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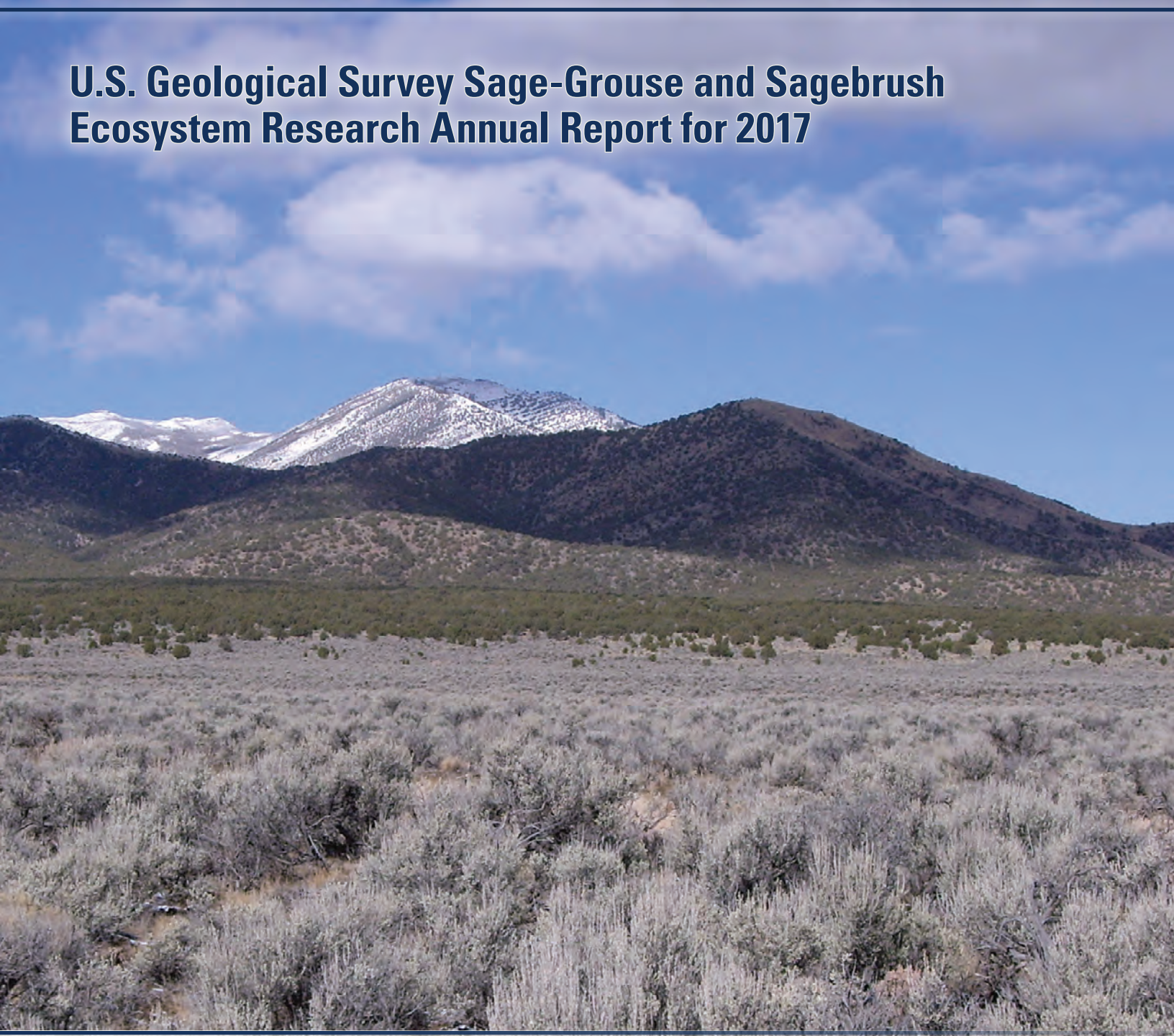
U.S. Geological Survey Sage-Grouse and Sagebrush Ecosystem Research Annual Report for 2017



Circular 1436

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

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

U.S. Geological Survey Sage-Grouse and Sagebrush Ecosystem Research Annual Report for 2017

Edited by Steven E. Hanser

Male greater sage-grouse. Photograph by Matt T. Lee.

Circular 1436

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

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

U.S. Geological Survey
William H. Werkheiser, Acting Director

U.S. Geological Survey, Reston, Virginia: 2017

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Suggested citation:
Hanser, S.E., ed., 2017, U.S. Geological Survey sage-grouse and sagebrush ecosystem research annual report for 2017: U.S. Geological Survey Circular 1436, 54 p., https://doi.org/10.3133/cir1436.

ISSN 1067-084X (print)
ISSN 2330-5703 (online)

ISBN 978-1-4113-4168-5

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Female greater sage-grouse on nest in sagebrush. Photograph from 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
DNA	deoxyribonucleic acid
DOI	U.S. Department of the Interior
FIAT	Fire and Invasives Assessment Tool
GIS	geographic information system
GPS	Global Positioning System
LTDL	Land Treatment Digital Library
RMP	resource management plan
STM	state-and-transition model
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VHF	very high frequency
WSB	weed-suppressive bacteria

U.S. Geological Survey Sage-Grouse and Sagebrush Ecosystem Research Annual Report for 2017

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.

