Indicators of Rangeland Health

Qualitative assessments of rangeland health using observable indicators help managers make informed land management decisions and communicate findings with the public. The USGS and other Federal agencies have jointly developed a system in which 17 indicators are used to gauge three attributes of rangeland health—soil and site stability, hydrology, and biology—and created a monitoring protocol for managers to assess the functional status of rangelands and provide early warnings of resource problems. Recent revisions to the protocol reflect changes learned through 13 years of teaching and applying previous versions. The evaluation is used widely by the BLM, the Natural Resources Conservation Service (NRCS), and many private ranchers and rangeland consultants.

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Effectiveness of Layering Treatments in the "Multiple Intervention" Response to Wildfire in Sagebrush Steppe

Improving postfire treatments to decrease exotic annuals and increase perennial plants is a priority science need for managers. Postfire treatments typically entail multiple interventions, such as herbicide or seeding applications, which can have reinforcing or canceling effects on treatment success. However, there is little science to guide decisions on how to order and time different treatments following fire. USGS scientists are conducting research on the 285,000 acres burned by the 2015 Soda Wildfire in southwestern Idaho to determine how different sequences of seeding and herbicide can be optimized to reduce exotics and increase perennials and how treatment effects are modulated by postfire grazing resumption. This project can help managers determine how treatments can be best phased to optimize postfire restoration outcomes.

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Postfire sagebrush seeding. Photograph from Bureau of Land Management.

Sagebrush seedling. Photograph by Matthew Germino, U.S. Geological Survey.

Phasing Herbicide, Drill Seeding, and Grazing Resumption in Postfire Sagebrush Steppe

Postfire management interventions in the sagebrush steppe often combine treatments, such as applying herbicides to reduce exotic annuals or seeding desirable perennials. Phasing these various treatment types in different postfire years may optimize effects and increase a site's ability to withstand impacts of resuming livestock grazing. USGS scientists are measuring how vegetation responds to phasing of land management actions—specifically herbicide spraying, drill seeding, and resumption of grazing—in the first few years following wildfire in sagebrush steppe. They will assess the relative abundance of exotic annual and desirable perennial grasses with respect to different sequences of seeding and spraying, and determine how treatments contribute to a site's resistance, resilience, and ability to withstand grazing. This research will provide information to rangeland managers about if and how to combine and phase herbicide and seeding treatments.

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Experimental Tests of Management Options for Improving Outplanting Success of Big Sagebrush

Methods for increasing success of seeded or planted sagebrush can be useful to land managers. USGS scientists are performing experimental tests of methods for improving sagebrush outplanting success, including the use of wind shelters, wattles, cluster plantings, landscape and topography strategies, and treatments of herb layers. Outcomes of this study may help provide managers with new methods for improving establishment of sagebrush in restoration treatments.

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Community Composition and Restoration of Biological Soil Crusts of Nevada's Sagebrush Shrublands

Biological soil crusts often exist in spaces between arid and semiarid plants and can improve soil stability, hydrology, nutrient cycling, and, potentially, the resistance of plant communities to invasive annual grasses. The USGS is leading a study to examine the extent of biological soil crusts in Nevada's sagebrush shrublands and some of the potential factors influencing the absence of crusts across the sagebrush ecosystem. Researchers will use existing data to find ecological sites with the potential to support biological soil crusts. Objectives include determining how soil properties, climate, livestock use, and fire affect the community composition of biological soil crusts. Results of this study may show how crusts respond to disturbances and the ecological factors that influence these important biological communities. This knowledge can help inform future management actions to maintain biological soil crusts in the sagebrush ecosystem.

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Biological soil crust. Photograph by David Pyke, U.S. Geological Survey.

Holding Their Ground: Does Biological Soil Crust Restoration Enhance the Germination of Native Plants and Reduce Soil Degradation?

In the Great Basin, soil erosion on burned slopes can be 10 times that on unburned slopes. Additionally, revegetation projects may fail because of annual fluctuations in precipitation. Biological soil crusts, particularly mosses, can reduce soil erosion and help retain soil water, improving native plant restoration after fires. USGS scientists are experimenting with moss restoration using two stabilization methods, a jute net and a hydro-mulch tackifier, which are already used by the USDA Forest Service for soil erosion control on some burned hillslopes. They will compare the jute net against the tackifier to determine how well each method prevents soil erosion and restores mosses and native plants. They will also mimic a 25-year-maximum storm event to determine soil erosion and water runoff. The study aims to aid Federal, State, Tribal, and private landowners throughout the Great Basin in their efforts to protect soils while restoring plants.

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Understanding the Ecological Importance of Biocrusts and Grazing Prescriptions That Minimize Their Disturbance

Biocrusts develop on the surface of soils, consisting of a community of cyanobacteria, mosses, and lichens, and they are commonly found across natural areas in the arid and semiarid Western United States. Biocrusts help maintain the integrity of soils and plants, reduce erosion, and increase postfire resilience and may have enormous ecosystem benefits, but there are many knowledge gaps. USGS researchers are partnering with the BLM on a study to determine how soil type and hydrology affect the vulnerability of biocrusts to disturbance by grazing. Results from this study may inform grazing prescriptions for various locations and seasons to promote conservation of biocrusts for their ecological benefits.

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Increasing Operational Resilience for Sagebrush Ecosystems by Integrating Multiscale Sage-Grouse Metrics

Conservation planning efforts in the sagebrush ecosystem increasingly use tools that link mapped variation in soil and plant processes to predicted outcomes from disturbance and restoration. Such efforts help make resilience concepts “operational” for managers. However, failure to consider obligate vertebrate species, such as sage-grouse, can hinder these efforts owing to spatiotemporal lags between slower reorganization of plant and soil processes following disturbance and corresponding faster behavioral and demographic responses of fauna to disturbance. USGS scientists are incorporating more refined models of sage-grouse habitat suitability and population performance into resilience-driven decision-support tools through the use of multiscale geospatial overlays, simulation analyses of postdisturbance land cover recovery, and improved sagebrush recovery estimates. These efforts aim to improve prioritization of threats from grass-fire cycles and conifer expansion in the Great Basin and apply more broadly rangewide.

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Bureau of Land Management Seed Warehouse Database

The BLM National Seed Warehouse program purchases and distributes millions of pounds of seed every year for BLM and partner seeding treatments. Currently, tracking of individual seed bags and pallets is accomplished through paper documents and electronic spreadsheets. Through a collaborative process, the BLM and the USGS are designing an online seed warehouse tracking database to store information about individual seed bags. The database can be used to enhance information collected from seed species, seed testing, seed lot, and vendors to facilitate analyses of seed germination and establishment on treatments throughout the Western United States. Analyses may provide insight on seed quality and treatment effectiveness.

FWS biologists collect sagebrush seeds in Wyoming. Photograph from U.S. Fish and Wildlife Service.

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Modeling Recovery of Sagebrush Ecosystems Using Remote Sensing Products

The ability to predict sagebrush recovery following disturbance is limited by a paucity of research quantifying the spatial and temporal factors influencing recovery across landscapes. USGS and CSU scientists are developing a framework for modeling changes in sagebrush cover on reclaimed oil and gas well pads using time-varying remote sensing products developed for the Wyoming Landscape Conservation Initiative (WLCI). The framework will allow scientists to model rates of change in sagebrush and bare ground cover at 2- to 5-year intervals from 1991 through 2015. This approach allows the prediction of rates of recovery across broad landscapes and assessment of effects of factors such as weather and soils on outcomes. This work is now being extended to the rest of Wyoming and the Great Basin and examining trends in vegetation following other disturbance such as fire and land treatments.

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Standards, Methods, and Monitoring—Improving Reclamation Success on Western Public Lands

USGS researchers are working to improve the success of reclamation efforts on public lands in the Western United States. Their multiphased approach includes (1) analyzing existing reclamation practices, monitoring protocols, and standards; (2) assessing current scientific information on reclamation methods and their effectiveness; and (3) developing a practical guidebook to inform management or policy decisions. USGS researchers will work closely with the BLM to examine previously compiled information on reclamation guidance, practices, monitoring protocols, and standards in resource management plans and other documents. A workshop for subject matter experts is planned to solicit input and refine the guidebook and potential data requirements. The resulting product can help identify a set of core standards, methods, and monitoring requirements that can be used across the Western United States.

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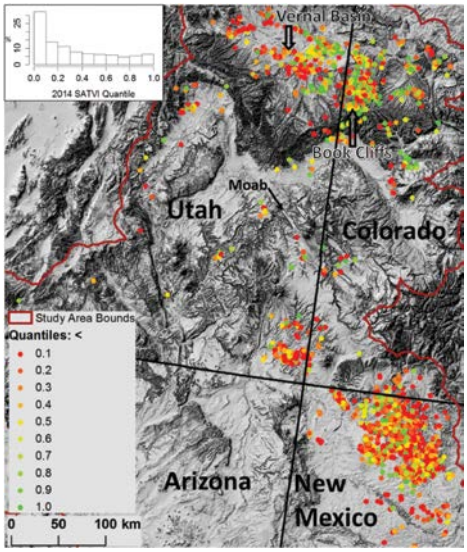
Evaluating Reclamation Success Following Oil and Gas Development

USGS scientists developed a new tool—the disturbance automated reference toolset (DART)—to provide regional assessments of land recovery following oil and gas drilling activities. This new tool was developed to help resource managers make informed decisions for future well pad development. The tool incorporates satellite imagery, digital soil mapping, predictive ecological modeling, and field assessments to evaluate vegetation recovery following well pad abandonment. Scientists used the tool to study 1,800 well pads in Colorado, New Mexico, and Utah, comparing vegetation cover of the abandoned sites to surrounding undisturbed areas with roughly equivalent climate, soil, topography, and management histories. Differing recovery rates across environmental gradients and land stewardship suggest that these attributes can be useful for identifying conditions that may promote or hamper pad recovery.



