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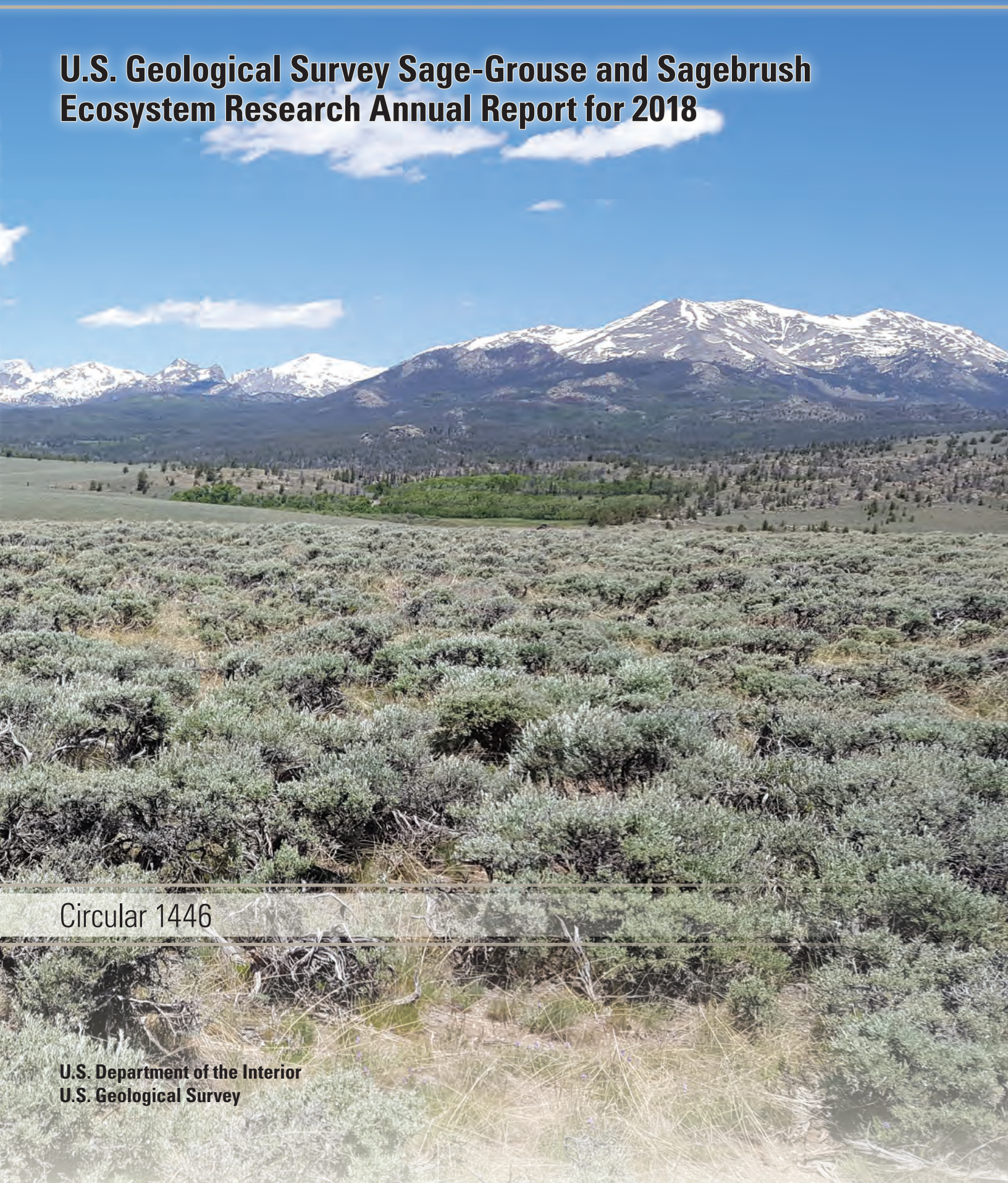
U.S. Geological Survey Sage-Grouse and Sagebrush Ecosystem Research Annual Report for 2018



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Cover. Sagebrush west of the Wind River Range in Wyoming. Photograph by Steven Hanser, U.S. Geological Survey.

U.S. Geological Survey Sage-Grouse and Sagebrush Ecosystem Research Annual Report for 2018

Edited by Steven E. Hanser

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

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U.S. Department of the Interior
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U.S. Department of the Interior
RYAN K. ZINKE, Secretary

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

U.S. Geological Survey, Reston, Virginia: 2018

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Greater sage-grouse displaying yellow air sacks. Photograph by Tatiana Gettelman, 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

BLM	Bureau of Land Management
CSU	Colorado State University
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
NGB	northern Great Basin
NRCS	Natural Resources Conservation Service
STM	state-and-transition model
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 Sage-Grouse and Sagebrush Ecosystem Research Annual Report for 2018

Edited by Steven E. Hanser

Research To Support the Management of Sage-Grouse and the Sagebrush Ecosystem

The sagebrush (*Artemisia* spp.) ecosystem extends across a large portion of the Western United States, and the greater sage-grouse (*Centrocercus urophasianus*) is one of the iconic species of this ecosystem. Greater sage-grouse populations occur in 11 States and are dependent on relatively large expanses of sagebrush-dominated habitat (fig. 1). Sage-grouse populations have been experiencing long-term declines owing to multiple stressors, including interactions among fire, exotic plant invasions, and human land uses, which have resulted in significant loss, fragmentation, and degradation of landscapes once dominated by sagebrush. In addition to the sage-grouse, over 350 species of plants and animals are dependent on the sagebrush ecosystem.