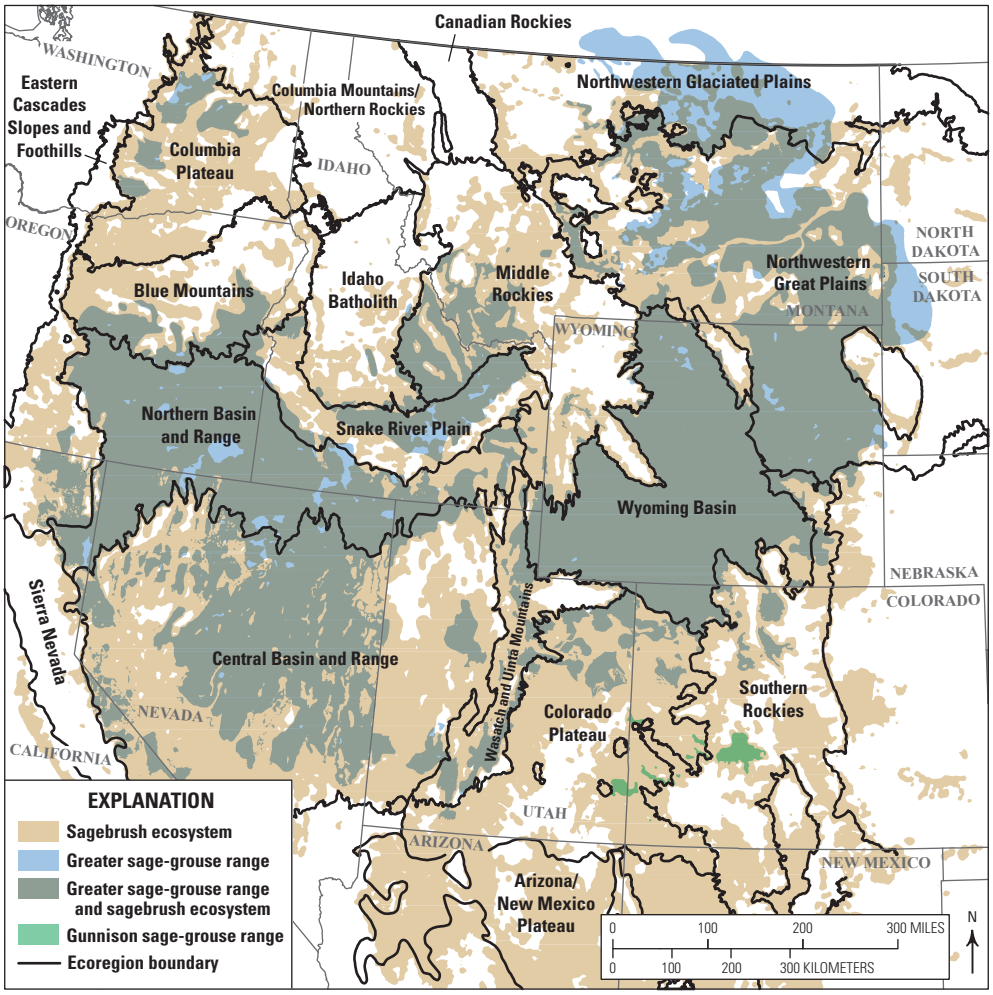

Figure 1. Location of the sagebrush ecosystem and distribution of greater and Gunnison sage-grouse in the Western United States. U.S. Environmental Protection Agency Level III ecoregions are labeled on the map. The Great Basin is composed of the Central Basin and Range, Northern Basin and Range, and 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 including those that precluded the need to list the greater sage-grouse under the Endangered Species Act, such as the Bureau of Land Management (BLM) and U.S. Department of Agriculture (USDA) Forest Service Land Use Plan Amendments and the U.S. Department of the Interior (DOI; 2015) Integrated Rangeland Fire Management Strategy. The USGS is continuing to build on that foundation to inform science-based decisions 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 at Science Centers in 9 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.
Utah Cooperative Fish and Wildlife Research Unit, Salt Lake City, Utah
Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, Wyo.

Climate and Land Use Mission Area Center

Earth Resources Observation Science Center, Sioux Falls, S. Dak.

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), which is organized into five thematic areas: Fire, Invasive Species, Restoration, Sagebrush and Sage-Grouse, and Climate and Weather. Project descriptions included in this report are organized according to these themes.

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

Project Descriptions

These descriptions are overviews of projects that are ongoing or were active during 2017. 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 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 big sagebrush. 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 Forest Service researchers are synthesizing 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, researchers can assess tradeoffs between the potential risks and benefits of fuel breaks.

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Mowed fuel break in southwest 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, the fuel breaks 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 scientists are working with the BLM to (1) quantify sage-grouse response to fuel breaks and similar linear interruptions in habitat, (2) use high-resolution fire and fuel break data to compare fire sizes and spread among areas with and without fuel breaks, and (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 to simulate effects of fuel breaks on sage-grouse under alternative scenarios of population responses, altered fire regimes, fuel break designs, fire control access and effort, and invasion of cheatgrass. Results of this study will indicate the conditions under which fuel breaks are likely to benefit sage-grouse populations and inform the strategic placement of fuel breaks.

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Woody Fuels Treatments Affect Native and Nonnative Plants in the Sagebrush Biome

When sagebrush becomes overcrowded, it presents significant wildfire risk, and 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. After 3 years, fire and mowing reduced woody shrubs, but fire also increased proportion of gaps among perennial plants, which can lead to invasion of cheatgrass. Fire, mowing, and some herbicides may be effective in reducing fuels, but each has potentially undesirable consequences on plant communities. USGS scientists and collaborators have completed 6 or more years of research on these sites and will be analyzing mid-term results.

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Publication

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.

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

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

Quantifying Fuels and the Effects of Reduction Treatments in Sagebrush Habitats

Keys to managing fire in sagebrush steppe landscapes are understanding successional change and plant productivity that are coupled to quantitative measures of fuels. Sagebrush ecosystems in the western Snake River Plain, Idaho, are a prime example of altered successional trajectories and dynamic fuel conditions, which are challenging for land managers who predict and control fire behavior, restore native communities, and provide ecosystem services. To better quantify and predict fuel loads and the effects of fuels manipulations in sagebrush habitats, and inform management of these shrubland ecosystems, the USGS is investigating the influence of grazing, nonnative species, and altered fire regimes on successional pathways in the Snake River Birds of Prey National Conservation Area, Idaho.

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

Publications

Brabec, M.M., Germino, M.J., Shinneman, D.J., Pilliod, D.S., McIlroy, S.K., and Arkle, R.S., 2015, Challenges of establishing big sagebrush (*Artemisia tridentata*) in rangeland restoration—Effects of herbicide, mowing, whole-community seeding, and sagebrush seed sources: Rangeland Ecology & Management, v. 68, no. 5, p. 432–435, http://dx.doi.org/10.1016/j.rama.2015.07.001.

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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.

Contact

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

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

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 will evaluate future scenarios of ecosystem dynamics using models that incorporate climate change, fire regimes, and fuel treatments. They will examine potential vegetation response to changing climate, fuel treatments, and postfire seedings, and assess the need for repeated maintenance of fuel treatment areas 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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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 researchers are conducting analyses to understand why fires occur, and are projecting where and when fire regimes will shift under expected future conditions. Working across sage-grouse management zones (four western and three eastern), major rangeland vegetation types (big sagebrush [*A. tridentata*], black sagebrush [*A. nova*] and low sagebrush [*A. arbuscula*], desert mixed scrub, floodplain, grassland, and mountain brush), and resistance and resilience classes, the researchers will analyze fire data to evaluate some of the assumptions regarding altered fire regimes that are incorporated into the Fire and Invasives Assessment Tool (FIAT). For example, 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 low resistance and resilience class and identify localities that have the strongest evidence for this relationship. This information can help managers prioritize their efforts within the extensive low resistance and resilience landscapes.

Contacts

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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., http://dx.doi.org/10.3133/ofr20151167.

Postfire Recovery of Sagebrush Steppe Ecosystems in the Northern Columbia Basin

Sagebrush ecosystems in the northern Columbia Basin (NCB) of Washington have been greatly reduced since European and American settlement. Remaining patches are typically isolated and highly fragmented, yet are critical to sagebrush-obligate fauna, including the sage-grouse and the sharp-tailed grouse (*Tympanuchus phasianellus*). The historical role of fire in the NCB is poorly understood, and land managers have to rely on research from more distant regions of the sagebrush biome, not all of which may be ecologically applicable. The USGS is quantifying and characterizing postfire recovery and successional trends in the sagebrush steppe of the NCB to inform efforts by land managers to carry out effective management and restoration activities. This information can help land managers better understand restoration potential after fire in these ecosystems.

Contact

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Publication

Shinneman, D.J., and McIlroy, S.K., 2016, Identifying key climate and environmental factors affecting rates of post-fire big sagebrush (*Artemisia tridentata*) recovery in the northern Columbia Basin, USA: International Journal of Wildland Fire, v. 25, no. 9, p. 933–945, http://dx.doi.org/10.1071/WF16013.

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 a large, contiguous sagebrush steppe that was highly productive sage-grouse habitat in northern Nevada and southeastern Oregon. USGS scientists and collaborators have initiated a long-term study using this 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.

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

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

In 2012, a large wildfire (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 third 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 benefit sagebrush-dependent birds, particularly sage-grouse. The USGS 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. Initial results for 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. Bird communities at treated locations have not stabilized up to 7 years posttreatment but continue to diverge from the pre-treatment community. As a result, managers may expect long-term response times when evaluating the effectiveness of treatments.

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

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Publications

Knick, S.T., Hanser, S.E., Grace, J.B., Hollenbeck, J.P., and Leu, Matthias, 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.

Knick, S.T., Hanser, S.E., and Leu, M., 2014, Ecological scale of bird community response to piñon-juniper removal: Rangeland Ecology & Management, v. 67, no. 5, p. 553–562, http://dx.doi.org/10.2111/REM-D-13-00023.1.

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, the USGS recently provided the first quantitative evidence that links long-term declines of sage-grouse to chronic effects of wildfire across the Great Basin. The analysis also indicated that projected declines may be slowed or halted by targeting fire suppression in remaining areas of intact sagebrush with high densities of breeding sage-grouse. Ongoing research is being conducted to determine 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. The USGS is expanding research to better understand factors influencing sagebrush ecosystem recovery postfire across the species range.