Spatial distribution and histogram of well pad recovery quantiles obtained using the disturbance automated reference toolset (DART). Points in red have lower vegetation cover signal and those in green have higher cover relative to reference areas (from Nauman and others, 2017).

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Using Long-Term Remote Sensing and an Automated Reference Toolset To Estimate and Predict Postdevelopment Recovery Potential

Predicting recovery rates of vegetation following disturbance could help inform future placement of energy development to minimize environmental impacts. In this study, USGS scientists are using a time-varying approach to monitor and predict recovery of sagebrush ecosystems following disturbance. Within areas where the DART (see above project) is currently developed in the WLCI study area, scientists will identify suitable reference sites near well pads and then characterize trends in vegetation at reference and disturbed sites at 2- to 5-year intervals from 1985 to 2015. These data can enable modeling to determine how recovery potential changes over time according to differences in soils, weather, and well pad characteristics, and predict time to recovery. This information and resulting spatial data can help inform future development and planning processes.

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Sagebrush, Sage-Grouse, and Other Sagebrush-Associated Species

Holistically understanding the dynamics within the sagebrush ecosystem can help land managers apply strategies to maintain the ecosystem for the plant and wildlife populations that depend on it. Activities to maintain and improve conditions to benefit sagebrush-associated wildlife, including the greater sage-grouse, can be enhanced through increased information about behavior, habitat use, and population structure of these species. USGS scientists are conducting research to inform management of the sagebrush ecosystem, such as developing sage-grouse monitoring and population analysis tools, mapping sagebrush vegetation cover, and improving the overall ecological understanding of sagebrush-associated species.

Sage-grouse habitat in central Montana. Photograph by Steven Hanser, U.S. Geological Survey.

Annotated Bibliography of Scientific Research on Greater Sage-Grouse

The greater sage-grouse has been a focus of scientific investigation and management action for the past two decades. The sheer number of scientific publications can be a challenge for managers tasked with evaluating and determining the need for potential updates to existing planning documents. To assist in this process, USGS scientists are reviewing and summarizing the scientific literature. Annually, USGS scientists conduct a structured search of reference databases for research or scientific review articles in peer-reviewed journals or formal government technical reports and retain only those products for which sage-grouse or their habitat was a research focus. Each product is summarized and assessed for relevance to a list of 31 management topics including sage-grouse biology and habitat characteristics along with potential management actions, land uses, and environmental factors related to sage-grouse management and conservation. The online version of this bibliography is searchable by topic and location and includes links to all original publications (https://apps.usgs.gov/gsgbib/index.php). An update is in progress that will add publications from 2018 and early 2019.

Male sage-grouse on a lek near Elko, Nevada. Photograph by Tatiana Gettelman, U.S. Geological Survey.

Contact

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Publication

Carter, S.K., Manier, D.J., Arkle, R.S., Johnston, A.N., Phillips, S.L., Hanser, S.E., and Bowen, Z.H., 2018, Annotated bibliography of scientific research on greater sage-grouse published since January 2015: U.S. Geological Survey Open-File Report 2018–1008, 183 p., https://doi.org/10.3133/ofr20181008. [Interactive, searchable version is available at https://apps.usgs.gov/gsgbib/index.php.]

Hierarchical Sage-Grouse Population Assessment Tool: Building a Foundation for True Adaptive Management

Incorporating spatial and temporal scales into monitoring strategies can provide more robust detection of population rates of change and indication of whether trajectories for those rates of change are driven by local or regional factors. USGS scientists and colleagues have designed a hierarchical monitoring framework for greater sage-grouse in Nevada, Wyoming, and northeastern California that can assist Federal, State, and private land managers by providing a monitoring and detection system to identify sage-grouse breeding locations (known as leks), clusters of leks, and populations where intervention may be necessary to sustain populations and to evaluate effectiveness of conservation efforts. The team is working with the State wildlife agencies and the BLM to expand these approaches to the geographic range of sage-grouse and will develop methods to assess population change relative to vegetation characteristics; climate; disturbances, such as fire and cheatgrass invasion; and other management-relevant gradients.

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Publications

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., https://doi.org/10.3133/ofr20171089.

Wann, G.T., Coates, P.S., Prochazka, B.G., Severson, J.P., Monroe, A.P., and Aldridge, C.L., 2019, Assessing lek attendance of male greater sage-grouse using fine-resolution GPS data—Implications for population monitoring of lek mating grouse: Population Ecology, v. 61, no. 2, p. 183–197, https://doi.org/10.1002/1438-390X.1019.

Using Advanced Technologies To Improve Population Estimation From Lek Counts

Population ecologists are challenged with estimating population growth of sensitive species on the basis of animal surveys that are often imperfect in detection. USGS scientists, in collaboration with State and university partners, are conducting multiple studies with advanced technologies to improve population estimates and growth rates from sage-grouse lek count observations. For example, scientists are using high-definition infrared cameras mounted on fixed wing aircraft simultaneously with double-blind ground observations to estimate detection probabilities. Moreover, scientists are employing advanced Global Positioning System (GPS) transmitters to collect fine-resolution movement data on male sage-grouse to calculate lek visitation rates. These findings can be used to calculate adjustment factors for lek surveys to account for sage-grouse not attending leks and those that were undetected. Adjusted counts could be used by State and Federal partners to improve accuracy of estimated population trends.

Male sage-grouse on a lek near Elko, Nevada. Photograph by Tom Koerner, U.S. Fish and Wildlife Service.

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Publications

Coates, P.S., Wann, G.T., Gillette, G.L., Ricca, M.A., Prochazka, B.G., Severson, J.P., Andrle, K.M., Espinosa, S.P., Casazza, M.L., and Delehanty, D.J., in press, Estimating sightability of sage-grouse at leks using aerial infrared and N-mixture models: Wildlife Biology.

Gillette, G.L., Coates, P.S., Petersen, S., and Romero, J.P., 2013, Can reliable sage-grouse lek counts be obtained using aerial infrared technology?: Journal of Fish and Wildlife Management, v. 4, no. 2, p. 386–394, https://doi.org/10.3996/032013-JFWM-025.

Marking Effects on Sage-Grouse Survival and Behavior

Reliable demographic estimates hinge on the assumption that marking animals does not alter behavior, reproduction, or survival. Violations of this assumption can change inferences from the demographic information and are particularly problematic for species of high conservation concern, such as greater sage-grouse, where managers depend on science to guide decisions. The deployment of GPS or similar devices in recent years represents a significant technological advancement that has contributed greatly to the understanding of avian ecology compared with traditionally used very high frequency (VHF) radio transmitters. However, major information gaps remain regarding GPS effects on bird demographic rates, movement behavior, and habitat selection. USGS scientists, in collaboration with scientists at the Nevada Department of Wildlife, Idaho State University, and others, are leveraging extensive data from sage-grouse across multiple sites and years in the Great Basin that have been marked with GPS and VHF devices using various attachment configuration designs. Results from these studies can help provide guidelines for device use and beneficial design modifications.

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Publication

Severson, J.P., Coates, P.S., Prochazka, B.G., Ricca, M.A., Casazza, M.L., and Delehanty, D.J., 2019, Global positioning system tracking devices can decrease greater sage-grouse survival: Condor, v. 121, no. 3, p. 1–15, https://doi.org/10.1093/condor/duz032.

The Importance of Simulation Assumptions When Evaluating Detection Bias in Lek Trend Models

Greater sage-grouse lek counts are important for investigating a variety of questions, and population models can estimate detectability from repeated counts when modeling population size and trends. Past simulations used to evaluate these models typically assumed detectability is constant or random across sites and years. Thus, it is unknown how these models perform under scenarios when detectability is not constant or random. To address this uncertainty, USGS and CSU scientists used GPS data from sage-grouse to inform simulations of the detection process for counts of this species, including scenarios where detection either varied randomly or declined linearly across years. This information can help inform monitoring protocols to provide State and Federal biologists with more accurate estimates of sage-grouse populations and can lead to improved sage-grouse monitoring and population analysis protocols.

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Publication

Monroe, A.P., Wann, G.T., Aldridge, C.L., and Coates, P.S., 2019, The importance of simulation assumptions when evaluating detectability in population models: Ecosphere, v. 10, no. 7, article e02791, 16 p., https://doi.org/10.1002/ecs2.2791.

Evaluating Trends in Greater Sage-Grouse Populations With Quantile Regression

USGS scientists are evaluating the use of a statistical technique known as quantile regression to develop models of sage-grouse population change. Estimates obtained from quantile regression are less sensitive to a few extreme population counts; can be estimated with an easier, more statistically justified approach to dealing with a few counts of zero; and can be extended to include additional covariates. Furthermore, this technique can provide a robust measure of trends and has fewer statistical assumptions. These features are likely to be especially beneficial in estimating population trends for greater sage-grouse.

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A Hierarchical Integrated Population Model for Greater Sage-Grouse in the Bi-State Distinct Population Segment in California and Nevada

Genetic research has indicated isolation and potential conservation risk for the greater sage-grouse in the Bi-State Distinct Population Segment. The USGS developed an integrated population model (IPM) for this area to estimate population growth rates. The model indicates that the Bi-State population is stable overall, but evidence suggests a declining trend for one subpopulation. Scientists recently expanded the IPM to identify relationships between population growth rate and precipitation patterns. These findings provide a framework for hierarchical modeling strategies that separate climate-driven changes in populations from local-scale

Male sage-grouse on a lek near Elko, Nevada. Photograph by Tatiana Gettelman, U.S. Geological Survey.

disturbances. Researchers are now assessing which components of sage-grouse life history are driving population change as well as how and when climate influences particular life-history stages. This research informs active management planning processes in the Bi-State, and this approach could be adapted to assess population trends for greater sage-grouse at other regional and landscape scales.