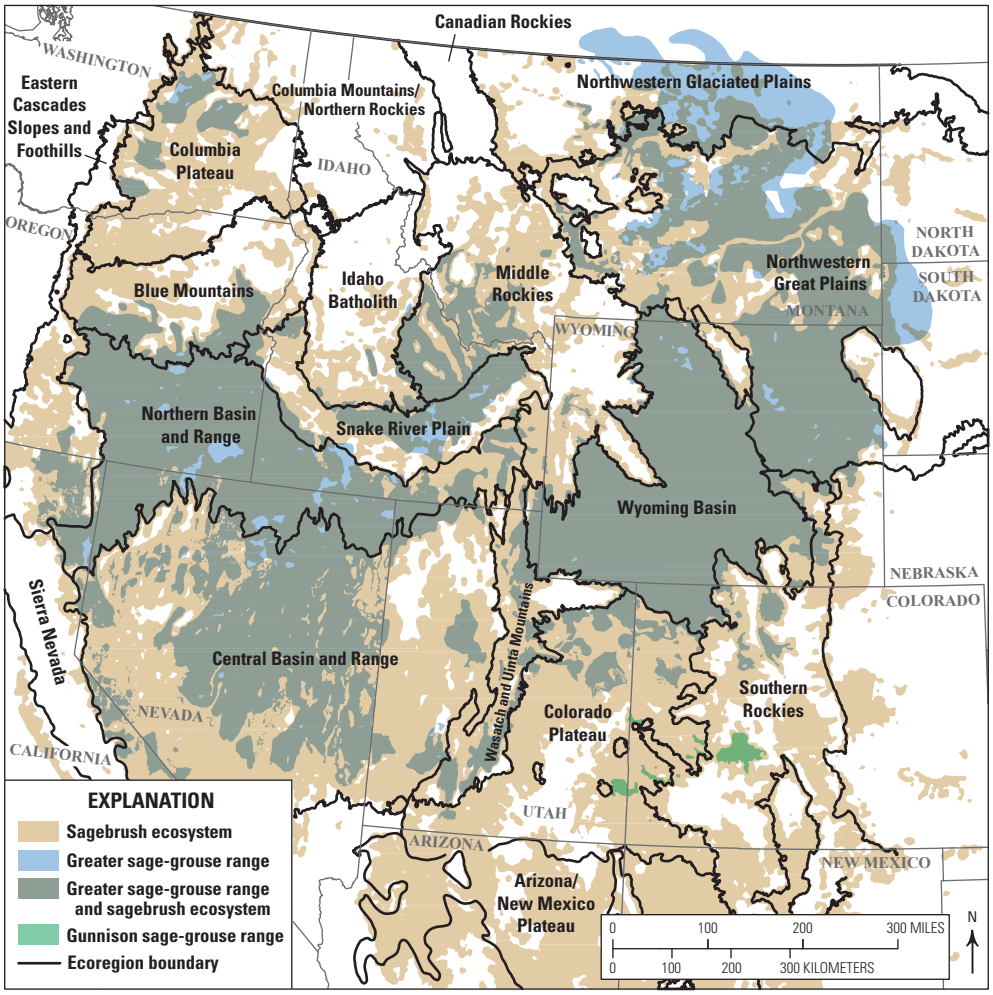

Figure 1. Location of the sagebrush ecosystem and distribution of greater and Gunnison sage-grouse in the Western United States. U.S. Environmental Protection Agency Level III ecoregions are labeled on the map. The Great Basin is composed of the Central Basin and Range, Northern Basin and Range, and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

Increasing knowledge about how these species and the sagebrush ecosystem respond to these stressors and to management actions can inform and improve strategies to maintain existing areas of intact sagebrush and restore degraded landscapes. The U.S. Geological Survey (USGS) has a broad research program focused on providing the science needed to inform these strategies and to help land and resource managers at the Federal, State, Tribal, and local levels as they work towards sustainable sage-grouse populations and restored landscapes for the broad range of uses critical to stakeholders in the Western United States.

USGS science has provided a foundation for major land and resource management decisions in the sagebrush ecosystem including actions that precluded the need to list the greater sage-grouse under the Endangered Species Act. 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 to help support local economies and the continued conservation, management, and restoration of the sagebrush ecosystem.

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 10 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.
- 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., 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). Research projects are organized into five thematic areas: fire; invasive species; restoration; sagebrush, sage-grouse, and other sagebrush-associated species; and weather and climate. Project descriptions included in this report are organized according to these themes.

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

Project Descriptions

These descriptions are overviews of projects that are ongoing or were active during 2018. 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 fire regimes in the sagebrush ecosystem, 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 U.S. Department of Agriculture (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. 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.

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Publication

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.

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

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 Bureau of Land Management (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 will help identify the important factors needed for the strategic placement of fuel breaks to suppress wildfire in sage-grouse habitats, and minimize negative impacts on populations.

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Evaluating Effects of Woody Fuels 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 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. USGS scientists and collaborators have completed 9 or more years of research on these sites and will be able to provide information on the long-term outcomes of these treatments.

Contact

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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., in press, Resilience and resistance in sagebrush ecosystems are associated with seasonal soil temperature and water availability: Ecosphere.

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 will develop scenarios of future invasion to assess impacts of potential future disturbances and use simulations to compare the effects of disturbance and invasion among current and future landscapes. This project will 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.

Quantifying Fuels and the Effects of Reduction Treatments in Sagebrush Habitats

Invasive annual plants create fine fuels that have increased wildfire frequency in the sagebrush habitats of the Great Basin. Land managers have invested considerable funding to decrease fuel loads, using techniques such as grazing, mowing, herbicides, and seeding with native and nonnative species. Yet, little information is available about how such restoration activities have influenced fuel loads. USGS scientists and university colleagues are developing a new approach to better quantify and predict fuel loads and the effects of fuel manipulations in sagebrush habitats. At study sites in southwestern Idaho, they are comparing the efficiency of commonly used restoration treatments and using remote sensing to estimate fuel loads and provide large-scale assessments of fuel conditions. The assessments will help land managers and fire scientists predict fire risk, assess effects of management activities on fuel loads and native species, and assess short- and long-range fire effects.

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Publications

Anderson, K.E., Glenn, N.F., Spaete, L.P., Shinneman, D.J., Pilliod, D.S., Arkle, R.S., McIlroy, S.K., and Derryberry, D.R., 2017, Methodological considerations of terrestrial laser scanning for vegetation monitoring in the sagebrush steppe: Environmental Monitoring and Assessment, v. 189, no. 11, article 578, 12 p., https://doi.org/10.1007/s10661-017-6300-0.

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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.

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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 will 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 the 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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Publication

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.

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 will 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.

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 sixth 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 will provide mangers with information regarding postfire management and help identify potential options for maintaining sage-grouse populations.

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Publication

Foster, L.J., Dugger, K.M., Hagen, C.A., and Budeau, D.A., in press, Acute effects of wildfire on greater sage-grouse vital rates: Journal of Wildlife Management.

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

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 fourth consecutive year, this ongoing study will increase ecological understanding of how sage-grouse respond demographically and spatially to wildfire and will help land managers better evaluate the efficacy of postfire actions designed to restore sagebrush habitat and ecosystem services.

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Response of Shrubland Birds to Prescribed-Fire and Mechanical Treatments

Prescribed fire and mechanical cutting are commonly used to reduce the cover of pinyon (*Pinus* spp.) or juniper (*Juniperus* spp.) and are thought to benefit sagebrush-dependent birds, particularly sage-grouse. As part of the SageSTEP project, USGS scientists studied yearly changes in the bird community after woodland reduction to measure how birds use the new vegetative structure and to evaluate the bird community response. Results 5 to 7 years posttreatment suggest that prescribed fire, as currently conducted in established woodland communities, is relatively ineffective in creating habitat for sagebrush-obligate birds. In addition, fires reduced existing sagebrush cover, further delaying the establishment of a desired sagebrush bird community. In contrast, mechanical treatments that removed all tree cover at locations adjacent to existing sagebrush landscape were effective in restoring sagebrush bird communities. However, bird communities at treated locations were not stable up to 7 years posttreatment and continue to diverge from the pretreatment community. As a result, managers may expect long-term response times when evaluating the effectiveness of treatments.

Contact

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Publications

Knick, S.T., Hanser, S.E., Grace, J.B., Hollenbeck, J.P., and Leu, M., 2017, Response of bird community structure to habitat management in piñon-juniper woodland-sagebrush ecotones: Forest Ecology and Management, v. 400, p. 256–268, https://doi.org/10.1016/j.foreco.2017.06.017.

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

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 by targeting remaining areas of intact sagebrush with high densities of breeding sage-grouse for fire suppression. 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.

Contact

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Publication

Coates, P.S., Ricca, M.A., Prochazka, B.G., Brooks, M.L., Doherty, K.E., Kroger, T., Blomberg, E.J., Hagen, C.A., and Casazza, M.L., 2016, Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems: Proceedings of the National Academy of Sciences, v. 113, no. 45, p. 12745–12750, https://doi.org/10.1073/pnas.1606898113.

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 management of 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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Vegetation Responses to Sagebrush-Reduction Treatments Measured by Satellites

Plant phenology and productivity are important habitat factors that influence resource use and migration of many wildlife species, but effects of sagebrush-reduction treatments on these vegetative characteristics are poorly understood. USGS scientists are comparing satellite-based metrics of vegetative cover, phenology, and productivity at sagebrush-dominated sites treated with fire, herbicide, and mechanical removals to paired, untreated sites. Results from this study will advance understanding of sagebrush recovery following disturbance and inform managers on the effectiveness of their actions.