Contact

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Publication

Coates, P.S., Ricca, M.A., Prochazka, B.G., Brooks, M.L., Doherty, K.E., Kroger, Travis, 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, http://dx.doi.org/10.1073/pnas.1606898113.

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 the understanding of sagebrush recovery following disturbance and help managers assess the effectiveness of their actions.

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Use of Sagebrush-Reduction Treatments by Mule Deer in Wyoming

In southwest 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. This project evaluates 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 recovery period. This study can provide wildlife manager with information regarding potential effects of sagebrush reduction treatment on this important game species.

Mule deer in Wyoming. Photograph from U.S. Geological Survey.

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Pollinator Use of Forbs in the Soda Wildfire Area

Pollinating insects are in serious decline across the United States, impacting native plants. In a new study, the USGS will examine insect pollinator communities and forb-pollinator relationships at sites across the area burned by the 2015 Soda Wildfire in southwest Idaho and southeast Oregon. Researchers will sample pollinators using vein traps and timed searches, and compare pollinators in seeded areas burned in the Soda Wildfire 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.

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Invasive Species

Invasive plant species, primarily cheatgrass (*Bromus tectorum*), are a significant threat to the sagebrush ecosystem by increasing fire frequency and competition with native plant species. USGS scientists are addressing the need to develop and assess prevention, eradication, and control measures for invasive plant species; determining the factors that influence invasive plant species distributions; and 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 mapping 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 and other management activities, such as application of weed suppressive bacteria, targeted grazing, and other cheatgrass control measures. Some selected localized map products at a higher resolution (30 meters) will be made to help inform local-scale research and management efforts.

Contact

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Publications

Boyte, S.P., and Wylie, B.K., 2016, Near-real-time cheatgrass percent cover in the Northern Great Basin, USA, 2015: Rangelands, v. 38, no. 5, p. 278–284, http://dx.doi.org/10.1016/j.rala.2016.08.002.

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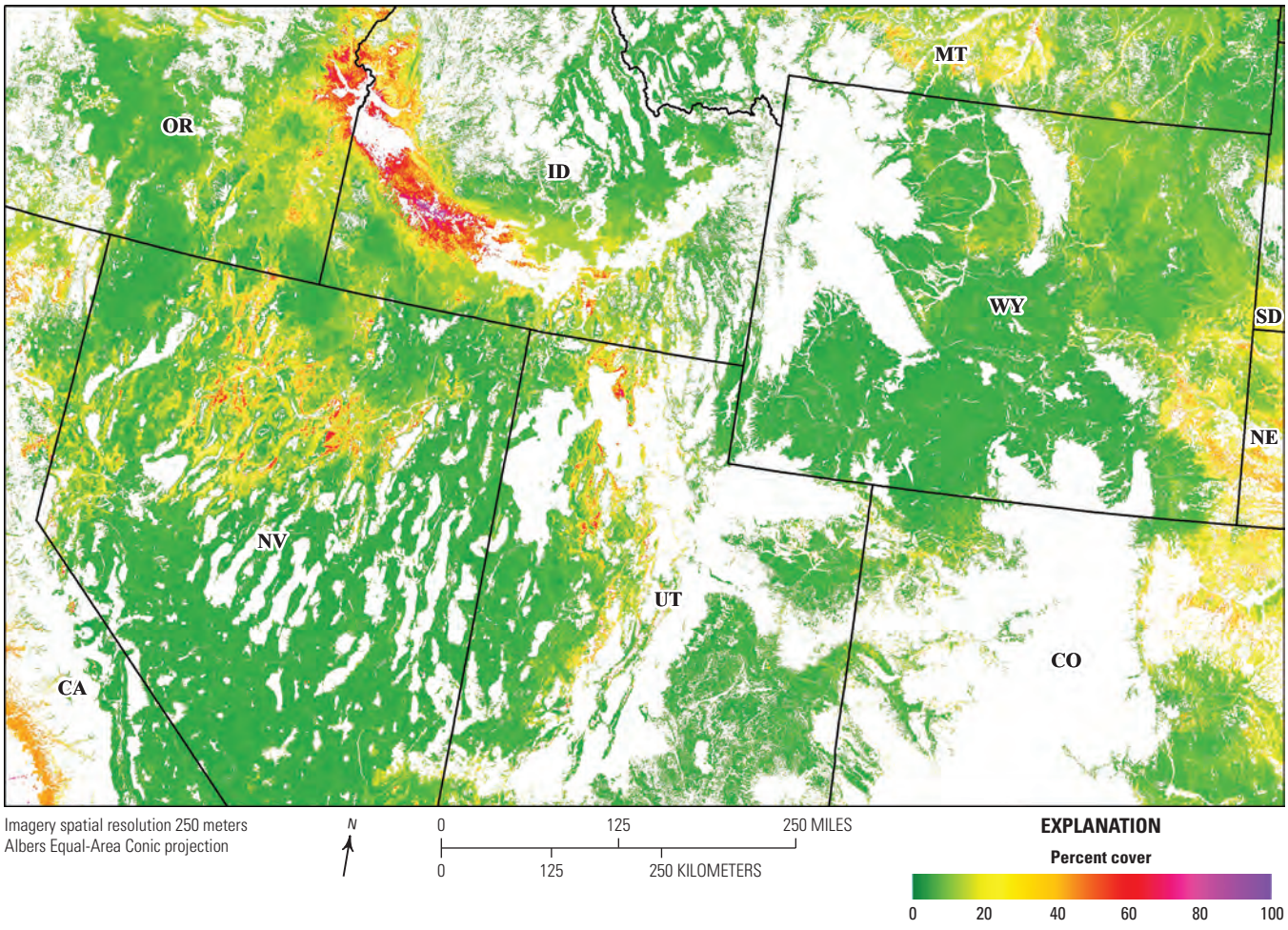

Distribution of cheatgrass and other annual herbaceous plants in 2017.

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*), can act as a stressor on 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 and big sagebrush (or deep-rooted native herbs). They are also examining the ecophysiological and hydrological mechanisms underlying the competition between these exotic and native species. 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

The Integrated Rangeland Fire Management Strategy Actionable Science Plan (Integrated Rangeland Fire Management Strategy Actionable Science Plan Team, 2016) places a high priority on assessing control measures for invasive annual grasses such as cheatgrass and medusahead (*Taeniatherum caput-medusae*), which 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. WSB can supposedly suppress exotic annuals for about 2 to 5 years, bridging the short-term action of herbicides and long-term resistance to weeds provided by bunchgrasses after they recover from fire or after seeding. USGS scientists and collaborators have established two projects: (1) comparison of all commercially available sources of WSB, with and without herbicides and other common postfire plant and soil treatments following fires that spanned southwest Idaho in 2016; and (2) comparison across sprayed and nonsprayed plots in topographically complex terrain after they burned in 2016. Objectives are to determine where and when WSB are effective on target (exotic) and nontarget (native) species, and 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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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 precipitation timing and total amount, changes which will alter cheatgrass dynamics. USGS scientists have previously integrated remote sensing data, site-specific variables, and weather data to estimate cheatgrass percent cover variation and means for 11 years throughout the NBG. In this study, the USGS is 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.

Contact

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Publication

Boyte, S.P., Wylie, B.K., and Major, D.J., 2016, Cheatgrass percent cover change—Comparing recent estimates to climate change-driven predictions in the Northern Great Basin: Rangeland Ecology & Management, v. 69, no. 4, p. 265–279, https://doi.org/10.1016/j.rama.2016.03.002.