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Publications

Coates, P.S., Halstead, B.J., Blomberg, E.J., Brussee, B., Howe, K.B., Wiechman, L., Tebbenkamp, J., Reese, K.P., Gardner, S.C., and Casazza, M.L., 2014, A hierarchical integrated population model for greater sage-grouse (*Centrocercus urophasianus*) in the Bi-State Distinct Population Segment, California and Nevada: U.S. Geological Survey Open-File Report 2014–1165, 34 p., https://doi.org/10.3133/ofr20141165.

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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: U.S. Geological Survey Open-File Report 2018–1177, 89 p., https://doi.org/10.3133/ofr20181177.

Spatially Explicit Conservation Planning Tool for the Bi-State Distinct Population Segment of Greater Sage-Grouse

Conservation planning efforts must account for a wide array of factors to assist future development, conserve native species, and improve habitat conditions. The USGS has developed a spatially explicit conservation planning tool within the Bi-State Distinct Population Segment that uses modeling results from sage-grouse habitat suitability and space use to assess and prioritize management actions (see citation on following page). Examples include decision support for prioritizing restoration projects related to wildfire and pinyon and juniper treatments. Results demonstrate how the model output can be an important step in identifying management projects that yield the highest quantifiable benefit to sage-grouse while avoiding costly misallocation of resources. This information helps highlight the importance of considering both changes in sage-grouse responses to habitat conditions and factors influencing sagebrush ecosystem resilience to disturbance and resistance to invasion. This novel framework can be adapted to answer other management questions aimed at improving habitat for species of conservation concern across sagebrush and other ecosystems.

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Habitat for sage-grouse in the Bi-State Distinct Population Segment on the California-Nevada border. Photograph from U.S. Geological Survey.

Publications

Duvall, A.L., Metcalf, A.L., and Coates, P.S., 2017, Conserving the greater sage-grouse—A social-ecological systems case study from the California-Nevada Region: Rangeland Ecology & Management, v. 70, no. 1, p. 129–140, https://doi.org/10.1016/j.rama.2016.08.001.

Ricca, M.A., Coates, P.S., Gustafson, K.B., Brussee, B.E., Chambers, J.C., Espinosa, S.P., Gardner, S.C., Lisius, S., Ziegler, P., Delehanty, D.J., and Casazza, M.L., 2018, A conservation planning tool for greater sage-grouse using indices of species distribution, resilience, and resistance: Ecological Applications, v. 28, no. 4, p. 878–896, https://doi.org/10.1002/eap.1690.

Translocations as Conservation Strategy for Imperiled Populations of Sage-Grouse

USGS scientists are working with Federal, State, and university collaborators to rescue severely declining populations of sage-grouse at the edge of the species' range. In 2017, translocation efforts began as part of a multiyear effort to infuse new individuals and genetic information into sage-grouse populations occupying the western extreme of the Bi-State Distinct Population Segment and the northeastern extent of the species range in western North Dakota. Using a variety of techniques that include VHF and GPS technology, soft-release methods, artificial insemination, and release of pre-nesting hens as well as hens with broods, the researchers aim to ultimately develop a set of guidelines for effective sage-grouse translocations.

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Publication

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: U.S. Geological Survey Open-File Report 2018–1177, 89 p., https://doi.org/10.3133/ofr20181177.

Greater Sage-Grouse Response to Habitat Restoration Efforts

Sagebrush restoration efforts and greater sage-grouse translocations were initiated in 2005 to augment population numbers and prevent extirpation of the Devils Garden population in the FWS Klamath Basin National Wildlife Refuge Complex. Early monitoring efforts were conducted opportunistically without targeted objectives and with limited quantitative data collection. Scientists from the USGS Oregon Cooperative Fish and Wildlife Research Unit, in collaboration with those from Oregon State University and the FWS, are initiating a project to provide a robust evaluation of sage-grouse response to concurrent restoration activities to assess habitat conditions that could be limiting population growth and range expansion. This research will address knowledge gaps regarding dispersal and seasonal movements related to life-cycle needs of greater sage-grouse to inform future restoration actions and sage-grouse translocations.

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Spatially Explicit State-and-Transition Modeling for Rangeland Conservation Planning: Application to Outcome-Based Grazing and Sage-Grouse Habitat Monitoring

The natural range of variability of the sagebrush ecosystem in the Great Basin is determined by local climate and topographic and soil relationships associated with plant community development. State-and-transition models (STMs) are widely used as a decision support tool for land managers and can be used to describe the ecological dynamics that occur within areas of similar ecological potential that respond similarly to natural or human-induced disturbances. These areas are referred to as Disturbance Response Groups (DRGs). Scientists from the USGS and University of Nevada-Reno are developing a conservation planning tool for sage-grouse across DRGs and testing the results of outcome-based grazing actions. This work will build on technological advances in remote sensing and land cover products to develop spatially explicit STM maps. Development of ecologically relevant maps can provide powerful tools for conservation planning for a variety of management actions including fuel treatments, grazing permit renewal, sage-grouse habitat management, and postfire rehabilitation.

Wildlife biologist monitoring sagebrush habitat. Photograph by Steven Hanser, U.S. Geological Survey.

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Impacts of Free Roaming Equids and Livestock on Greater Sage-Grouse and Sagebrush Ecosystems

Abundant populations of equids (wild horses and burros) in the Great Basin pose challenges for multiple-use management of BLM rangelands, which includes cattle production and conservation of sagebrush-obligate species such as greater sage-grouse. Although previous research points towards sagebrush degradation from overly abundant equids, direct linkages to sage-grouse population dynamics and behavior are sparse. USGS scientists and collaborators are bridging these information gaps through long-term studies of lek disturbance by large herbivores (equids, cattle, and native ungulates) and newly launched studies of cattle and equid movements and resource utilization encompassing sage-grouse monitoring across Nevada. These efforts can also help inform outcome-based grazing programs by separating equid effects from livestock effects.

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Publication

Muñoz, D.A., Coates, P.S., and Ricca, M.A., in press, Feral horses disrupt greater sage-grouse lekking activity in the Great Basin: Journal of Arid Environments.

Learning from the Land: Extending State-and-Transition Models for Adaptive Management of Wildlife Habitat on Western Rangelands

USGS and CSU scientists have been working with other Federal and university partners to streamline and test STMs that incorporate sage-grouse habitat conditions. The researchers have demonstrated the utility of STMs for adaptive management of sage-grouse habitat and livestock production by developing models that predict the distribution and abundance of sage-grouse and sagebrush-associated songbirds (Brewer's sparrow, sage thrasher [*Oreoscoptes montanus*], sagebrush sparrow [*Artemisiospiza nevadensis*]), and green-tailed towhee [*Pipilo chlorurus*]) in northwestern Colorado and by evaluating the effectiveness of sage-grouse as an umbrella species. This effort can increase awareness and may increase the adoption of STMs by ranchers, while contributing to NRCS objectives of revising ecological site descriptions and promoting adaptive management and monitoring of sage-grouse habitat for Federal and State agencies.

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Publication

Timmer, J.M., Aldridge, C.L., and Fernández-Giménez, M.E., 2019, Managing for multiple species—Greater sage-grouse and sagebrush songbirds: Journal of Wildlife Management, v. 83, no. 5, p. 1043–1056, https://doi.org/10.1002/jwmg.21663.

Greater Sage-Grouse Seasonal Habitat Models

Sage-grouse have a variety of habitat needs, and understanding these requirements in a spatial context is important to inform management strategies. USGS and CSU scientists developed seasonal habitat suitability models for the Great Basin by incorporating region-specific habitat conditions specified in the 2015 BLM resource management plans, the USGS National Land Cover Database (NLCD) Shrub Component products, and other resource-condition data. The researchers produced maps for breeding, nesting, brood-rearing, and summer habitat. These maps performed poorly at capturing sage-grouse telemetry locations, suggesting the need to develop regional seasonal habitat models based on sage-grouse telemetry data. USGS scientists are continuing to work with partners to explore opportunities to develop rangewide seasonal habitat models using collaborative and more advanced data-driven approaches.

Two-day-old sage-grouse chick. Photograph by Cameron Aldridge, used with permission.

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Sage-Grouse Ecology and Seasonal Habitats in South Dakota

Sage-grouse populations in South Dakota have declined significantly over the past decade for unknown reasons. Population declines in sage-grouse are commonly attributed to habitat loss, and conservation actions for sage-grouse often concentrate on habitat management. New GPS transmitters can record several locations each day to provide detailed information on habitat use that can improve understanding of habitat relationships by enabling assessment of variability among individuals in habitat use within seasons. In collaboration with the BLM, USGS scientists are tracking sage-grouse with GPS transmitters to (1) evaluate and map seasonal habitat suitability, (2) quantify effects of disturbances, and (3) evaluate changes in survival and reproduction over the past decade. Results of this study can inform habitat prioritization and identify factors that influence population dynamics.

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Seasonal Habitat Maps for Sage-Grouse in Montana and the Dakotas

Spatially extensive maps of habitat suitability with high spatial resolution are useful tools for wildlife management and research but are unavailable for sage-grouse in Montana and the Dakotas. USGS scientists are synthesizing existing telemetry data for sage-grouse across these States to develop maps of habitat suitability for nesting, summer, and winter seasons, based on new geographic information system (GIS) layers for habitat features in the sagebrush ecosystem. This study will provide information and habitat maps that can advance sage-grouse research and inform decision making at local and landscape levels, including prioritization to conserve and restore sage-grouse habitat in the region.

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Mapping of Greater Sage-Grouse Habitat in Nevada and Northeastern California

The USGS is studying the cumulative impacts of expanding human activities across sagebrush landscapes in Nevada and northeastern California. By combining land cover information with data on sage-grouse movement patterns, life history and reproductive ecology, and habitat preferences, researchers can create maps that forecast the interaction of proposed land use activities and the sagebrush ecosystem. Maps help predict where fragmentation of sage-grouse movement corridors and breeding grounds might occur and help in the assessment of relationships between land use and native and invasive species. Additional work is now underway that will (1) describe spatial variation in habitat selection through meta-analyses, (2) identify life-history-specific macrohabitat requirements, and (3) depict spatially explicit survival consequences of habitat selection decisions by sage-grouse. This research can inform land managers' conservation planning efforts for sage-grouse and the habitats on which they rely.