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Use of Sagebrush-Reduction Treatments by Mule Deer in Wyoming

In southwestern Wyoming, sagebrush-reduction treatments are applied to improve habitat for mule deer (*Odocoileus hemionus*), but recent population declines have raised concern over habitat management and integrity of migration routes. Plant phenology and productivity influence deer migration and can be altered by changes in vegetative communities associated with sagebrush treatments. Mismatches in plant phenology between treated and untreated areas could result in disrupted migration routes or suboptimal foraging for ungulates. USGS scientists are evaluating the use of sagebrush-reduction treatments by deer tracked with satellite telemetry for several years in Wyoming. The objectives are to determine whether (1) deer use sagebrush treatments differently from surrounding areas, (2) sagebrush treatments disrupt migration routes or alter the use of winter range, and (3) effects vary with treatment type (for example, fire, herbicide, mechanical) and time since treatment. This study can provide wildlife managers with information regarding potential effects of sagebrush reduction treatment on this important game species.

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

Pollinator Use of Forbs in the Soda Wildfire Area

Pollinating insects are in serious decline across the United States, affecting native plants. In a new study, USGS scientists will examine 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 will compare pollinators in seeded burned areas to unburned areas outside the Soda Wildfire. Researchers will also compare 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.

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

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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 respond 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 disturbances of mixed severity and overlap. Identifying the factors leading to increased sagebrush community resistance and resilience can help mangers prioritize actions and identify sound management options.

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Controlled burn at Hart Mountain National Wildlife Refuge, Oregon. 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. With recent analytical developments, researchers can annually produce 250-meter-resolution cheatgrass distribution maps by late May for the 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 will help inform local-scale research and management efforts.

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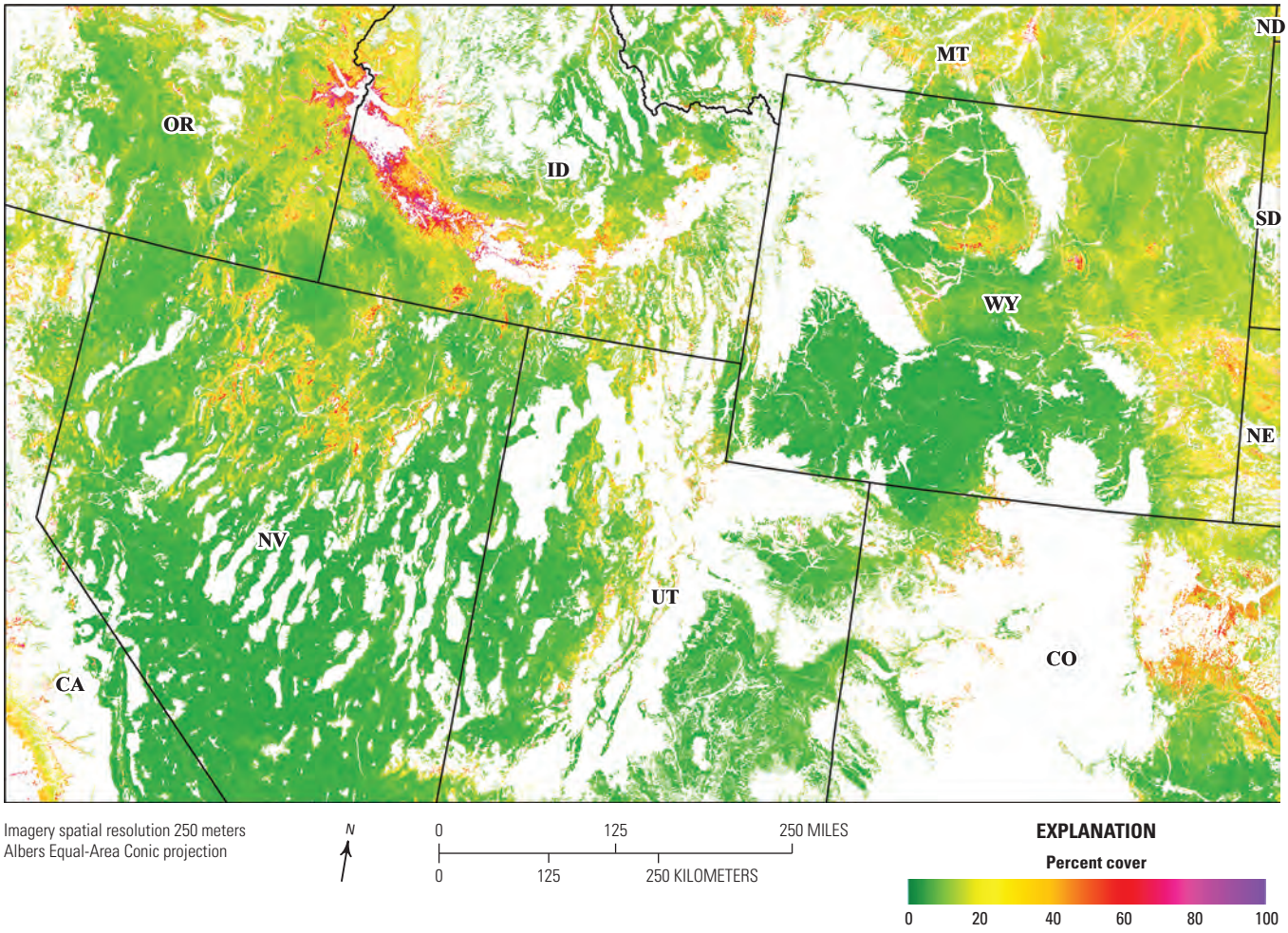

Distribution of cheatgrass and other annual herbaceous plants in 2018.

Cheatgrass Dynamics in the Northern Great Basin

Remote sensing technologies are used to effectively monitor terrestrial vegetation globally, including cheatgrass in the northern Great Basin (NGB). Future climate scenarios forecast that the NGB will experience increased temperatures and altered timing and total amount of precipitation, changes which will alter cheatgrass dynamics. Using near-real-time cheatgrass mapping products, USGS scientists are examining the potential climate-mediated changes in future cheatgrass dynamics. Future cheatgrass percent cover may be influenced by multiple mitigating factors including changes in precipitation timing and totals and freeze-thaw cycles. Understanding the effects of these factors can help direct land management activities meant to improve control of cheatgrass.

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

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 tool to help management agencies prioritize regional-scale management actions while maximizing conservation effectiveness. A strategic approach was developed for conservation and restoration of sagebrush ecosystems and sage-grouse that focuses specifically on habitat threats caused by invasive annual grasses and altered fire regimes. The tool uses 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 help develop management strategies at both landscape and site scales. The tool, 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.

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Publications

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

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 will inform management by providing a nuanced spatial perspective on invasion risk for current and potential invaders.

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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.

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

Use of Cheatgrass-Suppressive Bacteria To Restore Sagebrush Steppe

There are multiple reasons for using successful WSB that attack invasive annual grasses (particularly cheatgrass) of the Western United States and leave native perennial plants intact. USGS scientists and colleagues are using WSB (*Pseudomonas fluorescens*, strain D7) in two case studies at the Hanford Reach National Monument to examine these potential uses. WSB could be applied proactively to remaining sagebrush habitats that also have cheatgrass to "stop the bleeding," increasing resistance to further invasion while retaining existing native sagebrush steppe plant communities. WSB could be applied to sagebrush understories, reducing cheatgrass fuel loads, which would reduce fire risk and rate of spread. Finally, 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. This could be done without the negative impacts to native plants that have been observed with the use of herbicides.