Use of Cheatgrass Suppressive Bacteria To Restore Shrub-Steppe

There are multiple reasons for using successful WSB that attack invasive annual grasses (particularly cheatgrass) of the Western United States and leave intact native perennial plants. USGS scientists and colleagues are using WSB (*Pseudomonas fluorescens*, strain D7) in two case studies at the Hanford Reach National Monument in Washington State 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 Modifies Microbial Nitrogen Cycling in Sagebrush Soils

Cheatgrass invasion degrades native sagebrush ecosystems and increases fire frequency, and it can also cause soil microbial communities to change over time. These communities convert organic soil nitrogen into plant-available inorganic nitrogen. Scientists examined nitrogen cycling rates in sagebrush and cheatgrass-invaded soils over a 100-mile range in eastern Oregon and southern Idaho, adding antibiotics to study the roles that soil fungi and bacteria play in nitrogen transformations. Results point to the important role fungi play in nitrogen dynamics in native sagebrush steppe and suggest that alteration of the microbial community by cheatgrass may make nitrogen more available and further benefit the establishment and growth of this invasive grass. This information may help managers as they develop strategies to restore invaded landscapes across the northern Great Basin.

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Publication

DeCrappeo, N.M., DeLorenze, E.J., Giguere, A.T., Pyke, D.A., and Bottomley, P.J., 2017, Fungal and bacterial contributions to nitrogen cycling in cheatgrass-invaded and uninvaded native sagebrush soils of the western USA: Plant and Soil, v. 416, nos. 1–2, p. 271–281, http://dx.doi.org/10.1007/s11104-017-3209-x.

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

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 southwest 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. Efforts to revegetate burned areas have taken place in the past, yet 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 to create functional sage-grouse habitat in postfire landscapes, USGS 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. Using a modeling framework, the analysis will predict times to sagebrush and sage-grouse recovery and future outcomes of planting treatments.

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

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Restoration of Native Understory Plants in Degraded Sagebrush Steppe Ecosystems

Sagebrush steppe that is resistant to annual grasses typically has herbaceous perennials between sagebrush and other shrubs. When fires burn these resistant communities, they may eliminate sagebrush temporarily, but these understory plants survive and are able to 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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Microsite Soil Characteristics Influence Sagebrush Restoration Success

Fertile "islands" are important for germination, growth, and establishment of sagebrush and other plants in arid and semiarid environments because of the unique soil nutrients and properties 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 guide whether and how big sagebrush is seeded in the future.

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Sagebrush Seed Source Affects Restoration Success

Big sagebrush provides important habitat for greater sage-grouse and other wildlife that is threatened by an increasing number of large wildfires. Because big sagebrush cannot re-sprout after a burn and natural seedling establishment is limited, land managers have tried to recolonize big sagebrush by aerial or drill seeding burned areas. This study in southwest Idaho is examining how seeds from different climates and with different genetic characteristics grow in variable climates. Scientists are also exploring how different sagebrush seeds cope with traditional treatments, such as using herbicides or mowing to control competing vegetation. Results from this study will be useful to restoration managers interested in maximizing big sagebrush seedling establishment after wildfire, especially in the face of climate variability.

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Publication

Brabec, M.M., Germino, M.J., and Richardson, B.A., 2017, Climate adaption and post-fire restoration of a foundational perennial in cold desert—Insights from intraspecific variation in response to weather: Journal of Applied Ecology, v. 54, no. 1, p. 293–302, https://doi.org/10.1111/1365-2664.12679.

SageSuccess Project: Sagebrush Restoration for Sage-Grouse

The SageSuccess Project is a joint effort between the USGS and the BLM 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, soils, soil 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.

Postfire sagebrush seeding. Photograph from Bureau of Land Management.

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Soda Wildfire Assessment

The Integrated Rangeland Fire Management Strategy (Strategy hereafter) 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 southwest Idaho and southeast Oregon, 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 monitoring effort for response to the Soda Wildfire 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. Researchers have developed monitoring techniques using cutting-edge software and digital equipment. 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.

U.S. Geological Survey scientist, Matthew Germino, speaking on postfire field tour. Photograph from U.S. Geological Survey.

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Effectiveness of Vegetation Recovery Strategies in Sagebrush Ecosystems: A Case Study From Wyoming Using Remote Sensing Vegetation Maps and Historic Disturbances

The historic loss of vegetation and subsequent recovery trajectories after disturbances in sagebrush ecosystems are not well understood. Establishing rates of sagebrush recovery will aid in identifying the most effective sagebrush restoration strategies. Recently, USGS researchers have assembled spatial datasets characterizing disturbance-specific information from energy development, fire, mechanical, and chemical treatments within Wyoming. Researchers have demonstrated that pairing of these spatial datasets with historic sagebrush habitat maps within the Wyoming Landscape Conservation Initiative region allows for an evaluation of the time to "ecological recovery" as well as the time to "reclamation recovery" as defined by reclamation guidelines. Researchers are now concentrating on examining variation in these recovery rates across the State of Wyoming, focusing on disturbances of fires, well pads, and several vegetation treatments stratified across soil and climate patterns. The resulting vegetation recovery curves will aid in identifying sagebrush and habitat recovery expectations for a number of species of conservation interest, including the greater sage-grouse, and directly inform management efforts outlined within the Integrated Rangeland Fire Management Strategy and within the recently revised BLM and Forest Service resource management plans.

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Estimating Resilience and Recovery of Sagebrush Ecosystems Across Wyoming Using Remote Sensing Vegetation Products

The postdisturbance recovery of sagebrush-dominated ecosystems can range drastically from several decades to nearly a century, depending on local and regional site conditions, disturbance type, and restoration approach. In the past, localized studies have been used to infer landscape-scale vegetation recovery, yet these studies may be inadequate to inform restoration across the broader landscape. USGS and university researchers are using remote sensing products developed across Wyoming to evaluate

vegetation recovery from a variety of disturbance types including fire, oil and gas development, and sagebrush removal treatments. They are also modeling how vegetation recovery for each disturbance type varies with factors such as climate, soils, and reseeding or restoration practices. The resulting vegetation recovery curves will aid in identifying sagebrush and habitat recovery expectations for a number of species of conservation interest, including the greater sage-grouse, and directly inform management efforts outlined within the Integrated Rangeland Fire Management Strategy and BLM and Forest Service resource management plans.

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Synthesis of Climate and Seed Transfer Guidelines

Seeds used in sagebrush ecosystem restoration and rehabilitation projects often are transferred across climate zones and hundreds of miles. Development and application of climate-based seed zones are needed to improve seeding success and return on investment. The USGS, in collaboration with the Forest Service, has accumulated considerable data on climate responses of key native perennials across more than 30 climate experiments and common gardens spanning the Great Basin. Researchers are synthesizing and analyzing existing data on growth, survival, and physiologically determined thresholds in temperature and water tolerance for each species to help inform climate and seed transfer guidelines. This information will inform BLM's 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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Common Garden Studies With Big Sagebrush

Physiological fitness of different seed sources for big sagebrush restoration is under evaluation using common gardens. The results will fill a key data gap needed to inform the development of climatic seed-transfer zones. Preliminary data suggest that the populations (seed sources) differ appreciably in (1) water status and associated photosynthetic carbon gain and growth at midsummer, and (2) physiological tolerance of freezing during winter. Preliminary results from one of the gardens indicate a potential for local climate adaptation to be greater in tetraploid compared to diploid big sagebrush. The most extensive restoration seedings, restoration challenges, and seed supply problems are with Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*), a tetraploid. Results of this study can inform future seed selection and use.

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

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Publication

Chaney, Lindsay, Richardson, B.A., and Germino, M.J., 2017, Climate drives adaptive genetic responses associated with survival in big sagebrush (*Artemisia tridentata*): Evolutionary Applications, v. 10, no. 4, p. 313–322, https://doi.org/10.1111/eva.12440.

