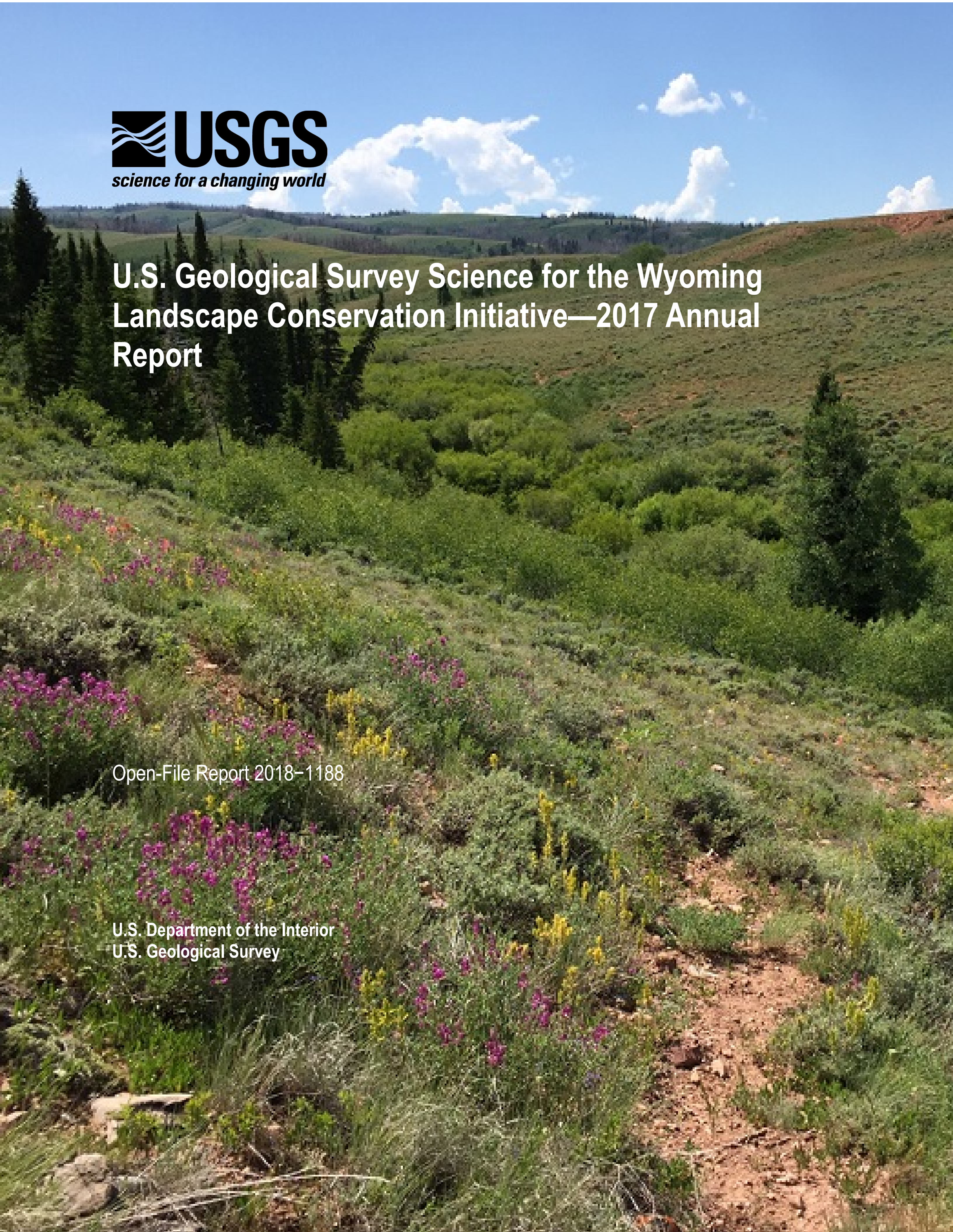

U.S. Geological Survey Science for the Wyoming Landscape Conservation Initiative—2017 Annual Report

Open-File Report 2018–1188

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

Front cover. The Beaver Creek drainage basin in the Wyoming Range, Wyoming. Photograph by Cheryl Eddy-Miller, U.S. Geological Survey.

Back cover. Participants in the Aspen Days workshop discuss aspen regeneration in the Bighorn Mountains, Wyoming, August 2017. Photograph by Tim Assal, U.S. Geological Survey.

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Open-File Report 2018–1188

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

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

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

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

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Conversion Factors

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)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)

Common and Scientific Species Names

Common name	Scientific name
Animal species	
Brewer's sparrow	*Spizella breweri*
Colorado River cutthroat trout	*Oncorhynchus clarkii pleuriticus*
Deer mouse	*Peromyscus maniculatus*
Elk	*Cervus elaphus*
Greater sage grouse	*Centrocercus urophasianus*
Moose	*Alces alces*
Mountain sucker	*Catostomus platyrhynchus*
Mottled sculpin	*Cottus bairdii*
Mule deer	*Odocoileus hemionus*
Pronghorn	*Antilocapra americana*
Pygmy rabbit	*Brachylagus idahoensis*
Sage thrasher	*Oreoscoptes montanus*
Sagebrush sparrow	*Artemisiospiza nevadensis*
Plant species	
Antelope bitterbrush	*Purshia tridentata*
Aspen	*Populus tremuloides*
Cheatgrass	*Bromus tectorum*
Chokecherry	*Prunus virginiana*
Curl-leaf mountain mahogany	*Cercocarpus ledifolius*
Mountain mahogany	*Cercocarpus montanus*
Sagebrush species	*Artemisia* spp.
Western serviceberry	*Amelanchier alnifolia*
Willow species	*Salix* spp.

Abbreviations

BLM	Bureau of Land Management
FY	fiscal year*
IA	Integrated Assessment (for the Wyoming Landscape Conservation Initiative)
LPDT	Local Project Development Team
USGS	U.S. Geological Survey
WGFD	Wyoming Game and Fish Department
WLCI	Wyoming Landscape Conservation Initiative

*The Federal fiscal year runs from October 1 through September 30; FY2017 covered October 1, 2016, through September 30, 2017.

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U.S. Geological Survey Science for the Wyoming Landscape Conservation Initiative—2017 Annual Report

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Abstract

The Wyoming Landscape Conservation Initiative (WLCI) was established in 2008 to address the scientific and conservation questions associated with land use changes because of energy development and other factors in southwest Wyoming. Over the past decade, partners from U.S. Geological Survey (USGS), State and Federal land management agencies, universities, and the public have collaborated to implement a long-term (defined here as more than 10 years), science-based program that assesses and enhances the quality and quantity of wildlife habitats in this region while facilitating responsible development. The USGS Science Team completes scientific research and develops tools that inform and support WLCI partner planning, decision making, and on-the-ground management actions. In fiscal year 2017, USGS published 18 products (including peer-reviewed journal articles, USGS series publications, and data releases), prepared an additional 7 products for publication, and presented 14 talks or posters at professional scientific meetings in addition to numerous informal presentations to WLCI partners at meetings and workshops. In this report, we summarize the science themes that describe USGS science for the WLCI and highlight work completed in fiscal year 2017 for each science theme. We also provide information on how USGS science is being used by land managers to better achieve habitat conservation objectives.

Introduction

The rapid expansion of energy development in southwest Wyoming that began in the early 2000s led to an increased interest in its economic benefits to local economies as well as concerns about wildlife, rangelands, water, communities, and wide-open spaces that characterize this landscape. Recreation, ranching, and farming economies form much of the rich cultural history and socioeconomic fabric of the communities of southwest Wyoming, but the region's economy also relies on abundant mineral and energy resources, including oil, gas, coal, wind, solar, trona, uranium, and phosphate. Increased human population and associated development across the region have accompanied the growth in energy and mineral extraction, adding to the changing land uses affecting the area.