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

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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Restoration

Restoration of sagebrush habitats following stressors, including wildfire, invasive species, and numerous disturbance types, is important for maintaining the sagebrush ecosystem. 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) quantifying the success of sage-grouse using revegetated habitat. This research will identify testable "ideal" sagebrush restoration approaches, experimenting with patch size, configuration, and proximity to edge of burn. This research will evaluate sagebrush restoration approaches, and predict times to sagebrush and sage-grouse recovery.

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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 these 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 and are at risk of being dominated by annual grasses after the next 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 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 will 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 U.S. Fish and Wildlife Service (FWS) to examine the factors that contribute to establishment of big sagebrush across the range of the 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 will inform site-level management activities and explore 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 will 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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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 well pads using time-varying remote sensing products developed for the Wyoming Landscape Conservation Initiative (WLCI) 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 approach 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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Improving Sagebrush Ecosystem Resistance and Resilience To Inform Conservation

Resistance and resilience concepts provide an important framework for sagebrush habitat management. Existing spatial products have been developed using Natural Resources Conservation Service (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 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.

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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.

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

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 Decision Support Tool

The LTDL houses information on nearly 40,000 land treatments in the Western United States. The BLM and the USGS are developing a decision support and planning 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 an area or that share similar characteristics, such as treatment types, ecological sites, seed mixes, or other factors. When queried, the tool will return 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 will aid in planning future land treatments and implementing adaptive management strategies for improved likelihood of success for future treatments.

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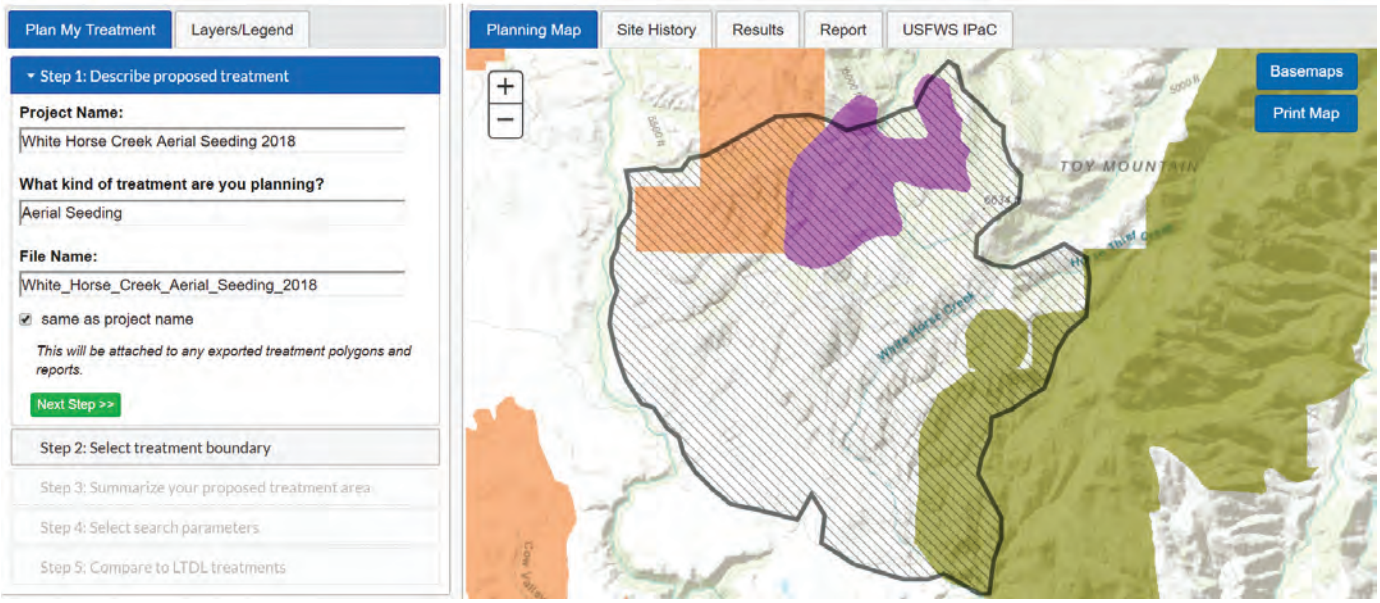

Example of the interactive map interface in the land treatment planning tool.

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 NRCS, and many private rangeland consultants.

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Publications

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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 will help managers determine how treatments can be best phased to optimize postfire restoration outcomes.

Postfire sagebrush seeding. Photograph from Bureau of Land Management.

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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 sites 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 are desired by 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 Steppe

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 steppe and some of the potential factors influencing the absence of crusts across sagebrush ecosystems. 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. The resulting information will show how crusts respond to disturbances and the ecological factors that influence these important biological communities.

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

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Publications

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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 often 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 land owners throughout the Great Basin in their efforts to protect soils while restoring plants.

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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 are developing a core set of data, models, and a web-based geospatial tool that provides an analytical backbone to support planning needs in the sagebrush biome. Initial efforts focus on making 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. Key functions of the web tools include (1) spatial data discovery and exploration; (2) summarization and reporting of data by predefined geographic units at different scales; and (3) summarization, reporting, clipping, and downloading 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.

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

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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 working to design an online seed warehouse tracking database to store information about individual seed bags. The database will 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 will provide insight on seed quality and treatment effectiveness.

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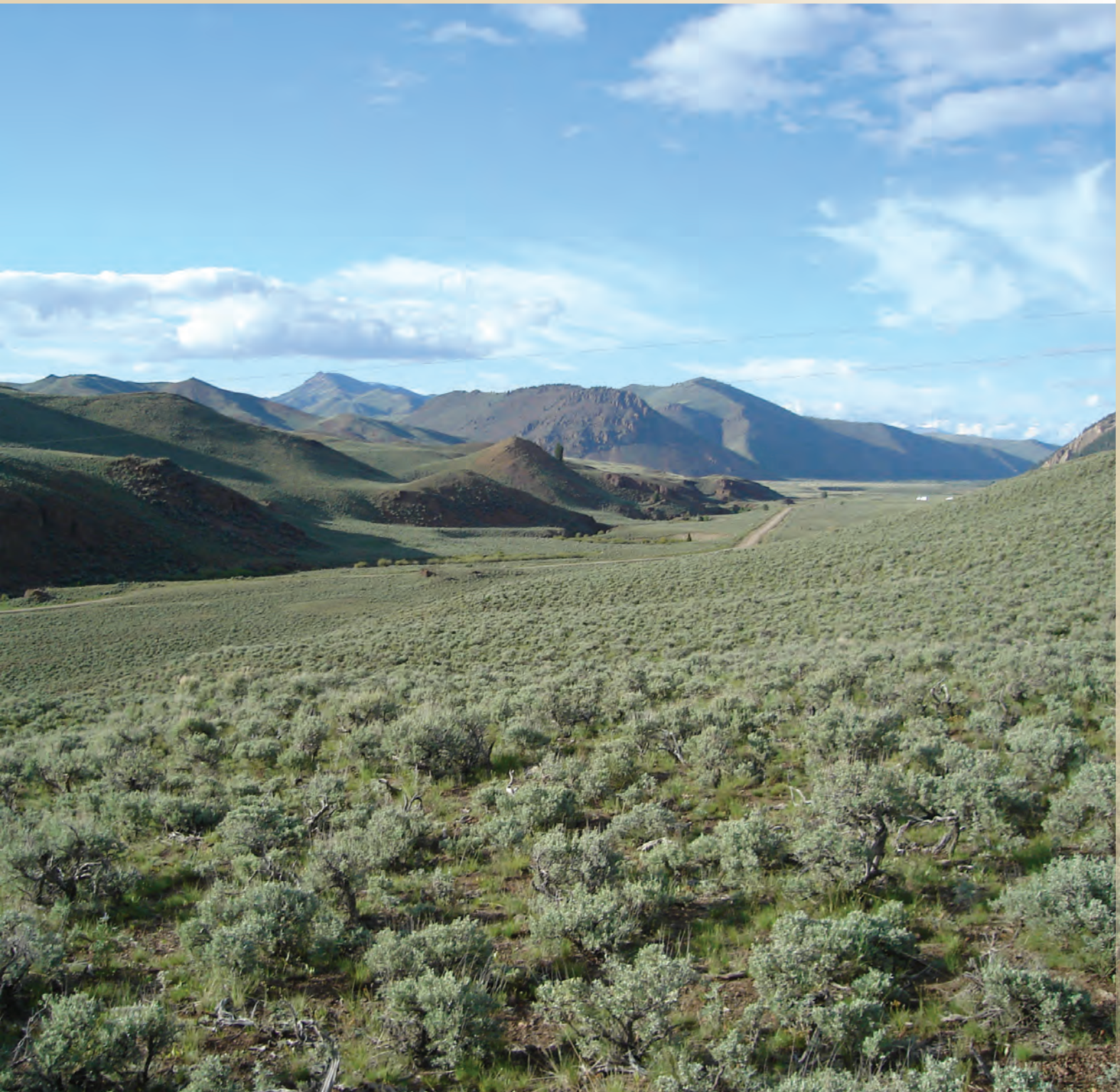
FWS biologists collect sagebrush seeds in Wyoming. Photograph from U.S. Fish and Wildlife Service.