Conifer woodland and sagebrush on Spruce Mountain in Nevada. Photograph by Steven Hanser, U.S. Geological Survey.

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Publications

Coates, P.S., Casazza, M.L., Brussee, B.E., Ricca, M.A., Gustafson, K.B., Sanchez-Chopitea, E., Mauch, K., Niell, L., Gardner, S., Espinosa, S., and Delehanty, D.J., 2016, Spatially explicit modeling of annual and seasonal habitat for greater sage-grouse (*Centrocercus urophasianus*) in Nevada and northeastern California—An updated decision-support tool for management: U.S. Geological Survey Open-File Report 2016–1080, 160 p., https://doi.org/10.3133/ofr20161080.

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Greater Sage-Grouse Population Ecology

USGS scientists and colleagues are developing a peer-reviewed book on comprehensive population ecology of greater sage-grouse including analyses of habitat associations in relation to demographic rates. The book will consist of different sections, each focusing on a specific life stage (for example, nesting, brood-rearing, wintering, and so forth) with individual chapters focused on estimated vital rates and specific macrohabitat and microhabitat needs across different ecoregions of the sage-grouse range. Book chapters will be written by subject experts from their respective ecoregions and will be quantitative in nature. This will provide a "desktop synthesis" for land and wildlife managers and policymakers to access and reference scientific information for land and wildlife management and policy decisions and can help form ecoregion-specific and comprehensive management guidelines.

Sage-grouse nest. Photograph by Cameron Aldridge, used with permission.

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Microhabitat Requirements of Greater Sage-Grouse Within the Great Basin

Habitat management guidelines with specific management objectives for greater sage-grouse habitat requirements have been published. A disproportionate number of the scientific studies on which these guidelines are based have focused on the northeastern portion of sage-grouse range and might not accurately reflect the Great Basin ecosystem. Building on information in the population ecology book being prepared by USGS scientists and colleagues (see previous project description), the second synthesis will culminate in an easy-to-follow management guideline handbook specifically focused on the Great Basin. This synthesis will include an evaluation of existing macrohabitat and microhabitat objectives across life-history stages and will use a multi-year dataset of VHF and GPS telemetry data and microhabitat measures collected across more than 12 sites in the Great Basin. The synthesis will provide statistics regarding numerous microhabitat factors for selection and survival to meet timely and best-available science needs for land managers and policymakers.

Sagebrush vegetation monitoring. Photograph by Collin Homer, U.S. Geological Survey.

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Publication

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., https://doi.org/10.3133/ofr20171087.

SageDAT: Data and Tools To Support Collaborative Sagebrush Ecosystem Conservation and Management

The USGS, the BLM, the FWS, and the Western Association of Fish and Wildlife Agencies have recently initiated development of a new DOI-funded effort, known as SageDAT. SageDAT, which can be accessed at https://sagedat.org, provides a mechanism for sharing and leveraging of data resources, increasing communication and coordination between organizations, and allowing for broader participation and transparency in decision making. The SageDAT team is using emerging technologies to allow effective sharing and discoverability of relevant data and tools that can be used to address the complex challenges that exist in sagebrush ecosystems including wildfire, invasive annual grass species, land use management, and assessments focusing on the greater sage-grouse.

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Remote Sensing Characterization and Monitoring of Shrubland Components in the Western United States

The USGS, in collaboration with the BLM, completed a remote-sensing-based characterization of shrublands across the Western United States, including all sagebrush areas as part of the National Land Cover Database 2016. This work provides a suite of datasets that not only characterize the landscape in ways to maximize application utility but also provide a foundation for both historical and future monitoring at ecosystem scales. In each 30-meter grid cell, these products quantify the proportion of shrub, sagebrush, herbaceous, annual herbaceous, litter, and bare ground at 1-percent intervals and the height of shrubs and sagebrush in centimeters. Research has shown this information enables generation of a variety of wildlife habitat predictions including sage-grouse habitat. Since products will be integrated into the National Land Cover Database, they are now planned for future updating on a regular 2-year cycle. Current products are available at https://www.mrlc.gov/data.

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Publication

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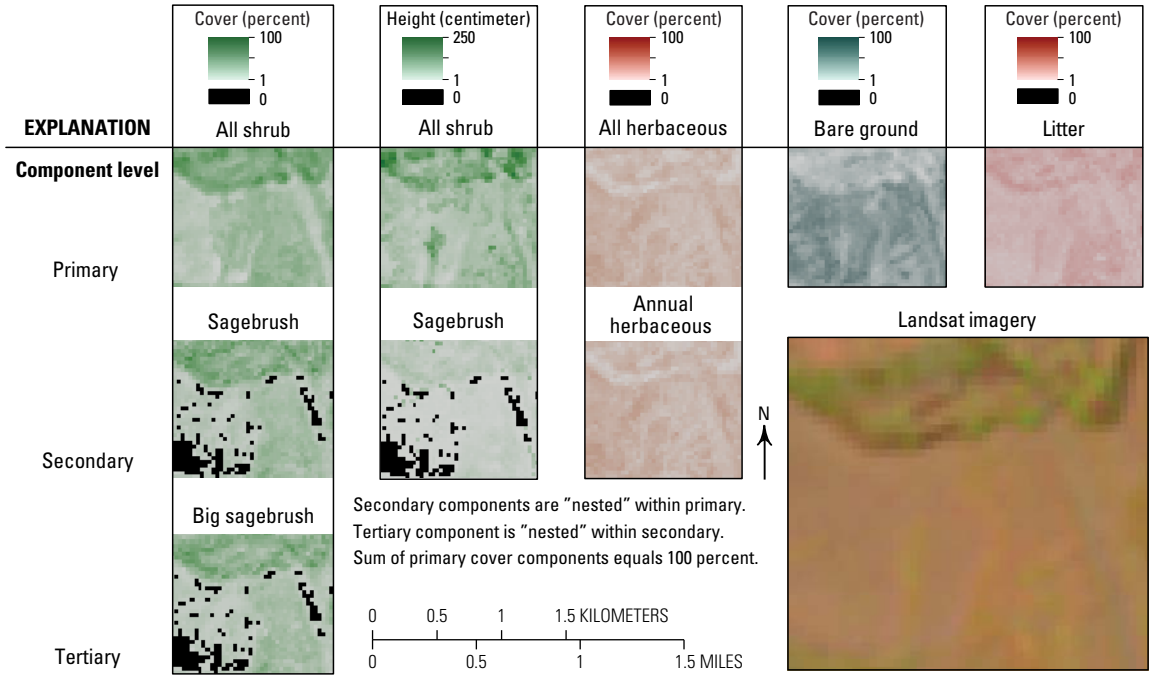

Mapped shrubland components, sorted by their hierarchical level. Component groups are contained by black boxes. For example, within the all shrub primary component group, sagebrush is secondary, and big sagebrush is tertiary. So big sagebrush cover and extent is never greater than sagebrush. Similarly, sagebrush cover and extent is never greater than all shrub cover. The sum of primary cover components (all shrub, all herbaceous, bare ground, and litter) is 100 percent in a typical rangeland environment. Pixels with zero percent cover or height for each component are depicted in black pixels (from Young, 2017).

Developing Temporal Trends in Sagebrush Vegetation Characteristics Over a Large Landscape

The completion of the USGS shrubland component maps (see previous project description) provides an opportunity to map vegetation component change, from 1984 through 2018 (that is, the most recent full calendar year). Products that describe change over time support research in sage-grouse habitat and population dynamics, restoration success, forecasting future climate change and trends, treatment recovery analysis, and cheatgrass change dynamics. This new approach automates component change analysis by Landsat path and row and has been developed as an extensive scripted process to support processing the large amounts of data this process requires. This approach allows unprecedented comprehensive analysis of shrub and grass change across time. Data for the Great Basin and Wyoming areas have been completed, with much of eastern Oregon and southern Idaho to be completed by September 2019. All areas of the Western United States where sagebrush occurs are targeted for completion by the summer of 2020. This process can be used to update these products in future years to ensure continuous change monitoring of these landscapes.

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Understanding Drivers of Change in Rangeland Vegetation

Rangeland vegetation is influenced by annual and seasonal variation in weather as well as grazing, invasive species, fire, and other factors. Understanding whether and why vegetation communities are resistant to change and resilient following disturbance is an important area of ecology and crucial for conservation and restoration strategies. This project takes advantage of multiple, existing data sources to improve understanding of the drivers of change in rangeland vegetation communities across the Western United States, including data from historic field surveys in the late 1970s (BLM's Soil-Vegetation Inventory Method) to ongoing field (BLM's Assessment Inventory and Monitoring Program) and remote sensing (USGS's grass-shrub products) datasets. Outcomes of this study can help improve monitoring strategies and management actions in the sagebrush ecosystem.

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Mapping Conifer Encroachment Within California and Nevada

Conifer encroachment is a threat to the extent of sagebrush shrublands in the Great Basin. High-resolution maps of conifers within sagebrush ecosystems are lacking. These maps would be highly useful to land and wildlife management agencies for habitat improvement plans. Therefore, the USGS is currently mapping conifer encroachment at 1-meter resolution across Nevada and northeastern California. This analysis uses specialized image recognition software to develop usable GIS files of conifer coverage. In areas thought to be pinyon and juniper, the USGS is using criteria to delineate the conifer map into cover classifications at 30-meter resolution to approximate phases of conifer encroachment. These maps can help inform management and conservation strategies including tree removal to enhance sagebrush ecosystems and sage-grouse populations.