The Wyoming Landscape Conservation Initiative (WLCI) was established a decade ago in 2008 by the U.S. Geological Survey (USGS) and public agencies with jurisdiction over land and (or) natural resources in southwest Wyoming (fig. 1) to address the scientific and conservation questions associated with land use changes in the region (D'Erchia, 2016). The WLCI partner agencies outlined the initiative's mission, objectives, organization, and partner roles. The goal of the WLCI is the implementation of a long-term, science-based program to assess and enhance the quality and quantity of aquatic and terrestrial habitats at a landscape scale in southwest Wyoming while facilitating responsible development through local collaboration and partnerships.

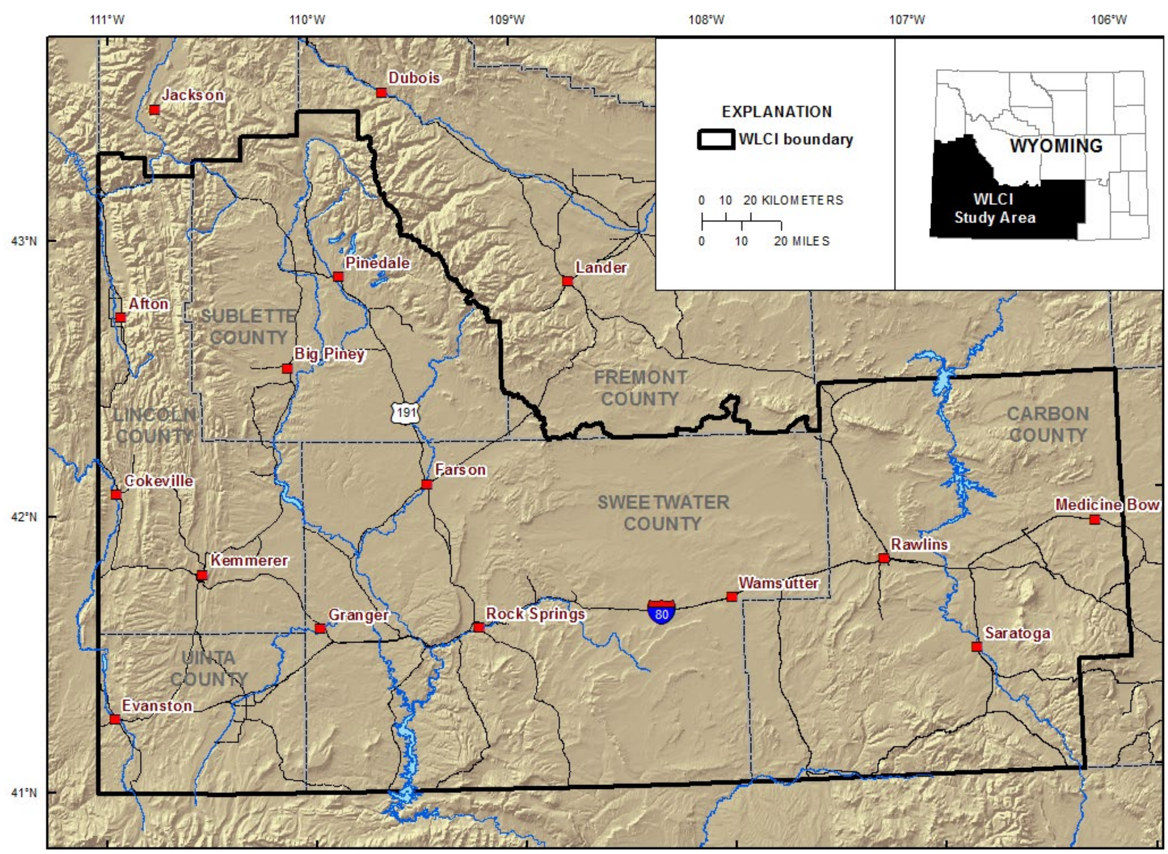

Figure 1. The boundary and major features of the Wyoming Landscape Conservation Initiative (WLCI) region.

Participants at early meetings and workshops identified potential partners, major management needs and objectives, focal habitats, and wildlife Species of Greatest Conservation Need (Wyoming Game and Fish Department, 2010) that would be central to WLCI-funded activities. At that time, the management needs and objectives that were identified (D'Erchia, 2008) fell into four broad categories:

- Identify and assess the cumulative environmental effects (current [as of 2008] and future) associated with energy resource development and other major drivers of landscape change.
- Develop methods for efficient, effective monitoring of ecosystem conditions across a vast and heterogeneous landscape.
- Evaluate the efficacy of habitat enhancement and restoration projects in meeting objectives.
- Develop the tools for housing, presenting, and disseminating data and other information to support planning and decision making for conserving ecosystem function and integrity in the WLCI region.

Roles of the U.S. Geological Survey in the Wyoming Landscape Conservation Initiative

The WLCI incorporates findings from scientific research into landscape-scale conservation planning, leading to measurable improvements in ecosystem functions. Science and conservation go together in the WLCI approach. Science provides information and support for conservation planning efforts and tools to evaluate the success of conservation activities. The following sections describe the role that USGS science plays in the WLCI partnership.

The Science Team

The USGS Science Team, a multidisciplinary team of more than 25 scientists and technological experts, includes terrestrial and aquatic ecologists; energy and mineral geologists; hydrologists; socioeconomic scientists; geographers; and specialists in remote sensing, geographic information systems, and geospatial analysis. The Science Team completes scientific research and develops tools that inform and support WLCI partner planning, decision making, and on-the-ground management actions. Results of USGS science serve as building blocks for future science projects. The Science Team integrates the approaches and results of many disciplines to enhance the scope and depth of its assessments, monitoring activities, research capacities, and products.

A member of the Science Team also acts as a liaison to the WLCI Coordination Team. The liaison facilitates coordination, communication, and activities among WLCI partners; helps WLCI partners integrate new information and technologies in their planning, decision making, and management actions; and facilitates the dissemination, interpretation, and use of USGS findings, products, and tools. The WLCI holds regular Local Project Development Team (LPDT) meetings, where public participation is needed and expected. There are four geographically organized LPDTs made up of stakeholders and managers that meet four times each year to plan and prioritize conservation needs, review past conservation actions and share information about their effectiveness, and provide tours and discussions regarding local conservation issues. The collaborative WLCI effort considers all activities on the landscape, incorporates multiple needs and concerns in project implementation, and leverages resources to accomplish more.

How We Work

The USGS Science Team uses a science-based approach to address resource management needs identified by WLCI partners. This three-phase process began by assessing what is already known about southwest Wyoming's ecosystems and the people who use the land, followed by completing monitoring and research to detect changes and improve knowledge of these ecosystems, and then developing ways to use and share that knowledge. The three phases are intended to be iterative, building continuously upon what has already been learned. Data compiled during assessments, monitoring, and novel research are combined with local input and knowledge to develop and implement conservation actions, such as habitat improvement projects (WLCI Science and Management Integration Plan, 2008; Bowen and others, 2009b). Research and monitoring are employed by USGS and other WLCI partners to evaluate effectiveness of conservation actions at achieving management objectives. This information, in turn, can be used to inform decision making for future conservation actions.