Postfire Sagebrush Growth

Growth and establishment of big sagebrush after fire is a critical component of restoration efforts in the Great Basin; however, these ecological processes often occur over several decades and thus they 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 re-measurement 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 will also assess how these changes influence cover of exotic annuals, especially cheatgrass, and native forbs. 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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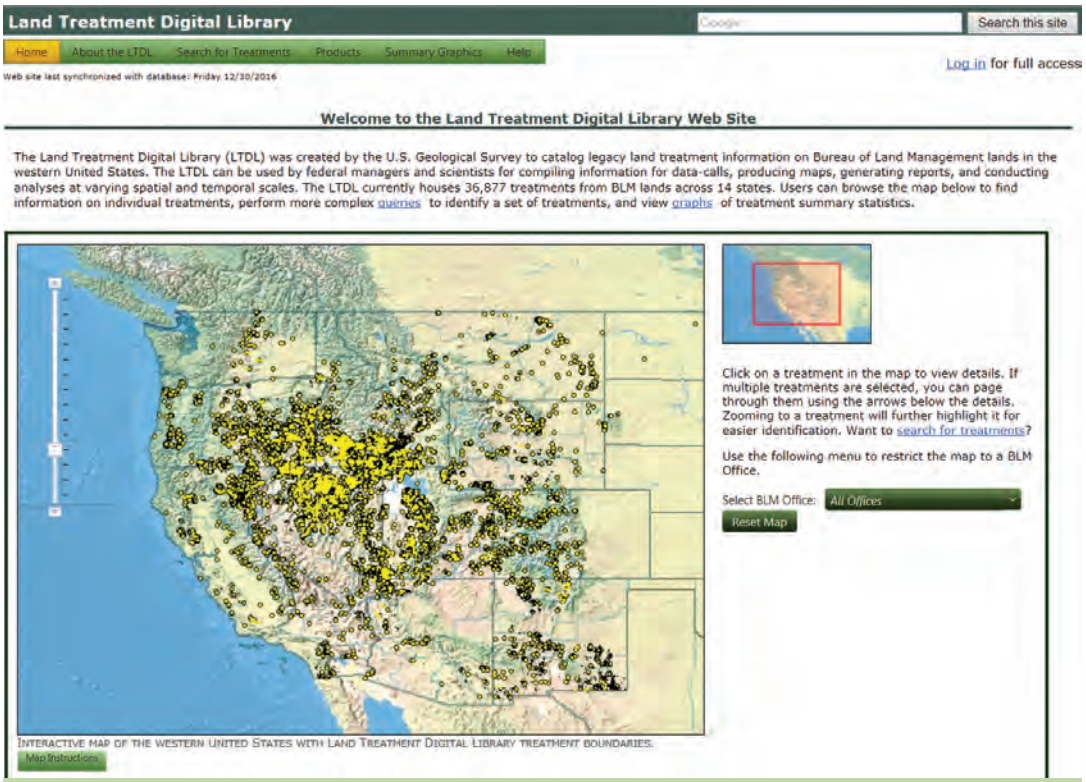
Land Treatment Digital Library

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 online 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 discuss 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.



The Land Treatment Digital Library homepage (https://ltdl.wr.usgs.gov).

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Publications

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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 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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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. The USGS is conducting research on the 285,000 acres burned by the Soda Wildfire in southwestern Idaho in 2015 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.

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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 (straw inserted into 9-inch mesh tubes), cluster plantings, landscape and topography strategies, and treatments of herb layer. Outcomes of this study may help provide managers with new methods for improving establishment of sagebrush in restoration treatments.

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Mapping Conifers 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.

Handbook for Restoration of Sagebrush and Grassland Ecosystems

USGS scientists developed a three-part handbook about effective implementation of restoration practices. Part 1 discusses background concepts about sagebrush ecosystems, landscape, and restoration ecology, with emphasis on greater sage-grouse habitats that are necessary to help practitioners and managers apply the decision tools that are the core of this three-part restoration handbook. Part 2 introduces the landscape-level decision tool designed to help managers develop effective strategies for restoration project placement. Part 3 describes project-level restoration tools, including use of either passive or active restoration techniques. Parts 2 and 3 are designed to be followed in a step-by-step progression to ensure that critical decisions are made in the appropriate order with best management practices while minimizing backtracking on the part of decision makers and practitioners.

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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 researchers will experiment with restoring mosses using two stabilization methods, a jute net and a hydro-mulch tackifier (a sticky glue-like substance), which are already used by the 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.

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

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Community Composition and Restoration of Biological Soil Crusts of Nevada's Shrub-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 shrub-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.

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Publication

Condon, L.A., and Pyke, D.A., 2016, Filling the interspace—restoring arid land mosses; Source populations, organic matter, and overwintering govern success: Ecology and Evolution, v. 6, no. 21, p. 7623–7632, https://doi.org/10.1002/ece3.2448.

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 provide 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, ranging from managers and decision makers to GIS professionals and resource specialists. Key functions associated with 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 and development projects that are focused on large landscape conservation.

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Conifer removal treatment in central Utah. Photograph by Steven Hanser, U.S. Geological Survey.

Sagebrush and Sage-Grouse

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.

Big sagebrush in southwest Utah. Photograph by Steven Hanser, U.S. Geological Survey.

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

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

Incorporating spatial and temporal scales into monitoring strategies results in more robust detection of population rates of change and helps in determining 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 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.

A Hierarchical Clustering and Landscape Regionalization of Greater Sage-Grouse Habitat

Using biologically relevant natural landscape characteristics of greater sage-grouse habitat at varying spatial scales, USGS scientists have evaluated spatial configurations of lek sites (mating grounds) to identify lek locations with similar landscapes and to develop a nested hierarchy of clusters, which will inform monitoring protocols and improve upon habitat modeling approaches and decision analyses for population trends. With the recent completion of pilot studies in Nevada and Wyoming, researchers are currently working with the Western Association of Fish and Wildlife Agencies and the U.S. Fish and Wildlife Service to apply these established procedures rangewide for population monitoring efforts. Overall, this framework could facilitate effective and responsive management actions for sage-grouse populations, and similar hierarchical approaches might be beneficial for other species.

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

To evaluate greater sage-grouse populations in Wyoming, a stronghold for the species, USGS researchers and colleagues investigated population trends statewide and at multiple spatial scales across existing management units. They incorporated lek count data in a population viability analysis across five geographic scales (cluster levels) to determine the finite rate of population change during the period 1993–2015. This approach can identify clusters that are out of sync with surrounding populations, providing insights into management decisions that may help conserve populations across broad landscapes.

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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, as well as different patterns of habitat selection and vital rates relative to the rangewide population. The USGS developed an integrated population model 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. 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 population. This approach could be adapted to assess population trends for greater sage-grouse at other regional and landscape scales.

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Publication

Coates, P.S., Halstead, B.J., Blomberg, E J., Brussee, Brianne, Howe, K.B., Wiechman, Lief, Tebbenkamp, Joel, 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://dx.doi.org/10.3133/ofr20141165.

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 is developing 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 help managers 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 and 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 adopted to help address other management questions aimed at improving habitat for species of conservation concern across sagebrush and other ecosystems.

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Publication

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, http://dx.doi.org/10.1016/j.rama.2016.08.001.

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

Translocations as Conservation Strategy for Imperiled Populations of Sage-Grouse

The USGS is 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 Global Positioning System (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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Learning From the Land: Extending State-and-Transition Models for Adaptive Management of Wildlife Habitat on Western Rangelands

The USGS has been working with Federal and university partners to streamline and test state-and-transition models (STMs) that incorporate sage-grouse habitat conditions. 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 northwest Colorado, and by evaluating the effectiveness of sage-grouse as an umbrella species. They have applied STMs to remote sensing and other spatial layers to map the current state within an ecological site. This effort could help to increase awareness and adoption of STMs by ranchers while contributing to USDA Natural Resources and Conservation Service 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 researchers 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. Researchers found that the explicit inclusion of population dynamics and movements can provide additional biological realism that can extend and, in some cases, contradict habitat use predictions generated from short-term or static resource selection analyses. Models suggest that while populations tend to persist in core areas, declines outside of cores can also affect core populations. 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.