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Publications

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Unmanned Aerial Systems for Improving Satellite-Derived Maps of Vegetation

Vegetation can be characterized at high spatial resolutions with stereo imagery from unmanned aerial systems (UAS) to improve and validate vegetation maps derived from Landsat imagery and field measures at BLM Assessment, Inventory, and Monitoring (AIM) plots. The goal of this study is to examine the use of UAS to complement AIM data and to inform the development of vegetation maps. USGS scientists are flying UAS concurrently with AIM surveys within the sagebrush ecosystem across Montana and the Dakotas to compare UAS data with AIM data to assess habitat heterogeneity at multiple spatial scales. Vegetation metrics from the UAS flights will be aggregated by Landsat pixels to evaluate vegetation maps derived from satellite imagery.

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Sagebrush Ecosystem Performance Mapping in the Great Basin

Vegetation productivity can be highly variable in arid and semiarid systems. Moisture-related variations in plant productivity add variability to time series data that is not related to management or disturbance. To isolate management and disturbance effects in these systems, "performance" models are being developed that predict sagebrush annual productivity. The deviations of the performance model account for both interannual variation in weather and spatial variation in site potential. Performance anomalies show where the vegetation is not responding to site and weather conditions as would be expected in a healthy sagebrush community. This information can identify areas that are overperforming or underperforming relative to the surrounding landscape and provide managers with a tool to refine or target actions to improve vegetation conditions.

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Landscape Influence on Gene Flow in Greater Sage-Grouse

The USGS and collaborators at the USDA Forest Service and University of Waterloo (Ontario, Canada) are using genetic information contained in sage-grouse feathers collected at leks to delineate the rangewide network of breeding populations. The genetic data have been analyzed in combination with landscape information to identify geographic distance, topographic features, anthropogenic land uses, and other factors that influence sage-grouse dispersal and genetic exchange. The last part of this work is defining genetic populations across the species range. The results from this study, perhaps the largest terrestrial effort of its kind, will be important for informing conservation planning efforts to delineate core or priority populations and reduce population fragmentation, isolation, and risk of extirpation.

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Greater sage-grouse in flight. Photograph by Tatiana Gettelman, U.S. Geological Survey.

Sage-Grouse Genomics

USGS scientists and their collaborators have assembled a reference genome for both greater and Gunnison sage-grouse and have performed whole-genome sequencing on six populations of greater sage-grouse (including several on the periphery of the species' range) and Gunnison sage-grouse. This study has helped identify intraspecific population structure and genetic differentiation across the range of these species. The researchers determined that regions that exhibited extreme population differentiation were also associated with candidate genes linked to the metabolism of xenobiotic compounds. Lab work on enzymes isolated from sage-grouse livers provided support for a role for these genes in detoxification of sagebrush, suggesting that the observed interpopulation variation may underlie important local dietary adaptations, warranting close consideration for conservation strategies that link sage-grouse to plant chemistry.

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Publications

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Connecting Hubs of Genetic Exchange Across the Range of Greater Sage-Grouse: Prioritizing Corridors for Conserving Genetic Diversity

Recent research by USGS scientists and collaborators at the USDA Forest Service and the University of Waterloo has identified hubs of genetic exchange and landscape features that affect gene flow, including identifying corridors of genetic connectivity across the contiguous range of greater sage-grouse. These efforts were made possible by collaboration across 11 States to collect and genotype 16,420 feathers from 2,139 leks. The products produced by this research team represent two distinctly different, yet equally important, approaches to quantifying genetic connectivity across the range of greater sage-grouse. Synthesizing these research products will identify the pathways of greatest connectivity among the hubs of genetic exchange, where genetic exchange is the greatest, and how greater sage-grouse disperse among these hubs. This research will facilitate the prioritization of areas for protection that are both (1) important hubs that maintain genetic connectivity and (2) corridors with suitable habitat and landscape features to maintain gene flow. Furthermore, this work will relate the locations of hubs and corridors to the probability of conversion to tillage agriculture in Montana, Wyoming, and the Dakotas; to the resistance and resilience of the landscape to fire and invasive grasses in the Great Basin; and to land management status across the species' range. These results can help inform ongoing management and conservation planning including actions meant to ensure long-term connectivity for greater sage-grouse populations range wide.

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Identifying Corridors and Connectivity Within and Among Sage-Grouse Priority Areas of Conservation Rangewide

Sage-grouse Priority Areas for Conservation (PACs) focus on targeting conservation across the species range in the areas of highest population abundance. While this PAC approach may protect the greatest number of sage-grouse, it is unclear how isolated these areas are both genetically and demographically. Specifically, any PACs that are relatively isolated or have lower genetic diversity and connectivity to neighboring PACs are at a higher risk of suffering deleterious impacts related to isolation and inbreeding. USGS scientists and collaborators at the USDA Forest Service and the University of Waterloo are developing a targeted assessment of the functional connectivity among PACs that will identify key genetic corridors among the PACs and assess levels of genetic diversity within each area. Additionally, metrics of genetic diversity and connectivity within PACs will be estimated and are another important consideration in assessing the importance of individual PACs to overall population health and sustainability.

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Integration of Genetic and Demographic Data to Assess the Relative Importance of Connectivity and Habitat in Sage-Grouse Populations

The integration of genetic and demographic data can provide multiple levels of insight into the patterns of distribution and abundance of species. Local demographic trends and population persistence are strongly influenced by patterns of regional connectivity. However, the relative contributions of connectivity, habitat amount, and habitat quality to patterns of abundance for sage-grouse is unknown. This makes it challenging to prioritize management aimed at increasing species abundance. Using the existing rangewide genetic and demographic data, scientists from the USGS, USDA Forest Service, and University of Waterloo will assess the relative contributions of habitat and genetic connectivity to lek size and stability. Additionally, given the extent of available data, the research team will assess whether the importance of connectivity varies over the range. This research can help identify which components of habitat configuration and connectivity have the largest influence on population abundance and how these factors vary regionally. These results can help facilitate targeted and regionally relevant management actions.

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Genetic Implications of Translocations in Gunnison Sage-Grouse

In an attempt to augment dwindling population sizes, Colorado Parks and Wildlife began translocating Gunnison sage-grouse from the largest population in the Gunnison Basin to small satellite populations. The effects of these translocations on the genetic composition of satellite populations are unknown. By characterizing genetic samples collected before and after translocations, USGS scientists have documented changes in genetic diversity and genetic differentiation and have determined that translocated individuals are reproducing. This information can help inform future translocations into isolated populations.

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Landscape Genetic Assessment of Gunnison Sage-Grouse

The range of the Gunnison sage-grouse has been fragmented into geographically and genetically distinct populations. The viability of the individual populations and long-term persistence of the species may be affected by the ability of individual birds to move between populations. USGS scientists and collaborators are using genetic samples to infer connectivity across the species range and between leks within the Gunnison Basin to gain insight on which landscape or habitat features are contributing to the fragmentation of the species range. The connectivity analysis within the basin will provide insight at a manageable scale and ultimately aims to inform current and future management scenarios by delineating corridors of movement and barriers to movement.

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Examining Adaptation in Gunnison Sage-Grouse

The satellite populations of the Gunnison sage-grouse occupy areas with a diversity of habitat and local environmental characteristics (fig. 1). With limited gene flow between populations and potential for different selective pressures acting on each population, there is the potential for locally adapted variation. Local adaptation is important to long-term persistence of populations and pertinent to current management efforts. Pressures of changing precipitation, temperature, and land use differ among the populations, and any existing variation adapted to the unique pressures are best maintained for the long-term success of the population. USGS scientists are using genomic methods to look within each population for evidence of selection correlated with environmental variation. Identifying adaptive variation can contribute to more targeted management efforts and inform the maintenance of this variation within populations.

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Identification of Crucial Late-Summer Brood-Rearing and Winter Habitat for Gunnison Sage-Grouse

Gunnison sage-grouse is considered a threatened species under the Endangered Species Act, and knowledge of resource requirements across all life states can assist conservation planning efforts. USGS and CSU scientists and colleagues are using telemetry data to develop resource selection models predicting crucial brood-rearing and winter habitat for Gunnison sage-grouse within the Gunnison Basin. These models can help improve the conservation and management of important Gunnison sage-grouse habitat, thereby enhancing the management of disturbances and increasing habitat connectivity.

A pair of Gunnison sage-grouse. Photograph from U.S. Fish and Wildlife Service.

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Landscape Variability and Gunnison Sage-Grouse Conservation

Loss and alteration of sagebrush habitat, owing to many factors, have been identified as primary reasons for declines in Gunnison sage-grouse populations. Within the Crawford population, one of seven remaining populations, USGS scientists are evaluating the impacts of habitat variability and developing spatially explicit models to better inform Gunnison sage-grouse conservation plans.

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Assessing Habitat, Risk, and Conservation Actions for Gunnison Sage-Grouse

The threatened Gunnison sage-grouse continues to experience declines, particularly in satellite populations, and an understanding of habitat needs, risks to habitat, and the feasibility of conservation actions to improve habitat and population conditions are required for multiagency conservation planning. USGS and CSU scientists are developing habitat selection and landscape change models for Gunnison sage-grouse throughout Colorado. This research can support the BLM in evaluating the efficacy of habitat restoration and conservation actions for stabilizing and increasing Gunnison sage-grouse populations. This research includes characterizing habitat and population responses to past conservation actions and developing a spatially explicit individual-based model to simulate population responses to habitat change and evaluating the relative efficacy of alternative conservation actions.