Moving Forward

Now, 10 years after the inception of the WLCI, USGS scientists, along with partners from other Federal science and land management agencies, State resource management agencies, and universities, have produced hundreds of products, including peer-reviewed scientific manuscripts, brochures, and government reports; publicly available maps and datasets; presentations and posters at workshops and meetings for the scientists, managers, and the public; and websites containing information about WLCI projects and data. In past years, we organized our science efforts and accomplishments following the funding structure of USGS. In this current annual report, we are organizing our research and accomplishments based on ecological themes that closely align with WLCI conservation priorities. These science themes will be evident in updated WLCI websites and current and future WLCI annual reports. In the following sections, we summarize this year's WLCI science themes that broadly categorize most of the completed and ongoing WLCI science, and we provide information on activities conducted in fiscal year (FY) 2017 for each science theme.

WLCI Science Themes

Natural Resources and Land Use Patterns
Water Resources
Ecology of Focal Wildlife Species Important to WLCI Partners
Mapping and Characterizing the Status and Trends of Focal Habitats
Relationships between Energy Development and Fish, Wildlife, and their Habitats
Supporting Conservation Planning and Conservation Actions

A Guide to Using This Report

The USGS has produced a comprehensive annual report to highlight its WLCI science accomplishments for each Federal fiscal year (FY2017 runs from October 1, 2016, to September 30, 2017) since inception of the WLCI (Bowen and others, 2009a, 2010, 2011, 2013, 2014a, b, 2015, 2016, 2018). Past reports can be accessed at the web addresses listed in the box below. This open-file report is the 10th WLCI annual report, and it highlights USGS science activities conducted in FY2017. The FY2017 activities and their relations to WLCI science themes and other WLCI activities are summarized in table 1.

Previous WLCI Annual Reports

2016 Annual Report: https://doi.org/10.3133/ofr20181048
2015 Annual Report: https://doi.org/10.3133/ofr20161141
2014 Annual Report: https://doi.org/10.3133/ofr20151091
2013 Annual Report: https://doi.org/10.3133/ofr20141213
2012 Annual Report: https://doi.org/10.3133/ofr20141093
2011 Annual Report: https://pubs.usgs.gov/of/2013/1033/
2010 Annual Report: https://pubs.usgs.gov/of/2011/1219/
2009 Annual Report: https://pubs.usgs.gov/of/2010/1231/
2008 Annual Report: https://pubs.usgs.gov/of/2009/1201/

To help WLCI partners focus on accomplishments, products, take-home messages, and applications of USGS work, this report provides (1) an overview of the new WLCI science themes and highlights of FY2017 science accomplishments (p. 8–17) and (2) individual one- to two-page reports for each FY2017 project, including snapshots of project needs and objectives, general approaches, recent findings, and major products (p. 18–48). Individual reports include indepth information on each new project. Indepth information on ongoing and completed projects is included in earlier annual reports. Project reports also include, where applicable, web addresses to directly access USGS and outside products published in FY2017. For more information on USGS WLCI activities, including coordination and integration, and evaluations of USGS science, contact the USGS Fort Collins Science Center (970–226–9100), Patrick Anderson (970–226–9488; andersonpj@usgs.gov) or Zachary Bowen (970–226–9218; bowenz@usgs.gov).

Table 1. Summary of U.S. Geological Survey science projects conducted in fiscal year 2017 organized by science theme for the Wyoming Landscape Conservation Initiative (WLCI).

[The summary includes project title; status as of September 30, 2017; focal species; and (or) habitats addressed by the project. The project titles and page numbers have been hyperlinked to the project reports included later in this report. Projects having no hyperlink or page number do not have an individual report because they had no substantial activity in current fiscal year. FY, fiscal year; no., number; N/A, not applicable].

Project title	Status at end of FY2017	Focal species and (or) habitat[1]	Page no.
Natural Resources and Land Use Patterns			
Modeling Land Use/Land Cover Change	Completed	Greater sage grouse, pygmy rabbit, mule deer; all focal habitats	N/A
Water Resources			
Long-Term Monitoring of Surface Water, Groundwater, and Water Quality	Ongoing	Riparian, aquatic	18
Evaluation of Groundwater Interaction with Small Streams in the Western Green River Basin to Enhance Understanding of Aquatic Communities	Ongoing	Aquatic	21
Long-Term Groundwater-Streamgage Data and Geologic Unit Description	Completed	Aquatic	22
Synoptic Streamflow Measurements on the New Fork and Green Rivers	Completed[2]	Aquatic	N/A
Ecology of Focal Wildlife Species Important to WLCI Partners			
Modeling Greater Sage Grouse Population Responses to Landscape Changes	Ongoing	Greater sage grouse; sagebrush steppe, sage grouse core areas	23
Identifying Impediments to Wyoming Mule Deer Seasonal Movements and Long Distance Migration	Ongoing	Mule deer; mixed mountain shrubland (crucial winter habitat)	25
Mapping and Characterizing the Status and Trends of Focal Habitats			
Framework and Indicators for Long-Term Monitoring	Ongoing	All focal habitats	27
Time-Series Analysis of Multiresolution Imagery to Quantify Sagebrush Defoliation and Mortality in Southwest Wyoming	Ongoing	Sagebrush species; sagebrush steppe	28
Remote Sensing and Vegetation Inventory and Monitoring	Ongoing	Sagebrush species; sagebrush steppe	30
Mapping Mixed Mountain Shrub Communities to Support Wyoming Landscape Conservation Initiative Conservation Planning and Monitoring of Habitat Treatments	Ongoing	Mountain mahogany and curl-leaf mountain mahogany, western serviceberry, chokecherry, antelope bitterbrush; mixed mountain shrubland	32
Status and Trends of Aspen and Willow Communities in the Bighorn Mountains	Ongoing[3]	Aspen, willow	33
Relations between Energy Development and Fish, Wildlife, and their Habitats			
Investigating the Influences of Oil and Gas Development on Greater Sage Grouse	Ongoing	Greater sage grouse; sagebrush steppe, sage grouse core areas	35

Table 1. Summary of U.S. Geological Survey science projects conducted in fiscal year 2017 organized by science theme for the Wyoming Landscape Conservation Initiative (WLCI).—Continued

[The summary includes project title; status as of September 30, 2017; focal species; and (or) habitats addressed by the project. The project titles and page numbers have been hyperlinked to the project reports included later in this report. Projects having no hyperlink or page number do not have an individual report because they had no substantial activity in current fiscal year. FY, fiscal year; no., number; N/A, not applicable].

Project title	Status at end of FY2017	Focal species and (or) habitat[1]	Page no.
Identifying Threshold Levels of Energy Development that Impede Wyoming Mule Deer Migrations	Ongoing	Mule deer; mixed mountain shrubland (crucial winter habitat)	36
Wind Energy and Wildlife in Southwest Wyoming	Ongoing	At-risk birds, bats, and other wildlife	37
Relationship Between Energy Development and Pygmy Rabbit Presence and Abundance	Ongoing	Pygmy rabbit; sagebrush steppe	38
Mechanistic Understanding of Energy Resource Development Effects on Songbirds	Ongoing	Brewer's sparrow, sagebrush sparrow, sage thrasher; sagebrush steppe	40
Drivers of Native Fish Community Response to Oil and Gas Development	Ongoing	Mountain sucker, mottled sculpin, Colorado River cutthroat trout, other native fish species; aquatic, riparian	42
Supporting Conservation Planning and Conservation Actions			
Application of Comprehensive Assessment to Support Decision Making and Conservation Actions	Ongoing	Any species and focal habitat in WLCI study area	43
Plant Phenology Metrics to Evaluate Sagebrush in the Wyoming Landscape Conservation Initiative Region	Ongoing	Mule deer, elk, sagebrush species; sagebrush steppe	44
Greater sage grouse use of vegetation treatments	Ongoing[4]	Greater sage grouse; sagebrush steppe	N/A
Aspen regeneration associated with mechanical removal of subalpine fir	Completed[2]	Aspen, conifer species	N/A
Herbivory, stand condition, and regeneration rates of aspen on burned and unburned plots	Completed[2]	Aspen	N/A
Economics of Greater Sage Grouse Conservation Strategies	New	Greater sage grouse; sagebrush steppe	46
Modeling Recovery of Sagebrush Across the Wyoming Landscape Conservation Initiative Using Remotely Sensed Vegetation Products	New	Sagebrush steppe	48