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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. Understanding the distribution of those habitats across the range of sage-grouse is important to inform management strategies. The USGS is developing greater sage-grouse seasonal habitat suitability models by applying the thresholds identified in BLM resource management plans (RMPs) to the USGS shrub-map products (Xian and others, 2013) derived for areas within the Great Basin. Spatial analyses and applications of habitat objectives were developed by applying region-specific thresholds to develop maps of nesting and breeding lek security habitat, nesting and breeding cover habitat, brood-rearing and summer habitat, and winter cover and food habitat. Models were limited, primarily owing to the issues with variation in identified RMP habitat objective thresholds across plans, and differences in linking those objectives, which were primarily based on fine-scale characteristics, to local-scale habitat maps. Researchers are summarizing these results, but ultimately, a telemetry-based approach will be required to characterize and map seasonal habitats across the majority of the range of sage-grouse.

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

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Idaho Greater Sage-Grouse Habitat Triggers Assessment

USGS scientists are developing a habitat trigger analysis and assessment protocol that includes methods, datasets used, and a description of limits of interpretation and inference. The study will include a retrospective causal factor analysis of habitat change and triggers associated with anthropogenic and other habitat disturbance. This work will provide background and context for ongoing causal factor analyses, as well as quantification of historic and contemporary change to provide context for future habitat trigger analyses. This work is highly collaborative with the Idaho Greater Sage-Grouse Adaptive Management Team, thus ensuring adequate vetting and feedback from interagency stakeholders, and can help facilitate adaptive management of sage-grouse habitats.

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Using Advanced Technology To Improve Lek Counts

The USGS, in conjunction with State and university partners, is in the seventh year of investigating how high-definition infrared cameras mounted on fixed wing aircraft can be used to improve lek survey protocols. By conducting simultaneous double-blind ground and aerial surveys in conjunction with aerial infrared counts of artificial leks of known size, researchers are able to quantify the precision and accuracy of each method, and derive correction factors for lek count data obtained with different methods. Moreover, the use of aerial infrared technology may be a substantial improvement over other aerial survey methods such as low-level helicopter flights that rely on flush counts, and can inform method development for surveys that are more accurate and efficient.

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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, http://dx.doi.org/10.3996/032013-JFWM-025.

Greater Sage-Grouse Population Ecology

USGS scientists and colleagues are developing a peer-reviewed and edited book on comprehensive population ecology of greater sage-grouse and analyses of habitat associations in relation to demographic rates. Each section of the book will focus 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. The book will provide a "desktop synthesis" for land and wildlife managers and policymakers to access and reference scientific information and help form the basis for ecoregion-specific and comprehensive management guidelines.

A 2-day old sage-grouse chick. 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 occurred in 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, a second synthesis will comprise an easy-to-follow management guideline handbook specifically focused on the Great Basin. The study includes an evaluation of existing microhabitat and macrohabitat 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.

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

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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.

Winter Ecology of Greater Sage-Grouse in Nevada

Perhaps the most ubiquitous characteristic of sage-grouse is their reliance on sagebrush as a food source, particularly during winter when they consume it almost exclusively. However, it is not known to what extent sage-grouse rely on different species of sagebrush as a source of food or for cover, and how food quality and availability of sagebrush may be affected by environmental characteristics, such as temperature and snow depth. USGS scientists and cooperators are conducting research on the winter ecology of greater sage-grouse in eastern Nevada to evaluate use of different sagebrush species as a food source while accounting for the availability of sagebrush under different circumstances. Tracking data will be used to understand how winter

conditions influence sage-grouse movement patterns and habitat use. This information may be used by land managers planning sage-grouse and sagebrush conservation actions based on winter season requirements of the species.

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Evaluating the Influence of Changing Sagebrush Habitat Conditions on Sage-Grouse Population Trends

Remote sensing products that estimate vegetation attributes in sagebrush-dominated communities can be used to characterize sage-grouse habitat at broad spatial scales. However, these products have been static and have not shown changes in habitat quality over time owing to previous technical and analytical constraints. The USGS has now created remote sensing products of sagebrush, herbaceous, and bare ground cover estimated at 2- to 3-year intervals in southwestern Wyoming during the period 1985–2015. Researchers are using this information to model changes in lek counts in response to changes in vegetation cover measured within a distance relevant to sage-grouse nesting and distribution. This approach could be useful for monitoring sage-grouse populations in response to changes in habitat over broad spatial and temporal scales, and could incorporate changes in vegetation, such as those caused by climate change or other disturbance like fire and energy development.

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

Gunnison sage-grouse (*Centrocercus minimus*) 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 scientists and colleagues used telemetry data to develop resource selection models predicting crucial brood and winter habitat for Gunnison sage-grouse within the Gunnison Basin. Broods selected moderate shrub cover in more productive sites but avoided habitats with development or with conifer species. During winter, birds selected moderate cover of taller big sagebrush but avoided coniferous forests and major roads. These models have been applied within the Gunnison Basin to improve the conservation of important Gunnison sage-grouse habitats , thereby enhancing the management of disturbances and increasing habitat connectivity.

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Assessing Risk and Threat Reduction Approaches for Gunnison Sage-Grouse

The threatened Gunnison sage-grouse continues to experience declines, particularly in satellite population locations, and population thresholds for recovery are required for near- and long-term conservation planning. USGS and university researchers are supporting the U.S. Fish and Wildlife Service as it develops scientifically based targets for the conservation and recovery of this species by developing spatially explicit models that assess habitat and population requirements for future stability. Researchers are also supporting the BLM in evaluating adaptive management options for the conservation of Gunnison sage-grouse populations. This process includes (1) characterizing habitat for the Gunnison Basin and satellite populations; (2) developing a spatially explicit individual-based model; (3) simulating population dynamics and persistence to identify population thresholds and to characterize and improve population resiliency, redundancy, and representation; (4) quantifying the impacts of alternative habitat restoration and translocation strategies on regional and local population persistence; and (5) comparing model outcomes and evaluating potential adaptive management scenarios. The modeling framework will enable better understanding of the response of Gunnison sage-grouse to potential threats and management actions.

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Public Grazing Records Reveal Patterns in Sage-Grouse Population Dynamics at Broad Scales

Livestock grazing can have profound impacts on ecosystems, yet our understanding of these impacts is often generalized from short-term, local studies that may not correspond with trends at broader scales. Improper livestock management has been implicated in population declines of greater sage-grouse because reductions in herbaceous cover can negatively affect sage-grouse reproductive success. USGS scientists and colleagues used 11 years of annual lek counts coupled with Normalized Difference Vegetation Index and BLM allotment grazing records to determine population trends and evaluate impacts from livestock management. Scientists discovered that livestock could have both positive and negative impacts on greater sage-grouse populations, and their results support consideration of local vegetation productivity when predicting effects of grazing timing and intensity on wildlife populations such as sage-grouse. These results also show the benefit of using a broad-scale approach when evaluating effects of livestock management because it reveals patterns that may not be readily inferred from more fine-scale studies. Findings from this research can help inform sustainable livestock management across sagebrush-dominated rangelands.

Cattle drive near Pinedale, Wyoming. Photograph by Theo Stein, U.S. Fish and Wildlife Service.

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Publication

Monroe, A.P., Aldridge, C.L., Assal, T.J., Veblen, K.E., Pyke, D.A., and Casazza, M.L., 2017, Patterns in greater sage-grouse population dynamics correspond with public grazing records at broad scales: Ecological Applications, v. 27, no. 4, p. 1096–1107, https://doi.org/10.1002/eap.1512.