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Migration Corridors for Big Game

As habitat loss and fragmentation increase across ungulate ranges, identifying and prioritizing migration routes for land use planning and conservation have taken on a new urgency. Currently, research attention is focused on determining whether continued energy development, without consideration for migration corridors, will lead to the loss of the foraging benefit of migration. Research from the USGS Wyoming Cooperative Fish and Wildlife Research Unit has increased understanding of the importance of migration for large ungulates in the Western United States, specifically quantifying how migrating animals track spring green-up during migration. In collaboration with Federal, State, and university partners, the Wyoming Unit has developed the Migration Mapper software (https://migrationinitiative.org/content/migration-mapper) that provides a step-by-step analysis to map

Mule deer in Wyoming. Photograph by Matthew Kauffman, U.S. Geological Survey.

migration corridors, including low-, medium-, and high-use corridors, from GPS locations. Resulting corridor maps can be easily made available for managers, policymakers, land trusts, sportsmans' groups, and other nongovernmental organizations to use in conservation planning. A current effort is underway, through USGS-led regional workshops, to train wildlife managers from Western States to analyze migration data, and the USGS continues to develop tools and methods necessary to identify opportunities to enhance conservation and management of ungulate migration corridors.

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Use of Sagebrush-Reduction Treatments by Mule Deer in Wyoming

In southwestern Wyoming, managers may apply treatments of fire, herbicide, and mechanical removal that reduce sagebrush cover to improve habitat for wildlife, including mule deer. Although much is known about vegetation responses to treatments, it is unclear whether ungulates, themselves, respond to treatments (for example, increased use and fitness) and how their responses vary across treatment type, size, and context. USGS scientists are using GPS-tracking data to determine whether deer use and benefit from sagebrush treatments within their winter range and migration corridors in southwestern Wyoming. This study was facilitated by the Wyoming Landscape Conservation Initiative in collaboration with the University of Wyoming, BLM, and Wyoming Game and Fish Department.

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Interactions of Phenology, Grazing, Hunting, and Prescribed Fire on Elk and Mule Deer in Southwestern Wyoming

In southwestern Wyoming, land managers are interested in understanding the patterns of elk (*Cervus elaphus canadensis*) migration, habitat use, and calving areas in the sagebrush ecosystem. USGS scientists are evaluating the likely triggers for initiation of fall migration, changes in the timing of forage during time periods crucial to elk reproduction (fall and spring), and the influence of prescribed fire, grazing, land cover, and other management activities on habitat use. This effort is leading to the identification of migration corridors, important calving areas, shifts in forage that correlate with population size, and environmental factors relevant to elk movements and habitat use that can inform future management of this important game species. New studies will (1) examine changes in forage quality and timing across the Western United States to help managers set population objectives and understand the role of forage in changes to ungulate numbers, (2) provide a framework for considering these changes relative to ungulate ecology when implementing habitat treatments, and (3) evaluate the factors influencing elk aggregation to provide options for monitoring management options for mitigating disease transmission, such as chronic wasting disease.

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Using Genetic Analyses To Inform On-The-Ground Conservation for Multiple Sagebrush-Associated Wildlife Species

Recent analyses of greater sage-grouse genetics have delineated areas of key genetic connectivity for this species and provided a prioritization tool for conservation and restoration of habitats essential for genetic exchange. While many of the seasonal migratory corridors for mule deer and pronghorn are known, key areas for genetic exchange in these species are not. USGS scientists and collaborators at the University of Wyoming are building on the growing information base of movements by marked deer and pronghorn and preliminary genetic work for both species to increase the understanding of gene flow through migration corridors. Genetically "mapping" multiple species on a landscape can help identify where conservation actions can be most beneficial to many species or where conservation for a single species might be harmful to others. Results of this study can assist in making smart conservation planning actions, maximize conservation efforts, and reduce potential conservation conflicts based on single species habitat management.

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Sage-Grouse as an Umbrella Species for Nongame Species of Concern in Wyoming

A common assumption of conservation practitioners in the Western United States is that the greater sage-grouse is an umbrella species for other co-occurring wildlife. This idea, however, has not yet been empirically examined. In particular, the types of species for which sage-grouse may be an appropriate umbrella and at which spatial scales remain unclear. In Wyoming, USGS scientists are modeling overlap between suitable habitat for 52 nongame sagebrush species of conservation concern in lands managed under the Wyoming Governor's Core Area Strategy. Nongame bird abundance and reproductive success is being quantified across gradients in sage-grouse habitat quality, and before and after habitat treatments (mowing) designed to augment sage-grouse brood-rearing habitat. This research aims to inform land management that uses sage-grouse as an umbrella species and can help fine-tune other actions needed for species that are not covered under this approach.

Sage thrasher. Photograph by Steven Hanser, U.S. Geological Survey.

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Evaluating Biodiversity of Sagebrush-Dependent Species Within Sage-Grouse Habitat: An Example From the Wyoming Basins

Concern for declining greater sage-grouse populations has prompted an unprecedented effort by Federal, State, and private stakeholders to implement large-scale habitat management actions and identify priority areas for conservation. Given the dependency of this species on sagebrush-dominated habitat, it is likely that these sage-grouse conservation efforts could benefit other obligate sagebrush species and the ecosystems on which they depend. USGS and CSU scientists and partners are developing a modeling approach to evaluate the conservation benefits of sage-grouse to other species of conservation concern within the sagebrush biome. Across the greater Wyoming Basin's sagebrush landscape (Hanser and others, 2011), they are (1) identifying biodiversity hotspots for sagebrush obligate and associated vertebrate species of conservation concern, (2) evaluating the degree of overlap with sage-grouse priority habitats and conservation areas, and (3) evaluating the degree to which sage-grouse core areas in Wyoming capture vertebrate species biodiversity hotspots within the sagebrush biome.

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The Influence of Climatic Conditions on Reproduction of Sagebrush-Dependent Birds: Implications for Climate Vulnerability Assessments and Habitat Prioritization Efforts

Birds in aridlands of western North America are some of the fastest declining bird species, and they are among those expected to be most affected by changing climate. USGS researchers are evaluating the reproductive vital rates of sagebrush songbirds in relation to climatic variation by leveraging several large existing datasets of nesting observations from Montana and Wyoming, archived weather station data, and gridded climate datasets. To further examine whether particular landscapes and (or) microhabitats may confer more protection in the face of increasingly more extreme weather events expected with climate change, habitat data collected remotely and at nests will be incorporated into climatic response models. Novel field efforts have also been designed to assess whether microhabitats at nests buffer ambient conditions and the associated fitness consequences. This project can inform managers about songbird species that may be vulnerable to potential changes in climate.

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Brewer's sparrow nestlings. Photograph by Steven Hanser, U.S. Geological Survey.

Developing Regional and Local Decision Support Tools for Sagebrush and Grassland Ecosystems in Northeastern Wyoming

In and around the Thunder Basin National Grassland of northeastern Wyoming, USGS and CSU scientists and other partners are developing monitoring tools to be directly applied to inform on-the-ground conservation decision making. Using data collected by the Bird Conservancy of the Rockies through their Integrated Monitoring of Bird Conservation Regions program, the monitoring tools will be built using indices generated by combining abundance estimates of individual songbird species reliant on sagebrush or grassland habitat types. Initial focus is on developing regional monitoring tools that evaluate bird community responses to broader scale habitat attributes such as agricultural land configuration and energy development. These regional-scale tools can help provide the foundation for developing site-specific monitoring tools to directly evaluate the response of bird communities to conservation actions and agricultural practices implemented through conservation programs administered by local and nongovernmental organizations.

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Smart Energy Development in the Sagebrush Ecosystem

The USGS is developing science and decision support tools to inform policy and management decisions about various aspects of the energy development life cycle. This is particularly important with ongoing demands for limited natural resources, and the need to be cost effective and to make decisions at the broader landscape scale. USGS scientists are working with Federal, State, and industry partners to develop the natural resource knowledge, management tools, risk assessments, and scenario planning that will form the scientific foundation for managers to use to target areas of high resource potential and low environmental concern and inform effective development.

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Oil and gas development near the Wind River Mountains in Wyoming. Photograph from Bureau of Land Management.

Quantifying the Potential Effects of Energy Development on Wildlife and Ecosystem Services

Energy resources are critical for a prosperous and secure nation, and a clear understanding of the potential effects of energy resource extraction is necessary for managers planning efficient and minimally impactful extraction. USGS scientists are developing and applying probabilistic models to evaluate the potential effects of energy development on landscapes, wildlife, and ecosystem services, building from the geology-based USGS assessments of undiscovered petroleum resources. Ongoing projects include (1) the development of the R package energySim and applying the model to understand potential surface disturbance associated with fully extracting technically recoverable continuous petroleum resources across the United States and (2) using the energy footprint model to evaluate the effects of sage-grouse core area policy on landscape patterns and wildlife habitat and to understand potential changes in sediment erosion under alternative energy development scenarios.

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Publications

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Greater Sage-Grouse Responses to Changes in Climate and Future Energy Development in Wyoming

Landscape changes are anticipated from future oil and gas development, and precipitation and temperature changes are expected to impact future greater sage-grouse populations in southwestern Wyoming, yet little is known about the potential magnitudes of these effects. In southwestern Wyoming, USGS and CSU scientists and colleagues simulated sage-grouse responses to future landscape change, including modified habitat selection and behavioral responses, using a time series of expected oil and gas development and climate-induced vegetation changes. The results of this study indicate that multiple sources of incremental landscape change should be jointly considered to estimate a species ability to withstand change (see citation below). This research can help land managers assess the influence of management actions on future sage-grouse abundance, distribution, and trajectories and aid in prioritizing future research and land use planning.

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Publication

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Mechanisms Underlying Sagebrush-Obligate Songbird Responses to Natural Gas Development

Extraction for energy resources can have consequences for wildlife populations including sagebrush-obligate songbirds. USGS research initiated in 2008 demonstrated decreased sagebrush songbird (Brewer's sparrow, sagebrush sparrow, and sage thrasher) abundance and nesting success with surrounding habitat loss owing to natural gas development in western Wyoming. The predominant source of nest losses was predation, and subsequent video camera data revealed that the main nest predators were rodents (deer mice [*Peromyscus maniculatus*], chipmunks [*Tamias* spp.], and ground squirrels [*Spermophilus* spp.]). The abundance of most rodent species increased with natural gas development. Current research is focused on testing alternative hypotheses for the rodent distribution patterns. Understanding the mechanisms underlying wildlife responses to energy development and other forms of human-induced habitat change are critical to informing targeted and effective management regimes.