[1]Scientific names of focal species: Animals—Greater sage grouse (*Centrocercus urophasianus*), pygmy rabbit (*Brachylagus idahoensis*), mule deer (*Odocoileus hemionus*), Brewer's sparrow (*Spizella breweri*), sagebrush sparrow (*Artemisiospiza nevadensis*), sage thrasher (*Oreoscoptes montanus*), mountain sucker (*Catostomus platyrhynchus*), mottled sculpin (*Cottus bairdii*), Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*), elk (*Cervus elaphus*). Plants—sagebrush species (*Artemisia* spp.), mountain mahogany (*Cercocarpus montanus*), curl-leaf mountain mahogany (*Cercocarpus ledifolius*), western serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*), antelope bitterbrush (*Purshia tridentata*), aspen (*Populus tremuloides*), willow (*Salix* spp.).

[2] Major phase of project completed in FY2017, but some final products continue to be produced.

[3] New project phase or new focus and title.

[4] Activities that entail ongoing work, including analysis, development of data-processing scripts, and (or) other product development, but which did not have major outcomes or products in FY2017 are not included in this report. See prior annual reports for more information on these projects.

Wyoming Landscape Conservation Initiative Science Themes and Fiscal Year 2017 Accomplishments

We have organized USGS research and accomplishments under several ecological themes that closely align with WLCI conservation priorities. These WLCI science themes broadly categorize most of the completed and ongoing WLCI science. We provide information on activities conducted in fiscal year (FY) 2017 for each science theme.

Natural Resources and Land Use Patterns

The goal of USGS natural resource and land use research is to identify land-management strategies that maximize persistence of habitat for wildlife species of special concern under future potential land uses and climatic conditions. Southwest Wyoming plays an important role in providing for increasing natural resource demands of the United States. Energy resources are abundant (Kirschbaum and others, 2002; U.S. Geological Survey, 2005) and include wind, natural gas, oil, coal, and uranium. Oil and gas development increased substantially in the region from 1990 to 2010 (Biewick, 2011) and development continued at a steady rate, though there have been some declines in the past 2–3 years (Petroleum Association of Wyoming, 2018; U.S. Energy Information Administration, 2018). Major mineral resources include phosphate and trona (sodium bicarbonate, a key component of many manufacturing processes), as well as other base (common and inexpensive) and precious (rare and valuable) minerals (Wilson and others, 2016). Mining products are among the top exports for the State of Wyoming and are vital components of the State's economy; however, mining and energy extraction activities are also important drivers of change on this landscape, affecting wildlife habitats, water quality, ranching and farming, and recreational opportunities that are vital to southwest Wyoming's ecology, economy, society, and culture (D'Erchia, 2008).

Energy and mineral development is accompanied by substantial disturbance (Hawkins and others, 2012; Brittingham and others, 2014), through the extraction process itself and the supporting infrastructure (such as roads, storage tanks, and pipelines). This disturbance can affect wildlife species in many ways, including through habitat fragmentation and habitat loss (Connelly and others, 2000), obstruction of migration routes (Sawyer and Kauffman, 2011), reduced water quality and quantity (Entrekin and others, 2015; Healy and others, 2015), and contamination of soil and water by toxic elements to name a few (Hinck and others, 2006; Bern and others, 2015). Future effects of natural resource development in southwest Wyoming will depend on the type and location of resources developed. Combining information on areas of active and potential future resource development and extraction in the WLCI region with data on critical wildlife habitat can allow planning for resource extraction at times and (or) locations that minimize effects on wildlife and plants (Bureau of Land Management, 2006, 2008).

Geologists from the USGS Energy Resources and Mineral Resources Programs have assessed energy and mineral resources within the WLCI region (Biewick, 2009, 2011; Biewick and Jones, 2012; Biewick and others, 2013; Biewick and Wilson, 2014; Wilson, 2015; Wilson and others, 2016). Social scientists have surveyed local ranchers and farmers to determine their perceptions of how energy development affects the economy, society, and culture of the region (Assal and Montag, 2012; Allen and others, 2014) and have developed a map of important agricultural lands in southwest Wyoming (Bowen and others, 2016). USGS scientists are combining these maps of energy and mineral resources with data on vegetation and wildlife habitat selection to create predictive models of the effects of current and future resource development on wildlife (Garman, 2018).

In FY2017, there were no active projects (and therefore, no individual project reports) in the science theme of natural resources and land use patterns, but one project had the final publication released online (the print version of the publication became available in FY2018). Garman (2018) developed a model to simulate energy development across the WLCI landscape to better understand the implications of current and future development on habitats and wildlife populations (https://my.usgs.gov/bitbucket/projects/WLCI/repos/energy_footprint_model/). Simulated development locations were guided by Bureau of Land Management (BLM) Environmental Impact Assessments and Records of Decision. Rules for development patterns, such as well, well pad, and road densities and locations, were derived from BLM specifications and historical patterns. Development scenarios included a gradient of the number of vertical and directional wells and the number of pads created, enabling explicit consideration of the implications of new technologies and development practices on wildlife and their habitats. Comparison of scenarios allowed consideration of the implications for surface disturbance area as well as potential effects on wildlife, such as big game, greater sage grouse, songbirds, and pygmy rabbits. This tool will allow planners and managers to consider tradeoffs among build-out scenarios facilitating the balance of energy development with other land uses and wildlife conservation.

Water Resources

The goal of USGS water resources research in the WLCI region is to assess and monitor water quality and quantity, to provide information about aquatic habitats, to study the dynamics of groundwater and surface waters, and to understand the effects of energy development on water resources. In arid southwest Wyoming, water is vital to the existence of wildlife and to the health of communities, and is crucial to the success of farming and ranching operations as well. Energy and other resource development can affect water quality, streamflow, and aquatic habitats (Brittingham and others, 2014; Vengosh and others, 2014; Entrekin and others, 2015; Healy and others, 2015). Land managers need information about aquatic habitats, water quality, and the dynamics of groundwater and surface waters to understand the effects of energy development on water resources and the fish and wildlife species they support (D'Erchia, 2008). Long-term monitoring of water resources allows assessment of trends in water quality and quantity; facilitates evaluation of the effectiveness of restoration, mitigation, or reclamation activities; and informs adaptive management for future land use planning (Taylor and Alley, 2001).

USGS water resources research in the WLCI region is led by hydrologists from the USGS Wyoming-Montana Water Science Center (https://www.usgs.gov/centers/wy-mt-water/science/wyoming-landscape-conservation-initiative). This work focuses on understanding the foundational dynamics of water in the region and development of monitoring strategies that will inform land use planning and resource management. Through partnership with the existing Wyoming Groundwater Quality Monitoring Network, expanded information on water quality in the region is being collected as well as long-term monitoring of groundwater, surface water, and water quality in the upper Green River and Muddy Creek watersheds (Boughton, 2011, 2014). Many USGS water studies contribute baseline information for the WLCI region and provide data for detection of trends in water quality and changing water dynamics in specific watersheds or subbasins in the WLCI (Soileau and Miller, 2013). USGS water research also supports ongoing studies of native fish communities through a study of groundwater and surface-water interactions (Bowen and others, 2016, 2018).