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

Efforts to maintain and improve conditions for sage-grouse depend on understanding the behavior, habitat use, and population structure of the species. Additionally, holistically understanding the dynamics within the sagebrush ecosystem can help land managers apply strategies to maintain the ecosystem and the plants and wildlife that depend on it. USGS scientists are conducting research to inform management of the sage-grouse and the sagebrush ecosystem, including development of sage-grouse monitoring and population analysis tools, maps of sagebrush ecosystem components, and improved ecological understanding of sagebrush-associated species.

Sagebrush in central Idaho. 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 have reviewed and summarized the scientific literature published from January 1, 2015, through January 6, 2018. USGS scientists conducted a structured search of reference databases for research or scientific review articles in peer-reviewed journals or formal government technical reports, and retaining only those products for which sage-grouse or their habitat was a research focus. Each product was summarized and assessed for relevance to a list of 31 management topics that included 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.

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Publication

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Greater Sage-Grouse Science (2015–17): Synthesis and Potential Management Implications

The USGS led an interagency team of Federal and State agency biologists to develop a report that synthesizes the scientific literature published since records of decision were completed for the 2015 BLM and USDA Forest Service land use plan amendments for greater sage-grouse and provides potential management implications of the science. The interagency team identified six primary topic areas for the report: (1) multiscale habitat suitability and mapping tools, (2) discrete anthropogenic activities, (3) diffuse activities, (4) fire and invasive species, (5) restoration effectiveness, and (6) population estimation and genetics. The team then reviewed all material in the "Annotated Bibliography of Scientific Research on Sage-Grouse Published Since January 2015" (Carter and others, 2018) to identify the science that addressed each topic, discussed the science related to each topic, evaluated the consistency of the science with existing knowledge prior to 2015, and summarized the potential management implications of this science.

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Publication

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

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 will 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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Publication

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.

Multiscale Statewide Wyoming Greater Sage-Grouse Trends Determined by Population Viability Analysis

In Wyoming, USGS and CSU scientists are using population viability analysis to determine the rate of population change statewide and at multiple spatial scales within nested clusters of leks and across existing management units. This approach can identify clusters that are out of sync with surrounding populations and help identify the influence of local trends on larger scale population trajectories. This can provide new insight into management decisions that may help conserve populations across broad landscapes.

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Publication

Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., and Monroe, A.P, 2018, Greater sage-grouse population trends across Wyoming: The Journal of Wildlife Management, v. 82, no. 2, p. 397–412, https://doi.org/10.1002/jwmg.21386.

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

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 will 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.

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Publication

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.

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

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. 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 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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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.

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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 very high frequency (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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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 soils 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 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 will provide powerful tools for conservation planning for a variety of management actions including fuels treatments, grazing permit renewal, sage-grouse habitat management, and postfire rehabilitation.

USGS wildlife biologist surveying vegetation near Parker Mountain in Utah. Photograph by Steven Hanser, U.S. Geological Survey.

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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 in northwestern Colorado and by evaluating the effectiveness of sage-grouse as an umbrella species. This effort will 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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Prioritizing Habitats for Dynamic Populations Using a Spatially Explicit Population Approach for Greater Sage-Grouse in Wyoming

Although the use of resource selection models to identify and prioritize habitat for conservation is increasingly common, their success with characterizing important long-term habitats for fluctuating populations and seasonally dynamic habitat needs is variable. To examine how habitats might be prioritized differently if resource selection was directly and dynamically linked with population fluctuations and movement limitations among seasonal habitats, USGS and university scientists constructed a spatially explicit individual-based model for greater sage-grouse across Wyoming. This approach integrates seasonal habitat selection with designated management core areas, demographic and lek data, movement behavior, and West Nile virus outbreaks. Spatial simulation modeling may provide an informative means of predicting long-term habitat use for sage-grouse, indicating habitats that are likely to be valuable for sage-grouse persistence in the future, thus providing land managers with habitat conservation targets. Such approaches can provide land managers with the tools to create nuanced and longer term habitat prioritizations to support sage-grouse populations across broad space, time, and population fluctuations.

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Publication

Heinrichs, J.A., Aldridge, C.L., O'Donnell, M.S., and Schumaker, N.H., 2017, Using dynamic population simulations to extend resource selection analyses and prioritize habitats for conservation: Ecological Modelling, v. 359, p. 449–459, https://doi.org/10.1016/j.ecolmodel.2017.05.017.

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 shrub-map products, and other resource-condition data. The researchers are producing maps for breeding, nesting, brood-rearing, and summer habitat. This first iteration of model development will be useful for identifying opportunities and limitations when using site-level habitat characteristics to develop landscape-level map products.

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

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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 will form the basis for 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 described above, the second synthesis will culminate in an easy-to-follow management guideline handbook specifically focused on the Great Basin. The study includes an evaluation of existing macrohabitat and microhabitat objectives across life-history stages and will use a multiyear dataset of VHF and GPS telemetry data and microhabitat measures collected across more than 12 sites in the Great Basin. This study 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, is producing a remote sensing-based characterization of shrublands in the Western United States, with sagebrush lands being the priority. This work will provide 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. Products will be integrated into the National Land Cover Database for future updating on a regular 5-year cycle, and current products are available at https://www.mrlc.gov/nlcdshrub.php.