A male Brewer's sparrow singing from his sagebrush perch. Photograph from U.S. Geological Survey.

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Publications

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Bumblebees in the Sagebrush Ecosystem

Bumblebees pollinate a broad diversity of flowering plants in the sagebrush ecosystem and are considered keystone species. The Western bumblebee (*Bombus occidentalis*) has been declining in recent years and has been considered for listing under the Endangered Species Act. USGS scientists have assessed information gaps, including the identification of areas with very limited sampling, and developed a protocol and sample design to help address science needs. In addition, little is known about bumblebee communities relative to species richness of flowering plants, or which species are preferred by bumblebees. USGS scientists are currently using occupancy modeling and other approaches to assess these questions on BLM lands in eastern Montana and in South Dakota.

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Restoring Sandberg Bluegrass Communities To Protect Packard's Milkvetch Habitat and Reduce Fuel Loadings

Packard's milkvetch (*Astragalus packardiae*) is a very rare plant of the sagebrush steppe ecosystem that is only found in northeastern Payette County in southwestern Idaho. USGS researchers are teaming up with the BLM to help inform the restoration of Sandberg bluegrass (*Poa secunda*) and other native species in areas adjacent to Packard's milkvetch habitat. Restoring surrounding areas may help to ensure long-term viability of remaining Packard's milkvetch populations by supporting native pollinator habitat and reducing fuel loadings and associated fire risk. USGS scientists will collect and analyze data that can help the BLM determine restoration effects and success.

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Effects of Livestock Grazing on Greater Sage-Grouse

Cattle grazing may be the most common land use within sage-grouse habitat. The USGS is working with ranchers and university and agency collaborators to quantify the effects of cattle grazing on sage-grouse through a suite of replicated landscape-scale experiments. This research is evaluating the effects of different cattle grazing regimes on survival, site fidelity, habitat selection, chick diet, and reproductive traits of greater sage-grouse. The experimental study uses replicate study sites across Idaho that receive either no grazing, 30- to 40-percent grass offtake during spring only, or 30- to 40-percent grass offtake during spring and fall. Researchers are also measuring the effects of these grazing treatments on vegetation (sage-grouse habitat features), arthropod abundance, and abundance of other sagebrush steppe birds. This research can help inform land management decisions related to the amount and timing of grazing practices that are compatible with sage-grouse habitat needs.

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Livestock grazing in central Idaho. Photograph by Steven Hanser, U.S. Geological Survey.

Effects of Invasive Cheatgrass on Sage-Grouse in Nevada

Invasion of sagebrush shrublands by cheatgrass is one of the primary threats to greater sage-grouse in the Great Basin. The USGS has multiple ongoing studies throughout the Great Basin evaluating the effects of cheatgrass on greater sage-grouse habitat selection and population vital rates. Researchers have measured cheatgrass abundance and height at radio- and GPS-marked sage-grouse locations and at random available locations. In a collaborative effort, the USGS and others are incorporating these cheatgrass data in nest-site selection and nest-survival models for northwestern Nevada. Additionally, researchers are analyzing the effects of cheatgrass on selection and survival within the brood-rearing life phase in study areas across Nevada. This work can provide land managers with information about the relative effects of cheatgrass at multiple life stages, improving the ability to effectively target management and mitigation efforts.

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Publication

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Implications of Anthropogenic Activities on Greater Sage-Grouse Populations in Nevada

The USGS is conducting research on a broad geographical scale at multiple study sites to understand the long- and short-term effects of anthropogenic disturbance caused by wind turbines, gold mining, geothermal energy production, hydraulic fracturing for oil, and transmission line development on greater sage-grouse habitat selection, population vital rates, and movement patterns. This research can provide resource managers with information and tools needed to develop guidelines for projects that strive to minimize negative effects on greater sage-grouse.

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Effects of Pinyon and Juniper on Sage-Grouse Movement, Distribution, and Survival

Conifer expansion into sagebrush shrublands is a major threat to sage-grouse habitat. Information is needed to understand the mechanisms leading to the decline and extirpation of sage-grouse in areas of conifer expansion. USGS scientists are using telemetry from multiple field sites across Nevada and northeastern California collected over a 10-year period, coupled with high-resolution conifer maps, to investigate the influences of trees within sagebrush shrubland on sage-grouse distribution and survival. Results from these analyses indicate that encroachment of sparsely distributed conifers into wet, high-elevation productive habitats strongly selected by sage-grouse may be an ecological trap (see publications listed on following page). Increased predation facilitated by trees serving as perch or nest site subsidies for raptors and ravens may explain this finding; subsequent analyses will identify causes and consequences of ecological traps at different sage-grouse life-history phases in relation to pinyon and juniper. This research provides greater understanding of the risk of conifer encroachment into sagebrush habitat to sage-grouse and can help inform conifer removal projects.

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Publications

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Area mechanically treated to remove junipers in central Utah. Photograph by Steven Hanser, U.S. Geological Survey.

Predation Effects on Sage-Grouse Population Dynamics

Information about sage-grouse predation is incomplete. The USGS has initiated a large-scale investigation of predation effects and underlying ecological drivers of predation at sites located throughout California and Nevada. Through use of nest videography, avian predator surveys, habitat assessment, geospatial analysis, and telemetry- and GPS-based sage-grouse monitoring, USGS and Idaho State University scientists are evaluating how habitat composition, anthropogenic impacts, and other spatial and temporal processes influence nest predation rates, as well as age- and sex-specific survival rates, and the distribution of predators themselves. Results from these site-level studies help inform the development of sage-grouse management plans aimed at reducing predation impacts on sage-grouse populations.

Two common ravens in Nevada. Photograph by Tatiana Gettelman, U.S. Geological Survey.

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Publications

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., https://doi.org/10.1002/ecs2.1203.

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McIntire, S.E., Rabon, J.C., Coates, P.S., Ricca, M.A., and Johnson, T.N., in press, Greater sage-grouse chick depredated by Great Basin gopher snake: Western North American Naturalist.

Raven Density and Management Across the Great Basin

Resource managers in the Great Basin region have become increasingly concerned about the implications of increasing predation on sage-grouse nest success and seek to understand where ravens occur and why they occur in numbers high enough to be detrimental to sage-grouse. USGS scientists and collaborators are conducting research to inform adaptive management of raven abundance under the broader goal of reducing predator impacts on sage-grouse populations. Initial information products describe establishment of reproducible survey protocols for estimating raven densities in sage-grouse habitats and in sagebrush ecosystems within the broader Great Basin region of the southwestern United States. In a recent publication, scientists generated spatially explicit maps that integrated high raven occurrence based on anthropogenic subsidies with priority sage-grouse habitat across the Great Basin to help inform future management efforts to reduce predation impacts on sage-grouse populations.

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Publication

O'Neil, S.T., Coates, P.S., Brussee, B.E., Jackson, P.J., Howe, K.B., Moser, A.M., Foster, L.J., and Delehanty, D.J., 2018, Broad-scale occurrence of a subsidized avian predator—Reducing impacts of ravens on sage-grouse and other sensitive prey: Journal of Applied Ecology, v. 55, no. 6, p. 2641–2652, https://doi.org/10.1111/1365-2664.13249.

Effects of Raven Removal on Nest Survival and Population Growth Rates of Greater Sage-Grouse

Common raven (*Corvus corax*) populations are increasing drastically within sagebrush ecosystems, largely as a result of increased anthropogenic resources. Ravens are effective sage-grouse nest predators, and increased raven numbers have been shown to decrease sage-grouse nest survival. Wildlife and land management agencies have considered the removal of ravens as an option to increase sage-grouse productivity in many areas throughout the Western United States. However, the effects of raven removal on sage-grouse nest survival, productivity, and population growth rates are unclear. USGS scientists and collaborators are estimating the effects of raven removal on greater sage-grouse population dynamics using 8 to 10 years of telemetry data. This research will help gain better understanding of the effects of ravens on sage-grouse and inform future management efforts to reduce predation impacts on sage-grouse populations.

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A common raven in Nevada. Photograph by Tatiana Gettelman, U.S. Geological Survey.

Plant Community Composition and Vegetation Structure in Core Sage-Grouse Habitats

The composition and abundance of plant species in sagebrush ecosystems are important habitat attributes for sage-grouse; however, the combined effects of altered disturbance regimes (for example, fire) and biological invasions (for example, cheatgrass) are affecting plant community dynamics, and these effects are anticipated to accelerate with warmer climatic conditions. The goal of this project is to understand how these interacting change agents may influence plant community dynamics in core sage-grouse habitat areas. USGS scientists and university collaborators are integrating field measurements of plant community structure and soil conditions with ecological simulation models to assess the influence of changing climate and other disturbance regimes on the plant species composition and vegetation structure of sagebrush-dominated ecosystems. Outcomes of the project can help inform develop potential climate adaptation strategies.

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Publications

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Pennington, V.E., Schlaepfer, D.R., Beck, J.L., Bradford, J.B., Palmquist, K.A., and Lauenroth, W.K., 2016, Sagebrush, greater sage-grouse, and the occurrence and importance of forbs: Western North American Naturalist, v. 76, no. 3, p. 298–312, https://doi.org/10.3398/064.076.0307.

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Renne, R.R., Schalepfer, D.R., Palmquist, K.A., Bradford, J.B., Burke, I.C., and Lauenroth, W.K., 2019, Soil and stand characteristics explain patterns of shrub mortality following global change type-drought and extreme precipitation: Ecology, Accepted Article posted September 11, 2019, https://doi.org/10.1002/ecy.2889.