To help evaluate future changes and assist in decision making, we developed a potentiometric-surface map (a visual representation of aquifer-water levels and flow directions) for the aquifer system that underlies the upper Green River Basin (Bartos and others, 2015). We have conducted studies of the Muddy Creek watershed that provide information on the geochemistry of this stream and surrounding soils and focus on salinity and trace elements such as selenium (Clark and Davidson, 2009; Bern and others, 2015).

In FY2017, 3 WLCI water resources projects resulted in 2 publications and online data available for all projects. On the first project, we continued monitoring streamflow and surface-water quality at four sites and groundwater levels at four sites. All streamflow, groundwater, and water-quality data are available online (https://www.usgs.gov/centers/wy-mt-water/science/wyoming-landscape-conservation-initiative). Initial findings indicate that streamflow and water quality are highly variable among streams and within the same stream in the WLCI area.

We continued data collection to better understand groundwater interactions with small streams in the western Green River Basin (Bowen and others, 2016, 2018) as part of the second project. This study is designed to assist in determining the health of all aquatic species in support of research being conducted by the Wyoming Cooperative Fish and Wildlife Studies Unit on effects of oil and gas development on native fish communities (see "Drivers of Native Fish Community Response to Oil and Gas Development" section on p. 77). An understanding of streamflow and where flows are sustained along the stream channel throughout the year will elucidate changes and differences in aquatic communities across the western Green River Basin. We are developing a new model to help explain why some streams flow perennially and some are intermittent because traditional methods of analysis were inconclusive for explaining how groundwater contributes to streamflow. This new approach uses a geospatial model based on many streamflow variables to identify the most important drivers of perennial streamflow in hydrologic small basins.

Establishing the real-time data collection equipment at the streambank groundwater monitoring well at Green River LaBarge streamgage. Photo by Jerrod D. Wheeler, U.S. Geological Survey.

Activities on the third project included continued development of a groundwater flow model based on data from streamside monitoring wells installed in FY2015 (Bowen and others, 2016). This model will help us understand how groundwater contributes to streamflow in the Green River Basin and will be important for managing water resources of the basin. We also published a detailed description of the lithology and physical characteristics of core sections from the Wasatch Formation near the New Fork River (Hallberg and others, 2017).

Ecology of Focal Wildlife Species Important to Wyoming Landscape Conservation Initiative Partners

WLCI research on the ecology of focal wildlife species gathers information on habitat requirements, seasonal movements, population trends, and drivers of change for several key wildlife species or species assemblages. Southwest Wyoming encompasses vast areas of high-quality crucial wildlife habitat for many high-profile game species such as elk (*Cervus elaphus*), moose (*Alces alces*), pronghorn (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*), as well as large habitat areas for greater sage grouse (*Centrocercus urophasianus*; Wyoming Game and Fish Department, 2017). Wildlife species that range over large areas may be vulnerable to population decline even when their populations are stable elsewhere in the surrounding landscape (Edmunds and others, 2018); however, basic information on habitat requirements, population trends, and animal movements for many important species are lacking (Keinath, 2015).

WLCI partners have identified five focal species/species assemblages that are priorities—pygmy rabbits (*Brachylagus idahoensis*), mule deer and pronghorn, sage grouse, native fish communities, and songbird communities. Collaborators in this research include USGS Fort Collins Science Center, USGS Northern Rocky Mountain Science Center, USGS Wyoming-Montana Water Science Center, Wyoming Cooperative Fish and Wildlife Research Unit at the University of Wyoming, Wyoming Natural Diversity Database, WEST Inc., and Wyoming Game and Fish Department (WGFD). Our studies over the past decade have been directed at assessing population trends and distributions of sage grouse (Fedy and Aldridge, 2011; Fedy and others, 2012; O'Donnell and others, 2015) and pygmy rabbits (Germaine and others, 2014); aspects of habitat use and requirements for all five priority species/assemblages; migratory songbird use of aspen stands (Bowen and others, 2013); and patterns of seasonal movement for breeding, nesting, and brood rearing in sage grouse (Fedy and Aldridge, 2011; Fedy and others, 2012) and migration in mule deer (Allen and Kauffman, 2012; Sawyer and Kauffman, 2011).

In FY2017, this work involved 2 species, greater sage grouse and mule deer, and led to 5 published products. We evaluated how grazing relates to sage grouse population trends across Wyoming (Monroe and others, 2017). Results illustrated that grazing may have positive and negative effects on sage grouse population trends depending on grazing timing and level, possibly reflecting the sensitivity of cool season grasses to grazing during peak growth periods. We developed a simulation framework that spatially evaluates long-term population viability of sage grouse (Heinrichs and others, 2017). We determined that areas that have lower habitat selection identified from seasonal habitat models could be important in sustaining the "overflow" of sage grouse during times of periodic high density, possibly reducing the risk of population declines and extinctions. Additionally, habitats of lesser quality near high-quality habitats can be important for sustaining viable populations of sage grouse. We analyzed sage grouse population trends across large-scale management units and determined that populations may have similar trends but different trajectories in individual core areas (Edmunds and others, 2018). We also developed hierarchical population clusters that more accurately reflect biologically significant population units, which will contribute to understanding drivers of population change (Coates and others, 2017).

In FY2017, we completed our first analysis of green-wave surfing in mule deer that migrate along the Wyoming Range (Aikens and others, 2017). We demonstrated that mule deer movements and migration timing closely track (surf) spring green-up patterns ("green-wave surfing"). Our findings indicated that alterations to green-up patterns strongly affected surfing. We continued long-term monitoring of the Red Desert to Hoback mule deer migration and increased our sample size of collared adult female mule deer. In addition, we deployed trail cameras along the migration corridor, including areas where migration routes cross fences and highways. This work contributed to the publication of a migration atlas for Wyoming ungulates that was in press at the end of FY2017 (Kauffman and others, 2018).

Mapping and Characterizing the Status and Trends of Focal Habitats

Research on the status and trends of focal habitats centers on identifying the distribution, condition, and ecological functions of important habitats in the WLCI region and examining trends in the condition of these habitats over time. A total of five focal habitats in southwest Wyoming—sagebrush (*Artemisia* spp.), mountain shrub, aspen (*Populus tremuloides*), riparian, and aquatic—have been identified as priority habitats for WLCI research and conservation. These areas provide crucial habitat for mule deer, elk, pronghorn, greater sage grouse, and a variety of fish as well as nongame bird and mammal species. Information on the condition and distribution of priority habitats and of wildlife populations that rely on these habitats is needed to inform resource planning. WLCI habitat conservation projects aim to preserve or improve condition in these priority habitats, but it is important to evaluate the efficacy of conservation management actions to assure that they are achieving their intended purposes.

In the WLCI region, we are identifying condition, trends, and important ecological functions in semiarid woodlands (Assal and others, 2015) and mixed mountain shrublands (Bowen and others, 2014a), and investigating the extent and trends in sagebrush die-off (Assal and others, 2016). To support habitat and movement analyses, USGS ecologists and biologists are developing new methods to use remotely sensed data to provide information on vegetation distribution, to monitor vegetation condition (Homer and others, 2015), and to track seasonal greenup of vegetation (Chong and Allen, 2012). To understand patterns of change (including historical changes) within sagebrush habitats that support many of these focal species across the WLCI region, our team has used satellite imagery and data to monitor long-term changes in vegetation cover (Homer and others, 2009, 2013; Xian and others, 2011, 2012). We have coupled information gained from historical data with future climate projections to assess potential changes in sagebrush habitats over the next three decades (Homer and others, 2015).