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Publication

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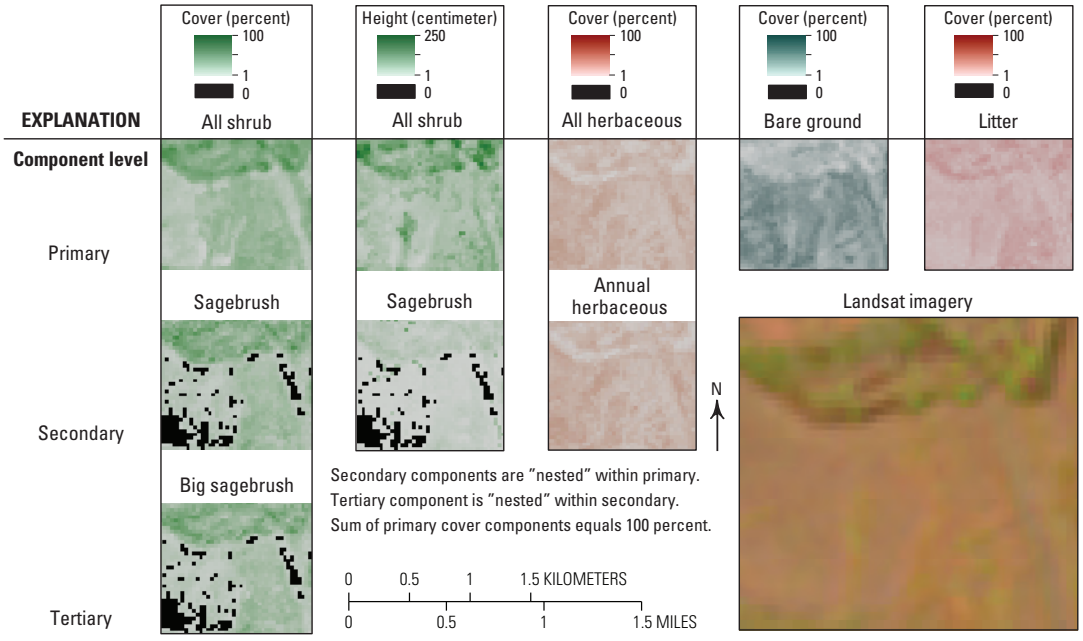

Mapped shrubland components, sorted by their hierarchical level. Component groups are contained by black boxes. For example, within the all shrub primary component group, sagebrush is secondary, and big sagebrush is tertiary. So big sagebrush cover and extent is never greater than sagebrush. Similarly, 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) provides an opportunity to map vegetation component change back in time, from 1984 through 2016. Products that describe change over time support research in sage-grouse habitat and population dynamics, restoration success, future climate change forecasting and trend analysis, 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 huge amounts of data. This approach allows unprecedented comprehensive analysis of shrub and grass change across time. Data for the Great Basin and Wyoming are now being processed. Once the historical analysis is completed, future imagery can be easily added to monitor changing conditions into the future. New areas are planned to be completed as funding becomes available.

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Publications

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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.

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Publication

Barker, B.S., Pilliod, D.S., Welty, J.L., Arkle, R.S., Karl, M.G., and Toevs, G.R., 2018, An introduction and practical guide to use of the Soil-Vegetation Inventory Method (SVIM) data: Rangeland Ecology & Management, Corrected Proof posted August 6, 2018, 10 p., https://doi.org/10.1016/j.rama.2018.06.003.

Mapping Conifer 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 at 1-meter resolution across Nevada and northeastern California. This analysis uses specialized image recognition software to develop usable geographic information system (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 will 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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Comparison of Techniques in Mapping Conifers

Accurate mapping of pinyon and juniper trees is important for planning the location of treatments. Despite multiple techniques in mapping conifers and developing coverages for a GIS, limited research is available that addresses the advantages and disadvantages to the most common techniques. The USGS is comparing two of the most used mapping techniques—spatial wavelet analysis and image recognition feature analysis—to help improve existing mapping efforts and spatial data layers for use in the planning process. This comparison will help management and conservation agencies develop and update coverages of conifers for sage-grouse and sagebrush ecosystem conservation planning.

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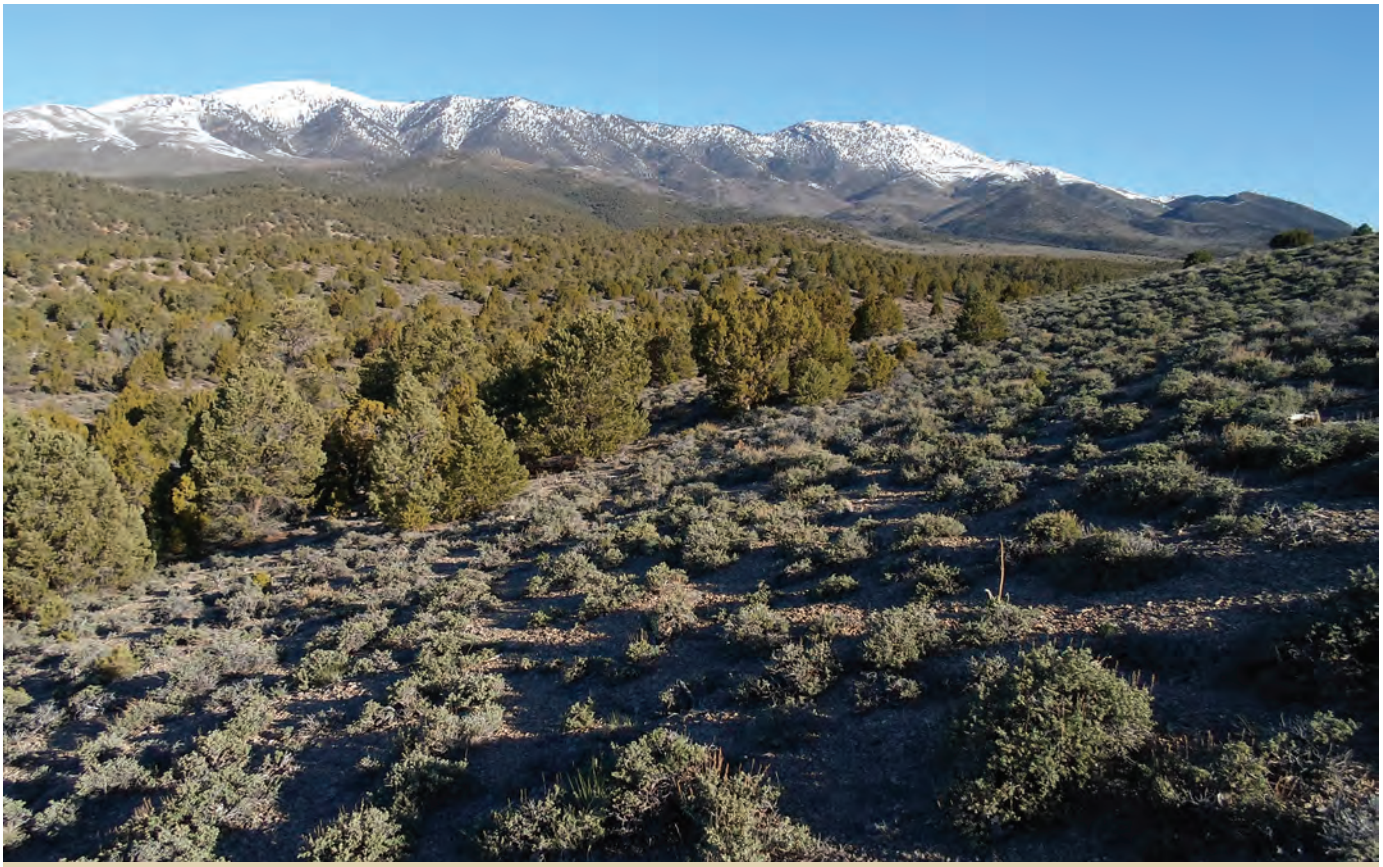

Conifer woodland and sagebrush on Spruce Mountain in Nevada. Photograph by Steven Hanser, U.S. Geological Survey.