Encyclopedia of the World's Biomes—Sagebrush Steppe and Shrubland

A USGS scientist is writing a chapter titled "Sagebrush Steppe and Shrubland" for a forthcoming comprehensive encyclopedia of the world's biomes. The USGS will join other scientists and biogeographers around the globe to describe Earth's biomes—large areas with distinct terrestrial and aquatic features, natural communities, characteristic climates, and natural processes. The goal is to provide an up-to-date source that is comprehensive in scope across the globe. Each chapter will discuss issues such as biodiversity importance, anthropogenic stressors, impacts of changing climate, and conservation strategies.

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Weather and Climate

Long-term climate and short-term weather patterns influence vegetation patterns across the sagebrush ecosystem and can influence the outcomes of restoration actions. USGS scientists are conducting research to increase the understanding of variables that control soil moisture and drought, determine plant distribution and seeding success, inform development of climate adaptation strategies, and improve the collection of locally appropriate seeds for land use management activities.

Sagebrush steppe and approaching storm on Seedskadee National Wildlife Refuge in Wyoming. Photograph from U.S. Fish and Wildlife Service.

Mapping Projected Soil Temperature and Moisture Regimes in a Changing Climate

The current understanding of resistance of sagebrush ecosystems to invasion by exotic annual grasses and resilience to disturbance has led to maps of vulnerability using estimates of soil temperature and moisture conditions. USGS scientists are projecting those soil temperature and moisture conditions into the future to understand the potential implications of altered precipitation and temperature on sagebrush ecosystems. This project includes three tasks: (1) simulating soil moisture and soil temperature patterns under current conditions across the range of sagebrush (at approximately 10-kilometer resolution), (2) relating those simulations to the distribution of resistance and resilience classes to characterize simulated conditions within each class, and (3) simulating future soil moisture and temperature patterns under a suite of future scenarios to determine how the location of resistance and resilience classes shift in the middle and end of the 21st century.

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Publication

Bradford, J.B., Schlaepfer, D.S., Andrews, C.A., Palmquist, K.A., Lauenroth, W.K., Chambers, J.C., Maestas, J.D., and Campbell, S.B., in press, Shifting 21st century soil temperature and moisture regimes suggest opportunities to enhance dryland vulnerability assessments: Frontiers in Ecology and Evolution.

Soil-Climate Modeling To Improve Understanding of Pattern and Processes in Sagebrush Ecosystems: A Spatially Explicit Soil Classification

Resistance and resilience concepts provide an important framework for sagebrush habitat management. Existing spatial products have been developed using NRCS soil data; models using new data and methods can improve these products. USGS scientists are using information on soils, climate, solar radiation, and daily snowmelt to develop new continuous estimates of seasonal moisture balances and refined soil temperature and moisture regime estimates. Enhancements will account for temporal lags of water release, modified temperature, seasonal moisture budgets, and refinements of moisture-temperature regimes. These results will help provide enhanced understanding of historic and future conditions that may influence the distribution of invasive plants and invasion risk, the distribution and dynamics of sagebrush, and recovery rates. Model and data development have been completed in the initial pilot project area in southwestern Wyoming, and this effort is now being expanded across the entire sagebrush biome.

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Assessing Ecological Drought Risk in Restoration of Burned Sagebrush Steppe

The sagebrush ecosystem is one of the largest plant communities in North America and is rapidly being lost to wildfires. Postfire management strategies such as seedings and plantings, herbicide applications, and grazing represent one of the most significant conservation investments into western landscapes. USGS researchers are studying how ecological drought affects seeding or planting outcomes across a range of climate, topographic, and soil conditions. Using field and remote sensing data from historic postfire sagebrush seedings or plantings and weather information, the scientists are quantifying ecological drought in terms of how much less precipitation must be before vegetation recovery is affected. Results will be used to create a drought risk assessment module for the USGS Land Treatment Exploration Tool (described on p. 29). Additionally, a model will be developed to simulate the benefits of repeated seedings or plantings or those that are timed to hedge against drought. Results can assist managers during the treatment planning phase to evaluate potential drought impacts over current one-off postfire management practices. These outcomes will be important steps towards justifying and enabling adaptive management of burned areas.

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Assessing Vulnerability to Drought in Dryland Ecosystems of the Western United States

Managers of public lands in the Western United States face enormous challenges under recent warmer, drier conditions that are expected to worsen with climate change. This enhanced aridity can lead to permanent degradation of wildlife habitat and ecological services upon which humans depend. To help managers confront these challenges and inform possible future management scenarios meant to address altered temperature and precipitation regimes, USGS scientists have initiated a project that integrates plot- and remote sensing-based vegetation monitoring data collected by management agencies in the Western United States with climate and soil water conditions to determine which types of habitat are vulnerable to drought and climate change, what habitat changes may occur, and where across the landscape these changes will be most pronounced.

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Publication

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Assessing the Future of Sagebrush Ecosystems with Changing Precipitation and Temperature

Sagebrush directly acquires water from the soil, and patterns of available soil moisture that are altered by changes in precipitation and temperature may influence the health and distribution of sagebrush ecosystems. This project characterizes the ecohydrological conditions that support sagebrush ecosystems, identifies how those conditions could change in the future, and assesses the rangewide potential impacts for sage-grouse habitat. In collaboration with university scientists, USGS scientists are (1) quantifying how changes in precipitation and temperature may affect areas suitable to support sagebrush, (2) understanding the controls over sagebrush regeneration (a key limiting life stage for sagebrush), (3) describing uncertainty in species distribution models, and (4) improving the quality and usability of models that identify future suitable sagebrush extent. Outcomes of the project can help inform the development of potential climate adaptation strategies.

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Sagebrush. Photograph by Conservation Media, used with permission.

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Weather-Centric Rangeland Revegetation Planning

Rehabilitation and restoration of rangelands impacted by invasions of annual weeds are challenging because climate and weather variability affects seed germination, survival and establishment of seedlings, annual weed dynamics, wildfire frequency, and soil stability. In this collaboration, USDA Agricultural Research Service, USGS, and university partners are developing tools to inform revegetation efforts using site-specific weather information from historical observations, seasonal climate forecasts, and climate-change projections. Incorporating climate and weather information into rangeland revegetation planning could reduce management uncertainty, improve understanding of the ecological processes driving succession, and increase the efficiency of rehabilitation and restoration efforts. Seasonal climate forecasts and climate-change projections could improve the cost efficiency of management treatments and help managers develop mitigation and adaptation strategies for long-term practices.

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Rainbow on Steens Mountain in southeastern Oregon. Photograph by Steven Hanser, U.S. Geological Survey.

Response of Sagebrush Ecosystems to Precipitation Shifts

Rangelands store approximately 30 percent of the world's terrestrial carbon, yet it is unclear how changes in precipitation associated with changing climate will influence carbon storage capacity in these dry ecosystems. To investigate how rangelands will respond to altered precipitation patterns, USGS and university researchers have been investigating how changes in the amount and timing of precipitation affect litter decomposition and soil carbon stabilization in plots that received supplemental precipitation in either winter or summer. These experiments were conducted over a 21-year period in plots dominated by native sagebrush and crested wheatgrass (*Agropyron cristatum*), an introduced species that has become invasive. Results may inform predictions of how carbon storage in rangeland communities will be affected by the interaction of altered precipitation and conversion of diverse native communities to exotic grasslands.

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Late season snow in pinyon-juniper near Scipio, Utah. Photograph by Steven Hanser, U.S. Geological Survey.

Phenological Responses to Long-Term Environmental Drivers in the Northern Great Plains

Ecological response of vegetation over relatively short time periods (months to years) is often influenced by the broader spatial and temporal context; therefore, longer term analyses are needed to understand site response within typically measured time periods. In order to inform rangeland monitoring efforts on BLM-managed lands across Montana, North Dakota, and South Dakota, USGS scientists are examining variability of phenology and productivity to (1) define the frequency and variability in climate patterns; (2) compare climate drivers of productivity including temperature, precipitation, and vapor pressure deficit; (3) improve the understanding of ecological memory in the response of key phenological measures to climate drivers; and (4) use these processes to develop models of current productivity and ecological site potential based on climate and management scenarios. An understanding of these feedbacks and mechanisms can improve the assessment of management practices such as restoration, treatment, timing adjustments, and other actions employed to meet natural resource objectives.

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Tracking Drought-Induced Variability in Sagebrush Ecosystem Productivity

USGS scientists, in collaboration with WLCI partners, are investigating the recovery of sagebrush ecosystems after a recent, severe drought in the Upper Green River Basin, Wyoming. The scientists are using satellite data to characterize broad characteristics of growing season productivity and detect monthly anomalies associated with drought from a 17-year period (2000–16). They are investigating the timing and lags of seasonal temperature and moisture on vegetation condition and determining if reduction in productivity is mediated by local biophysical properties. Map products will identify the extent and severity of the disturbance, and highlight areas for plant community assessment. This approach can be used to assess the status and trends of sagebrush ecosystems over broad spatial and temporal scales and assess the recovery of sagebrush ecosystems exposed to multiple stressors and disturbance such as drought, energy development and management treatment.

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Sagebrush Ecosystem Research Funded by Climate Adaptation Science Centers

The USGS manages the network of Climate Adaptation Science Centers that provide funding for several of the USGS-led projects listed in this document, as well as supporting research by external partners (universities, nongovernmental organizations, and so forth). Research funding provided to external partners is helping address a variety of climate-related science needs with a focus on those identified in the “Integrated Rangeland Fire Management Strategy Actionable Science Plan” and related management-oriented science needs assessments. The North Central, Northwest, and Southwest Climate Adaptation Science Centers have and will continue to provide resources for supporting activities identified as high-priority needs by the major management entities. Additional information can be found at https://casc.usgs.gov/.

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Sage-grouse on a lek at sunrise. Photograph by Tatiana Gettelman, U.S. Geological Survey.

Sagebrush in the northern Columbia Basin. Photograph by Susan McIlroy, U.S. Geological Survey.

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