The results of these studies have many practical applications. The knowledge we have gained about habitat distribution, quality, use, and occupancy for individual species can assist in prioritization of areas for conservation, restoration, and mitigation (Bowen and others, 2009b). For example, we have linked plant greenness to mule deer migration, which may help in preserving migration corridors and important stopover areas (Aikens and others, 2017). The ability to assess past climatic trends and current vegetation condition to forecast the future extent and condition of wildlife habitat (Homer and others, 2015) can be a valuable tool to help land managers plan development in a manner that best sustains wildlife habitat (Kitchell and others, 2015). Currently, we are using these baseline data to move forward with studies of energy development and its potential effects on focal wildlife and their habitats (Hethcoat and Chalfoun, 2015 a, b; Edmunds and others, 2018; Garman, 2018).

In FY2017, five projects focused on the status and trends of mixed mountain shrublands, sagebrush steppe, and aspen/deciduous habitats in FY2017. This work resulted in 2 data releases and 4 presentations, as well as publication of the WLCI Monitoring Fact Sheet (Manier and others, 2017), which summarizes the purpose and value of research and monitoring of resources and wildlife across WLCI.

We started a new phase of research on deciduous tree and shrub communities by applying approaches developed within the WLCI to assess the status and condition of aspen communities to areas outside the WLCI. The WGFD and the Bighorn National Forest began research with

USGS to assess the current trends of aspen and willow (*Salix* spp.) communities in the Bighorn Mountains. In FY2017, the USGS created a synthesis map of coniferous and deciduous communities in the Bighorn Mountains of Wyoming (Assal, 2018a) using a species distribution modeling approach developed in the WLCI's Little Mountain Ecosystem (Assal and others, 2015).

Three projects focused on trends in sagebrush communities in the WLCI. We completed the first phase of a project examining the extent and causes of sagebrush mortality using long-term satellite data to determine how drought affected sagebrush vegetation in space and time and to examine the relationship among temperature and moisture and vegetation responses (Assal, 2018b). Results indicated that vegetation response was not solely affected by a lack of precipitation; temperature also had a strong effect on productivity during drought events.

In FY2017, we also continued monitoring of long-term change in vegetation across the WLCI using ground and satellite measurement (Homer and others, 2015). Preliminary analysis of ground transect measurements taken between 2008 and 2016 indicate significant change in shrub, sagebrush, herbaceous, and bare ground cover on ground transects. Trend analysis of changes from 2008 to 2017 along transects reveals the average shrub canopy, average sagebrush canopy, and average herbaceous canopy have increased, whereas bare ground has decreased. These changes likely reflect changes in climate, because increasing precipitation and increasing minimum and maximum temperatures were measured during this same period. We began production of new and updated historical mapping products for WLCI in FY2017, incorporating methodological improvements and data to provide a complete historical analysis of component change (five components of vegetation cover—shrubs overall, sagebrush, herbaceous vegetation, litter, and bare ground—which are quantified at 1-percent intervals) back to 1985.

Scientists from several USGS Science Centers collected field data to assess postfire conditions of sagebrush communities across the Wyoming Basin Ecoregion (which includes the WLCI region), including seeded and untreated burned areas and a range of time since fire. Analyses indicated clear evidence of herbaceous species recovery; occasional, but not ubiquitous, invasion by cheatgrass (downy brome, *Bromus tectorum*); and reestablishment of sagebrush. Analysis of postfire treatment effects revealed positive effects of broadcast and drill seeding on sagebrush reestablishment and reduction of exposed bare ground after aerial and broadcast seeding; however, aerial seeding was significantly and positively correlated with abundance of cheatgrass.

Relationships Between Energy Development and Fish, Wildlife, and Their Habitats

Our research on the relationship between energy development and wildlife focuses on detecting the direct and indirect effects of energy development activities on five species or species assemblages identified by WLCI partners: pygmy rabbit, sage grouse, sagebrush songbirds, mule deer, and native fish communities. The WGFD lists more than 150 wildlife species in southwest Wyoming as Species of Greatest Conservation Need (Wyoming Game and Fish Department, 2017). Over the past decade, rapid energy development has happened in the region's sagebrush steppe, mountain shrublands, and watersheds that support many Species of Greatest Conservation Need (Headwaters Economics, 2009). Some potential effects of natural resource extraction on fish and wildlife include habitat fragmentation or loss, invasions of nonnative species, creation of barriers along migration routes, altered predator communities, and degraded water quality (Copeland and others, 2009; Brittingham and others, 2014; Souther and others, 2014; Keinath, 2015). To help address these concerns, our research efforts have focused on (1) documenting wildlife distributions, population trends, habitat requirements, and seasonal movements (see Ecology of Focal Wildlife Species section; Fedy and Aldridge, 2011; Sawyer and Kauffman, 2011; Allen and Kauffman, 2012; Fedy and others, 2012; Germaine and others, 2014; O'Donnell and others, 2015) and (2) conducting research on how energy development affects the habitats, behaviors, reproduction, and survival of native wildlife.

Energy development can affect wildlife, particularly focal wildlife species, through a variety of mechanisms (Brittingham and others, 2014). Oil and natural gas development may affect fish habitats and communities through loss of vegetation cover, pollution from oil and gas spills, and high levels of sediments and salts that erode from denuded slopes or run off from roads and into nearby streams (Entrekin and others, 2015). Large, intact patches of sagebrush habitat are important to many wildlife species in the WLCI region, including sage grouse, sagebrush-obligate songbirds, and pygmy rabbits (Green and Flinders, 1980; Baker and others, 1976; Connelly and others, 2000). Human activities and developments can alter the amount and quality of sagebrush habitat in several ways, including disturbance from noise and activities (Ingelfinger and Anderson, 2004; Francis and Barber, 2013); roads and disturbance can lead to increases in invasive plants (Manier and others, 2014) and changes in predator populations (Hethcoat and Chalfoun, 2015a, b). Migratory ungulates are susceptible to development along their migration routes (Lendrum and others, 2012; Sawyer and others, 2013). For migratory mule deer, migration corridors are key habitats where deer spend time foraging to regain energy stores along the route (Sawyer and Kauffman, 2011). Our research is working to identify the underlying mechanisms that drive changes to focal and other species' populations in areas where energy development is happening.

In FY2017, 6 ongoing research projects produced 4 published papers and data releases, 5 draft manuscripts, and 6 presentations. Green and others (2017) determined that increasing density of oil and gas development within 6.4 kilometers (km) of leks resulted in declining attendance of male sage grouse at those leks. Spatially explicit, individually based, population viability models for WLCI were developed to evaluate the effects of potential future energy development (as well as climate change) on sage grouse demography and habitat use.

Germaine and others (2017a, b) found gas field infrastructure to be negatively associated with pygmy rabbits. Pygmy rabbits became more likely to be absent than present once 1–2 percent of the area on a gas field was converted to roads, well pads, and pipelines, and pygmy rabbit abundance declined sharply once 2 percent of the area was developed.