Effects of Spring 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 spring cattle grazing on sage-grouse through a suite of landscape-scale experiments. This research will evaluate the effects of different cattle grazing regimes on survival, habitat selection, and reproductive traits of greater sage-grouse. The before-and-after 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 will also measure 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 while considering sage-grouse habitat needs.

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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. Products quantify the proportion of shrub, sagebrush, herbaceous, annual herbaceous, litter, bare ground, shrub height, and sagebrush height at 1-percent intervals in each 30-meter grid cell. Research has shown this information enables generation of a variety of wildlife habitat predictions including sage-grouse habitat. Products have been completed for the Great Basin, the Mojave Desert, Montana, and Wyoming. Current mapping is underway to complete the remaining areas in western States that contain significant portions of shrub and grass. Products will be integrated into the National Land Cover Database for future updating on a regular 5-year cycle, and current products are available on www.mrlc.gov.

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Publication

Xian, George, Homer, Collin, Meyer, Debbie, and Granneman, Brian, 2013, An approach for characterizing the distribution of shrubland ecosystem components as continuous fields as part of NLCD: ISPRS Journal of Photogrammetry and Remote Sensing, v. 86, p. 136–149, https://doi.org/10.1016/j.isprsjprs.2013.09.009.

Developing Temporal Trends in Sagebrush Vegetation Characteristics Over a Large Landscape

The completion of the USGS shrubland component maps (see previous project) in the Great Basin and Wyoming provide an ideal opportunity to map vegetation change through time, from 1984 through 2016. Products that describe change over time support planned 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 the change analysis 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 through time. Data for two initial ecoregions are now being processed across portions of northern Nevada, southern Idaho, and Wyoming. Once the historical analysis is completed, future imagery can be easily added to monitor changing conditions into the future.

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Publication

Homer, C.G., Xian, George, Aldridge, C.L., Meyer, D.K., Loveland, T.R., and O'Donnell, M.S., 2015, Forecasting sagebrush ecosystem components and greater sage-grouse habitat for 2050—Learning from past climate patterns and Landsat imagery to predict the future: Ecological Indicators, v. 55, p. 131–145, https://doi.org/10.1016/j.ecolind.2015.03.002.

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 conservation planning efforts for sage-grouse and the habitats on which they rely.

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Publications

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

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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 using the Normalized Difference Vegetation Index at a 250-meter resolution through the growing season relative to seasonal weather and long-term site potential (derived from soils, elevation, rain shadows, slope, aspect, and so forth). 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.

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Landscape Influence on Gene Flow in Greater Sage-Grouse

The USGS and collaborators 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.

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

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Population Connectivity in Wyoming Greater Sage-Grouse

The identification and demographic assessment of populations that are biologically meaningful is fundamental to species management. Given the significance of animal dispersal to population dynamics and geographic variability, understanding how dispersal is impacted by landscape patterns has major ecological and conservation importance. USGS researchers and collaborators have used fine-scale genetic data to define subpopulations, identify the landscape components that most influence connectivity, and assess the role of population connectivity in maintaining genetic diversity of greater sage-grouse across Wyoming. This information can help target management actions to maintain or improve sage-grouse population connectivity.

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Publications

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Sage-Grouse Reference Genome

Whole-genome sequencing can provide powerful tools for understanding and managing wild populations, including detailing current and historical population trends, defining conservation units, and identifying vulnerable populations. Recent technological advances in deoxyribonucleic acid (DNA) sequencing techniques have dramatically reduced the cost and time required for whole-genome sequencing, thus making such tools feasible for a broad range of species of management concern. USGS scientists are leveraging these technologies to sequence the entire genomes of both greater and Gunnison sage-grouse. These reference genomes will facilitate future studies of both neutral and potentially adaptive genetic variation in sage-grouse.

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Population Genomics of Interspecific and Intraspecific Divergence in Sage-Grouse

Identifying the genetic changes that underlie divergence between populations and species can assist in defining conservation units and understanding the processes that contribute to biodiversity. Capitalizing on current sage-grouse reference genomes, USGS scientists are using a technique called multiplexed whole-genome resequencing to scan for differentiation among birds from previously identified unique greater sage-grouse populations (Bi-State, Washington, Jackson Hole, and others) and also in relation to Gunnison sage-grouse. Annotated reference genomes from closely-related gallinaceous species are being used to identify putative genes involved with divergence. This study will provide unprecedented resolution regarding the timing of divergence of isolated populations and will help identify factors that impact gene flow.

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Investigating Sage-Grouse Metabolic Adaptation to Different Types of Sagebrush

Identifying and preserving unique genetic adaptations is an important consideration for conservation and management strategies, particularly for species with geographic distributions that span diverse ecological conditions. New genomic resources for both greater and Gunnison sage-grouse are being used to investigate metabolic adaptations to different types of sagebrush diets within and between both sage-grouse species. Using whole-genome resequencing from birds sampled across the West, the scientists are using two complementary approaches to discover genes that are likely to be involved in dietary adaptations. First, whole-genome scans are being performed to identify regions within the genome with elevated divergence between populations and species. Second, a candidate gene approach is being used to evaluate numerous genes that may underlie molecular adaptations among sage-grouse from distinct populations. The results of this study are likely to hold important implications for common management practices including translocation of birds and restoration of sagebrush communities.

Black sagebrush (*Artemisia nova*) in central Nevada. Photograph from U.S. Geological Survey.

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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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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 taking a comprehensive approach to these questions through use of experimental studies and development of statewide species overlap models. Overlap between suitable habitat for 52 nongame

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

sagebrush species of conservation concern in Wyoming and lands now managed under the Wyoming Governor's Core Area Strategy are being evaluated. 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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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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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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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. The authors suggest that land management strategies, such as establishing native bunchgrasses after wildfire, could benefit burrowing prey species and preserve the trophic functions they provide.

American badger. Photograph by Michael McGee, Bureau of Land Management.

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Publication

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Harvester Ants Nest in Burned Areas Where Exotic Grasses Thrive

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 these changes on harvester ants, USGS and university researchers 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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Publications

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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. The USGS is using VHF and GPS 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. This study links avoidance behavior to survival and can assist wildlife managers in designing conifer removal projects. Moreover, results from these analyses indicate that encroachment of sparsely distributed conifer habitat 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 focus on identifying 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.

Tracking greater sage-grouse using very high frequency telemetry. Photograph by Tatiana Gettelman, U.S. Geological Survey.

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Publications

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

The USGS is conducting greater sage-grouse 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 sage-grouse habitat selection, population vital rates, and movement patterns. The goal of this research is to answer questions related to effects of multiple development types on sage-grouse habitat selection, population vital rates, and movement patterns. Results of this work 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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Investigating Impacts of Oil and Gas Development on Greater Sage-Grouse Using a Bayesian State-Space Model

Global energy demand is expected to increase substantially in the next two decades, with fossil fuels accounting for more than one-third of that demand. To better understand how male sage-grouse lek attendance is affected by oil and gas development, USGS and university researchers analyzed changes in male lek counts in Wyoming from 1984 through 2008. Disturbance owing to oil and gas development was measured as well density (number of active wells per square kilometer) and disturbance area, which accounted for well pad size and the spatial arrangement of well pads near a lek. Preliminary results indicate that under current regulations, continuing allowable well densities within sage-grouse core areas will likely result in sustaining current rates of decline, and leks outside of core areas are likely to decline more rapidly if development were to increase in the future.

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Publication

Green, A.W., Aldridge, C.L., and O'Donnell, M.S., 2017, Investigating impacts of oil and gas development on greater sage-grouse: The Journal of Wildlife Management, v. 81, no. 1, p. 46–57, https://doi.org/10.1002/jwmg.21179.