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 assess the 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.

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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 each year from 2000 to 2016. 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 will 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.

Healthy sagebrush in Wyoming. Photograph by Theo Stein, U.S. Fish and Wildlife Service.

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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 are using genetic information contained in sage-grouse feathers collected at leks to delineate the rangewide network of breeding populations. The genetic data are being 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 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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Publications

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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 (*Centrocercus minimus*) 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. They found pronounced intraspecific population structure and highlighted differentiation of a small isolated population of greater sage-grouse in the northwest portion of the range. Patterns of genome-wide differentiation were largely consistent with limited gene flow among populations. Inferred ancient population demography suggested persistent declines in effective population sizes that have likely contributed to differentiation within and among species. Several genomic regions that did exhibit extreme population differentiation were associated with candidate genes linked to metabolism of xenobiotic compounds. In vitro activity of enzymes isolated from sage-grouse livers supported 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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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. USGS scientists are investigating changes in genetic diversity, genetic differentiation, and whether translocated individuals are reproducing by characterizing genetic samples collected before and after translocations. 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 various areas with a diversity of habitat and local environmental characteristics. With limited gene flow between populations and the 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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A pair of Gunnison sage-grouse. Photograph from U.S. Fish and Wildlife Service.

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.

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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 a primary reason 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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Publication

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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 supporting the FWS, along with Colorado Parks and Wildlife, as they develop habitat selection models for Gunnison sage-grouse throughout Colorado. Researchers are also supporting 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 evaluate the relative efficacy of alternative conservation actions.

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Sagebrush in Great Basin National Park in Nevada. Photograph by Steven Hanser, U.S. Geological Survey.

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 that provides a step-by-step analysis to map 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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Mule deer in Wyoming. Photograph by Matthew Kauffman, U.S. Geological Survey.

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Interactions of Phenology, Grazing, Hunting, and Prescribed Fire on Elk 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 will inform future management of this important game species.

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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.

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Publications

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

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 using 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 will 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 will 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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Fire-Cheatgrass Cycle Effects on Sagebrush Ecosystem Engineers

Burrowing mammals, such as American badgers (*Taxidea taxus*) and Piute ground squirrels (*Urocitellus mollis*), modify soil properties through digging and provide subterranean habitat for other species. USGS and university scientists evaluated how fire, cheatgrass, and other environmental factors influence the occupancy and abundance of these ecosystem engineers within a sagebrush ecosystem. Squirrel abundance was negatively associated with cheatgrass, fire frequency, and shrub cover—characteristics influenced by the fire-cheatgrass cycle. Badgers occupied areas where ground squirrels were present, as they are important badger prey. This study highlights how the fire-cheatgrass cycle influences a predator-prey system by directly affecting prey and by indirectly affecting predators. Land management strategies, such as establishing native bunchgrasses after wildfire, may benefit burrowing prey species and help preserve the trophic functions they provide.

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Ground squirrel following the Soda Wildfire. Photograph by Justin Welty, U.S. Geological Survey.

Influence of Harvester Ants in Burned Areas Invaded by Exotic Annual Grasses

Sagebrush ecosystems are experiencing vegetation-state changes because of fire and invasion by exotic annual grasses. Harvester ants (*Pogonomyrmex* and *Messor* spp.) modify their habitat by consuming seeds, removing vegetation, and altering soil properties and nutrients. To study the effects of the changes affecting the sagebrush ecosystems on harvester ants, USGS and university scientists sampled sites across the northern Great Basin where shrublands were replaced by grasslands after fire. Results suggest that harvester ants can increase habitat heterogeneity and create "islands of influence" within sagebrush shrublands, even after fire and invasion by nonnative grasses, and that harvester ants may be one of the few winners among a myriad of losers linked to vegetation-state changes within sagebrush ecosystems.

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Harvester ant mound in Utah. Photograph by Steven Hanser, U.S. Geological Survey.

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 needed 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 Range in Wyoming. Photograph from Bureau of Land Management.

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. Findings showed that most abandoned oil and gas pads in the study were characterized by more bare ground and less vegetation than surrounding undisturbed areas, even more than 9 years after well abandonment. Differing recovery rates across environmental gradients and land stewardship suggest that these findings can be useful for identifying conditions that may promote or hamper pad recovery.

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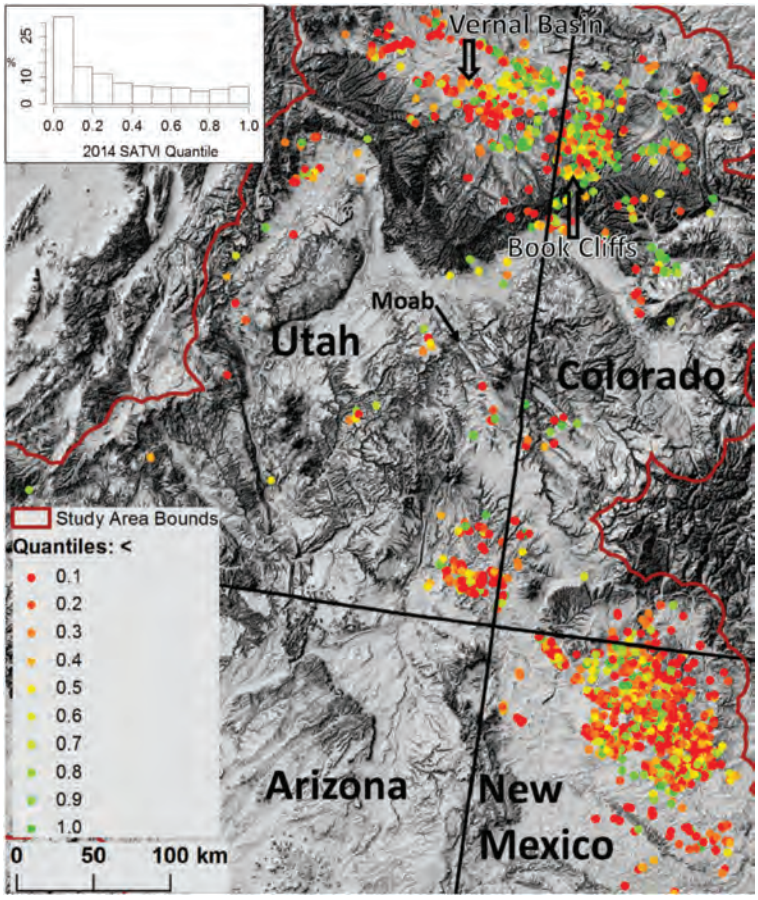

Photograph by Alan M. Cressler, U.S. Geological Survey.

Left: Map showing 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). Right: Photograph of shut in gas well on Bureau of Land Management lands in Grand County, Utah.

Using Long-Term Remote Sensing and an Automated Reference Toolset To Estimate and Predict Post-Development 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 previous project) is currently developed in the WLCI study area, scientists will identify suitable reference sites near well pads and then characterize vegetation and bare ground cover at reference and disturbed sites at 2- to 5-year intervals from 1985 to 2015. These data will enable modeling to determine how recovery potential changes over time according to differences in soils, weather, and well pad characteristics. This information and resulting spatial data can help inform future development and planning processes.

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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 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 Precipitation and Temperature and Future Energy Development in Wyoming

Landscape changes in the form of 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 are simulating sage-grouse responses to future landscape change, including modified habitat selection and behavioral responses, using a time series of planned oil and gas development and climate-induced vegetation changes. The results of this study 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 [*Spizella breweri*], sagebrush sparrow [*Artemisiospiza nevadensis*], and sage thrasher [*Oreoscoptes montanus*]) 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 24-hour infrared 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.