We continued monitoring nests and nest predators of sagebrush-obligate songbirds to determine the spatial and temporal consistency of these relationships. As part of this project, we also examined alternative hypotheses for why there is an increase in nest predation by rodents where natural gas developments are located and discovered that mice utilize reclaimed areas for foraging. Reclaimed areas usually differ in vegetation composition from adjacent sagebrush patches. We detected several nonnative species of plants, located exclusively within reclaimed areas, in mouse diets. Collectively, our results indicate that energy development in western Wyoming increases songbird nest predation by attracting rodents to areas reseeded with forbs and grasses not typically found within native sagebrush steppe.

Wyckoff and others (2018) determined that development affects the ability of mule deer to track plant phenology by evaluating movement relative to three types of development (energy, residential, and dispersed rural) in southwest Wyoming. Specifically, mule deer shift their stopovers away from most types of development. In the rapidly developing Atlantic Rim project area, our findings indicated that deer have reduced ability to track phenology through time, linking development to the loss of the foraging benefits of migration.

We continued our studies of the response of native fish communities to energy development. In FY 2017, we collected our sixth year of fish community data and started analysis of data on two other important potential mechanistic pathways by which oil and gas development can affect fish: hydrology and resource availability. In addition, we measured physiological and immunological responses of mountain sucker (*Catostomus platyrhynchus*) and mottled sculpin (*Cottus bairdii*) to energy development. Preliminary results indicate differing physiological responses of the species to temperature and salinity.

Fish and aquatic habitat sampling site on Dry Piney Creek. Photo by Annika Walters, U.S. Geological Survey.

In FY2017, we completed an assessment of research needs and assembled spatial data for investigation of disturbances from wind developments. We compiled information on existing and proposed wind farms throughout Wyoming to determine their status, distribution, and overlap with areas of conservation concern for at-risk birds, bats, and other wildlife, including core areas for greater sage grouse and crucial range for ungulates.

Supporting Conservation Planning and Conservation Actions

Integration of science with conservation management is a key function of the USGS WLCI science program. The WLCI program conducts inventory and assessment of species and habitats to determine what habitat enhancement projects, such as vegetation treatments, are necessary and where these projects will be most beneficial to wildlife. The WLCI addresses the conservation aspects of its mission through LPDTs that identify the individual conservation needs for a particular geographic area and develop and prioritize projects such as fencing, wetland creation, vegetation treatments, riparian enhancements, weed treatments, and river restoration (see https://www.wlci.gov for more information on conservation projects).

USGS science supports conservation planning and actions of WLCI partners through several approaches. We compile and synthesize data from WLCI partners, USGS, and other sources to inform conservation planning. We design and conduct individual investigations to specifically assess the effectiveness of conservation actions and to evaluate long-term trends of focal habitats and their responses to drought and other drivers. We use data, maps, tools, and findings from studies designed to address other USGS WLCI science themes to further assess effectiveness of conservation actions and inform future planning. These activities help USGS integrate science with conservation actions and improve the ability of WLCI's land management agency partners to implement adaptive management strategies, best management practices, and prioritization of on-the-ground habitat projects.

We developed a comprehensive assessment to direct data synthesis and assessment activities, so they will inform and support LPDTs and the WLCI Conservation Team in their conservation planning efforts (Bowen and others, 2011, 2013, 2014a, b, 2015, 2016, 2018). The assessment included developing data and tools that assist with identifying landscape-level conservation priorities and strategies, prioritizing geospatial areas for future conservation actions, supporting the evaluation and ranking of conservation projects, and evaluating spatial and ecological relations between proposed habitat projects and WLCI priorities. The comprehensive assessment project also provides fiscal support for the development and publication of the USGS WLCI annual reports and revisions to USGS science narratives on the WLCI web page. A component of the comprehensive assessment includes a multidisciplinary Integrated Assessment (IA) of factors affecting successful conservation and management across the WLCI region (https://www.wlci.gov/integrated-assessment). The IA is a tool that was developed to identify areas of high conservation and restoration value and areas of high development potential, based on the current landscape; consider scenarios of potential future development; and evaluate the conservation and restoration potential of a given area. As conditions on the landscape change, the IA can provide a framework for conducting quick assessments by land managers to understand spatial and temporal trends and land use in the WLCI area.

We had 7 active projects directly supporting conservation planning and conservation actions in FY2017, resulting in 2 publications, 1 presentation, and 1 draft manuscript. Application of the comprehensive assessment and research on applications of plant phenology to habitat management continued as ongoing projects. One project (greater sage grouse use of vegetation treatments) had ongoing data collection but did not have major outcomes or products in FY2017. Two other projects (aspen response to burning and mechanical removal of subalpine fir) completed field data collection in FY2017, but some final products are yet to be produced. As a result, these three projects do not have individual project reports. We started two new studies, one addressing the economics of sage grouse conservation and the other using remote-sensing products, to evaluate vegetation recovery rates and how they vary as factors (such as climate, soils, restoration practices, and prior conditions) change.

In FY2017, we continued research at the intersection of wildlife, plant phenology, and habitat management. Our findings thus far indicate that drought interacts with the ability of mule deer to track plant phenology during spring migration, which has important implications for identifying migration routes and habitats for conservation (Aikens and others, 2017). We have also learned that phenology strongly affects elk calving locations. Changes in plant phenology correlate with declines in calf to cow ratios. Johnston and others (2018) determined that sagebrush reduction by prescribed fire has the most enduring effects on sagebrush communities.

We began an analysis of the economic value of sage grouse conservation in FY2017. Many resources have been directed at conservation efforts to help avoid Federal threatened species listing for the greater sage grouse. Unlike oil and gas products, the economic value of preserving sage grouse is not reflected in conventional markets and thus requires nonmarket valuation approaches. Our research indicates that sage grouse conservation strategies may be best framed as a “lowest-cost” economic problem; for example, if managing sagebrush density is the stated objective, a least-cost framework will help decide which habitat treatment options (for example, chemical, mechanical) will meet the stated goal in the cheapest way.

To improve our practical understanding of environmental effects on postdisturbance sagebrush recovery, we began a study using time-varying remote-sensing products to model rates of change in sagebrush cover over time. We evaluated effects of static and time-varying factors such as soils, topography, and weather. Understanding variations in recovery rates based on these factors could be helpful in determining the most effective conservation actions to be implemented given the characteristics of a particular site.

Our science activities in support of conservation actions also extended to data management and the comprehensive assessment. The comprehensive assessment is a collaborative effort among WLCI partners to collect and integrate data synthesis and assessment activities to support LPDTs and the WLCI Coordination Team to (1) develop landscape conservation priorities and strategies, (2) identify priority areas for future conservation actions, and (3) support the evaluation and ranking of conservation projects. In FY2017, members of the USGS Science Team assisted the WLCI Coordination Team to update the WLCI Conservation Action Plan and associated habitat treatment spatial database using information from FY2016 habitat projects. We linked the WLCI Conservation Project Database with project location boundaries so WLCI accomplishments and funding attributes can be presented as maps. We assisted with the 2016 BLM WLCI annual report and provided maps and other materials to support evaluations and rankings of WLCI conservation projects.

Project Reports

Water Resources

Long-Term Monitoring of Surface Water, Groundwater, and Water Quality

Riparian and aquatic ecosystems in semiarid landscapes like southwest Wyoming contribute substantially to regional biodiversity. Long-term monitoring data that describe streamflow, surface-water quality, and groundwater levels are needed for assessing possible effects of changes in land use on those ecosystems. WLCI funding supported collection of, continuous streamflow and surface-water quality, and monthly water-quality samples at four sites, and quarterly water-quality samples at one additional site (Green River near LaBarge). Groundwater levels and temperature have been monitored in four wells; two wells are at each site (fig. 2, table 2) since March 2015. We selected monitoring sites that would provide baseline characterization of the upper Green River and Muddy Creek watersheds.