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 southwest Wyoming, yet little is known about the potential magnitudes of these effects. In southwest Wyoming, USGS 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. In preliminary analyses, oil and gas development outweighed the influences of climate on abundance and distribution inside the protected core area. The influences of climate and development were consequential, indicating that, despite core area protections, the future of sage-grouse in Wyoming's stronghold population may not be certain. The results of this study will 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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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, the USGS and collaborators 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. This information can inform future management efforts to reduce predation impacts on sage-grouse populations.

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Publications

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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. The USGS 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

Common raven. Photograph from U.S. Fish and Wildlife Service.

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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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. The USGS 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 estimation of raven densities in sagebrush ecosystems within the broader Great Basin region of the southwestern United States.

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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. The USGS and university collaborators are integrating field measurements of plant community structure and soil conditions with ecological simulation models to assess the influence of changing climate and other disturbance regimes on the plant species composition and vegetation structure of sagebrush-dominated ecosystems. Outcomes of the project can help to inform potential climate adaptation strategies.

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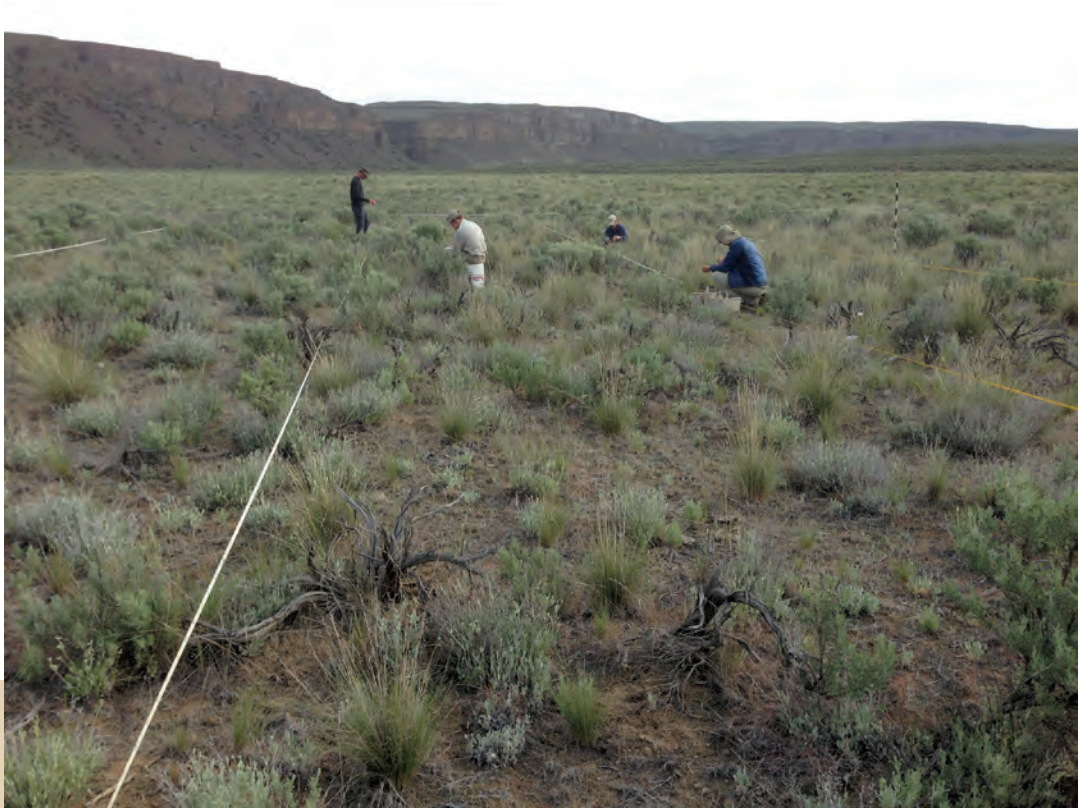

Researchers monitoring sagebrush in central Utah. Photograph by Scott Shaff, U.S. Geological Survey.

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Sagebrush 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 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

Big sagebrush. Photograph by Theo Stein, U.S. Fish and Wildlife Service.

populations to help develop management strategies at both landscape and site scales. A related report documents another strategic, multiscale approach to conservation that addresses threats based on resilience science for the Gunnison sage-grouse range and the eastern portion of greater sage-grouse range. The report may help managers determine the most effective management strategies to meet conservation goals.

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Chambers, J.C., Beck, J.L., Bradford, J.B., Bybee, Jared, Campbell, Steve, Carlson, John, Christiansen, T.J., Clause, K.J., Collins, Gail, Crist, M.R., Dinkins, J.B., Doherty, K.E., Edwards, Fred, Espinosa, Shawn, Griffin, K.A., Griffin, Pau, Haas, J.R., Hanser, S.E., Havlina, D.W., Henke, K.F., Hennig, J.D., Joyce, L.A., Kilkenny, F.M., Kulpa, S.M., Kurth, L.L., Maestas, J.D., Manning, Mary, Mayer, K.E., Mealor, B.A., McCarthy, Clinton, Pellant, Mike, Perea, M.A., Prentice, K.L., Pyke, D.A., Wiechman, L.A., and Wuenschel, Amarina, 2017, Science framework for conservation and restoration of the sagebrush biome—Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions; Part 1. Science basis and applications: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS–GTR–360, 213 p., https://www.treesearch.fs.fed.us/pubs/53983.

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Perennial Grass Response to Postfire Grazing Management in the Great Basin

Perennial grasses are a vital component of a functioning sagebrush ecosystem and an important source of food for grazing cattle. In the event of a wildfire, burned perennial grasses need time to recover—but when are perennial grasses stable enough to accommodate grazing again? The USGS has initiated a new study to investigate 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, the study examines 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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Publication

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Book Chapter: Rangeland Monitoring Protocols

Monitoring and adaptive management are fundamental concepts to managing rangelands. Historically, rangeland monitoring was limited to determining impacts or maximizing the potential of specific land uses, typically livestock grazing, yet more contemporary practices address the increased uses of and disturbances to rangelands. Advances in rangeland ecology, changes in natural resource policies and societal values, and developments in remote sensing techniques over the past 25 years have facilitated new approaches to monitoring that can support rangeland management's diverse information needs. In a chapter from the book titled "Rangeland Systems: Processes, Management, and Challenges," Agricultural Research Service and USGS authors review some of the conceptual and technological advancements and provide examples of how they have influenced rangeland monitoring. They also discuss implications of these developments for rangeland management and highlight challenges and opportunities for implementing effective rangeland monitoring. Researchers conclude with a vision for how monitoring can contribute to rangeland information needs in the future.

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Publication

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Low sagebrush (*Artemisia arbuscula*) in southern Idaho. Photograph by Steven Hanser, U.S. Geological Survey.

Climate and Weather

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.

Storm brewing in mountain big sagebrush. 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 (Chambers and others, 2017). 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. Specifically, the work focuses on using an ecosystem water balance model to quantify how changing climatic conditions could impact the soil temperature and soil moisture conditions that define the regimes used in the resistance and resilience matrix. 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, the USGS has 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 approaching at Seedskadee National Wildlife Refuge in Wyoming. 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, the USGS is (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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Rangeland Carbon Balance and Precipitation Seasonality

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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Manuscript was approved on August 16, 2017

Prepared by the USGS Science Publishing Network Reston and
Rolla Publishing Service Centers
Edited by Natalie Juda
Layout by Suzanne C. Roberts

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Or visit the Sage-Grouse and Sagebrush Ecosystem Program
https://www.usgs.gov/science/mission-areas/ecosystems/sage-grouse-sagebrush-steppe

ISBN 978-1-4113-4168-5
ISSN 1067-084X (print)
ISSN 2330-5703 (online)
https://doi.org/10.3133/cir1436