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Publications

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

Pygmy Rabbit Distribution and Abundance Relative to Ongoing Energy Development in Wyoming

Pygmy rabbits (*Brachylagus idahoensis*) rely year-round on sagebrush for both food and cover and are sensitive to oil and gas development. They are a species of conservation concern in several States and have been petitioned for listing under the Endangered Species Act across their range. In Wyoming, USGS scientists are investigating the influence of oil and gas development on pygmy rabbit populations. This research will help determine the distribution of pygmy rabbit habitat relative to ongoing oil and gas well development and how far from the nearest well pad, road, or pipelines pygmy rabbit presence and abundance may be affected. This information can help inform the development of future oil and gas fields and reduce the effects of disturbance on pygmy rabbits and other sagebrush obligate wildlife. The scientists anticipate expanding this work to other states where pygmy rabbits and energy development co-occur to help future energy development and efforts to manage this sagebrush-obligate species.

USGS biologist holds a juvenile pygmy rabbit. Photograph from U.S. Geological Survey.

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Publications

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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 will inform land management decisions related to the amount and timing of grazing practices that are compatible with sage-grouse habitat needs.

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

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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 will 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. 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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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 develop sage-grouse management plans aimed at reducing predation impacts on sage-grouse populations.

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Publications

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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

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

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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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 will help inform potential climate adaptation strategies.

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Publications

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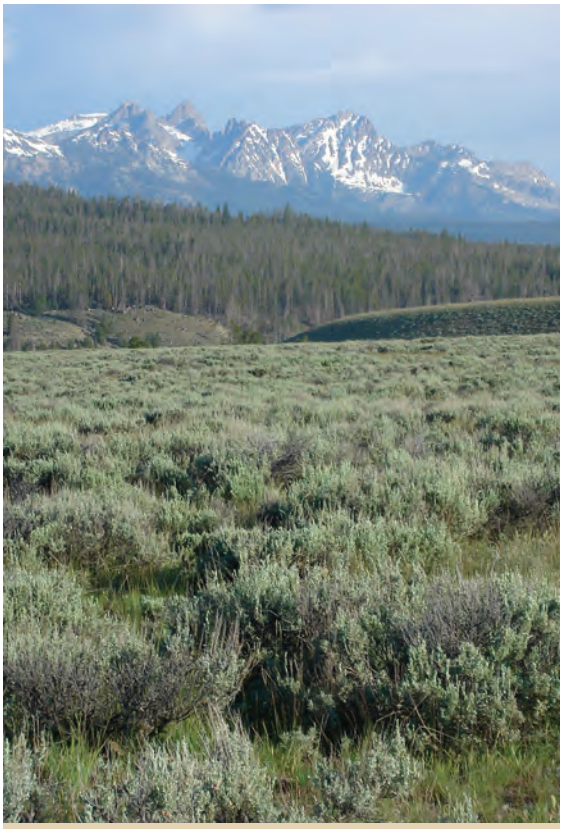

Sagebrush in the Sawtooth Valley, Idaho. Photograph by Steven Hanser, U.S. Geological Survey.

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 seeding success, inform development of climate adaptation strategies, and improve the collection of locally appropriate seeds for use land management activities.

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

Postfire Wind Erosion and Integration of Weather Prediction Tools

Postfire soil stability is a major issue for restoration and rehabilitation of big sagebrush habitat owning to variability in weather patterns and potential for wind erosion of exposed soils. The USGS is performing field measurements and simulations to help determine where, when, and why wind and water erosion occurs. This will help managers assess landscape suitability for seeding and will be important for climate vulnerability assessments that use information from advanced weather prediction tools to inform future land treatment implementation.

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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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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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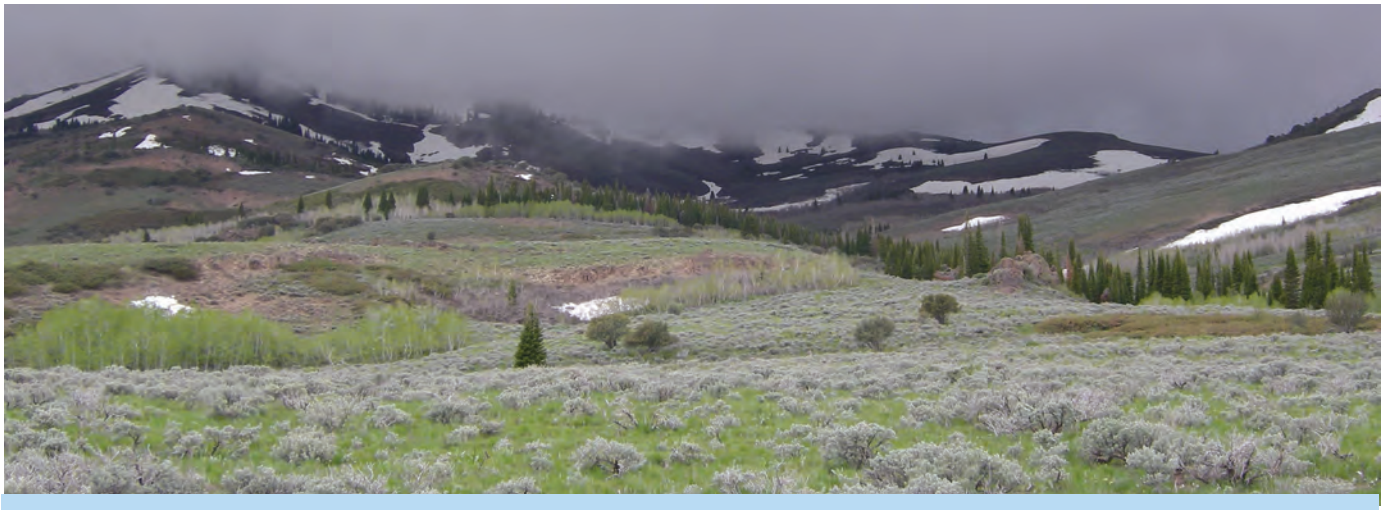

Storm brewing in mountain big sagebrush. Photograph from U.S. Fish and Wildlife Service.

Assessing the Future of Sagebrush Ecosystems

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 will help inform develop potential climate adaptation strategies.

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Sagebrush. Photograph from Conservation Media, used with permission.

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 develop mitigation and adaptation strategies for long-term practices.

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Understanding Changes in Sagebrush Distribution and Abundance Under Climate Change: Integration of Spatial, Temporal, and Mechanistic Models

A collaborative research team led by several academic institutions, in partnership with the USGS and CSU, used multiple modeling approaches to evaluate climate change impacts on sagebrush, the dominant plant species on roughly 110 million acres in the Western United States, and a key resource for many endemic wildlife species like sage-grouse. Performance, as measured by change in cover, growth, or recruitment, was predicted to decrease at the warmest sites but increase throughout the cooler portions of sagebrush's range. A sensitivity analysis indicated that sagebrush performance responds more strongly to changes in temperature than precipitation. Most of the uncertainty in model predictions reflected variation among the ecological models, raising questions about the reliability of forecasts based on a single modeling approach. Results of this study highlight the value of a multimodel approach in forecasting climate change impacts and uncertainties and should help land managers to maximize the value of conservation investments.

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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 climate and management scenarios. An understanding of these feedbacks and mechanisms will 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 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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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 central Montana. Photograph by Steven Hanser, U.S. Geological Survey.

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