Additionally, during FY2017, we used data collected at these four stream sites to describe water-quality trends. Results of the analyses of surface-water data indicated that dissolved minerals in the water have increased over time at the upper site on Muddy Creek, and this increase corresponds to increasing development; whereas no change in water quality under similar and even greater development conditions was observed at the sites on the New Fork River. Trend analyses of data from the other two sites had mixed results, and a definitive conclusion was not determined. The sensitivity of any stream system to energy development and other land disturbances was dependent on the amount and timing of precipitation inputs into the stream and the ability of groundwater to sustain the stream during times of the year when precipitation (or snowmelt) was low, combined with the soils and underlying geology of the drainage area. Streams in areas having highly erodible rocks where precipitation is lower will be more sensitive to development. Our results also indicated that in sensitive areas of low level development followed by oil and gas well maintenance (rather than development of new wells), water quality may improve due to long-term recovery of the landscape. During energy development, when wells are being drilled, there is a large amount of overall disturbance (large drill rigs, roads, ponds). But when wells are in place and extraction begins, human activity on the landscape is reduced, though not eliminated, as wells still must be maintained.

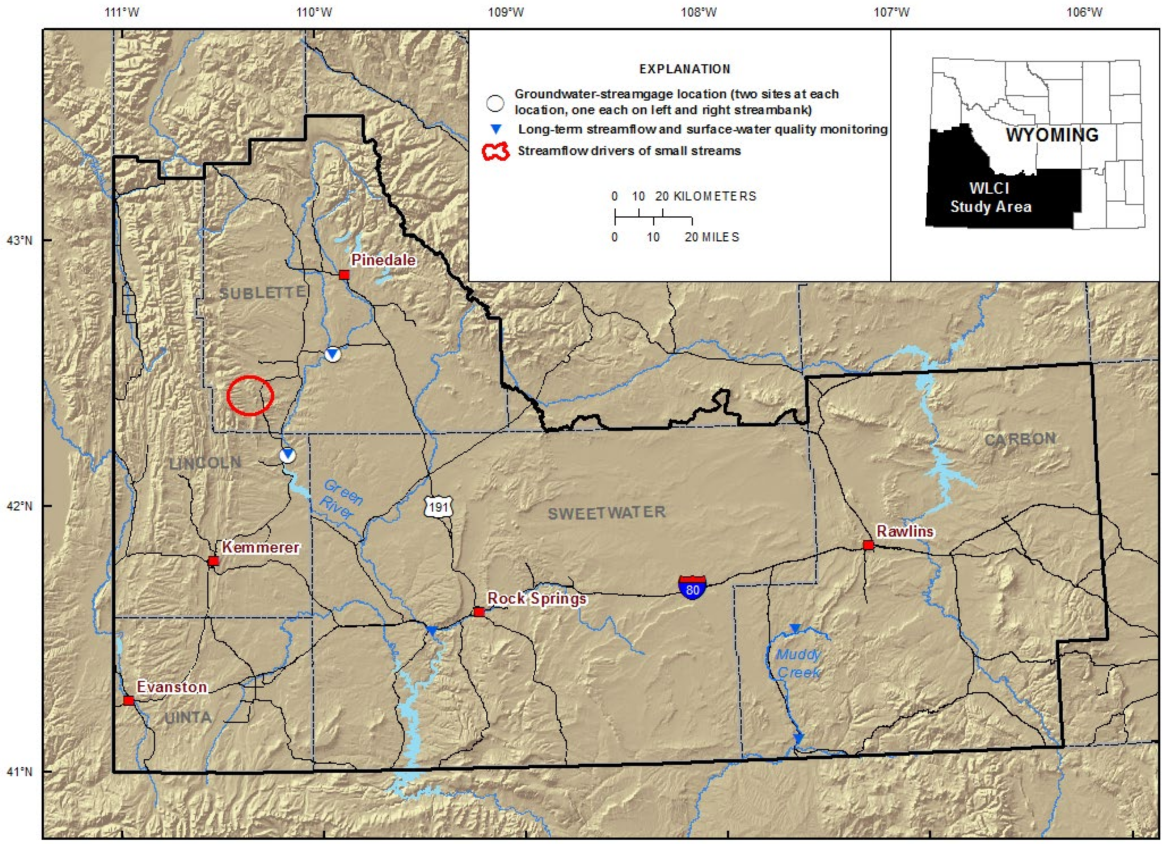

Figure 2. Locations of U.S. Geological Survey field-based study areas associated with long-term water monitoring projects during fiscal year 2017 in the Wyoming Landscape Conservation Initiative region.

These initial findings from our four WLCI study sites demonstrate great variability in streamflow and water quality among streams and within the same stream in the WLCI area. Additional data collection over a longer period will allow robust analysis to better understand these relations.

During FY2017, in addition to the data collection described above, we collected additional surface-water quality and quantity data in the WLCI area in cooperation with the State of Wyoming, BLM, and Bureau of Reclamation. We intend to combine these data to create a larger water-resources dataset that can be used to support resource management and research in the WLCI study area and beyond.

Accomplishments in Fiscal Year 2017

- Preliminary data for all sites were available in real time, and for each site, we published an online annual report that finalizes and summarizes the data (table 2).

Table 2. Products published in fiscal year 2017 related to work on long-term monitoring of surface water, groundwater, and water quality in the Wyoming Landscape Conservation Initiative region.

Real-time and water-quality data	Water-year summary report
New Fork River near Big Piney, Wyoming	
https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09205000	https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=09205000
Green River near Green River, Wyoming	
https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09217000	https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=09217000
Muddy Creek above Olson Draw, near Dad, Wyoming	
https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09258050	https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=09258050
Muddy Creek below Young Draw, near Baggs, Wyoming	
https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09258980	https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=09258980

- Completed manuscript on streamflow and water-quality characteristics of selected sampling sites in the Wyoming Landscape Conservation Initiative Water-Quality Monitoring Program, Wyoming, Water Years 2006–2016.

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Measuring the stage of Muddy Creek at the streamgage near Dad, Wyoming. Real-time streamflow and water-quality data have been collected at this site since 2007 and are being used to describe changes in the hydrologic system. Photo by Cheryl A. Eddy-Miller, U.S. Geological Survey.

Evaluation of Groundwater Interaction with Small Streams in the Western Green River Basin to Enhance Understanding of Aquatic Communities

Resource development has occurred on the eastern flank of the Wyoming Range since the early 1900s, and the geographical extent of development has increased in the past 20 years. An evaluation of groundwater interaction with small streams in the western Green River Basin, as well as precise streamflow measurements are important components to assist in determining the health of all aquatic species (see "Drivers of Native Fish Community Response to Oil and Gas Development" section on p. 42). An understanding of quantity of streamflow and where along the stream channel it is sustained throughout the year will elucidate changes and differences in aquatic communities.

We collected streamflow data during November 2016 and February, July, and September 2017 in the South Beaver Creek, Fogarty Creek, and Dry Piney Creek drainages. These data were collected at the same sites where we collected streamflow data in FY2015 and FY2016. Traditional methods of analysis, namely seepage runs, were inconclusive for explaining how groundwater contributes to streamflow; therefore, we developed a new approach, evaluating many variables, not just groundwater, to help explain why some streams flow perennially and why some are intermittent. This new approach uses a geospatial model and a larger number of variables that affect streamflow (streamflow drivers), such as geology, topography of the stream channel, faults, precipitation, and snowpack. The variables are static (such as geology) and dynamic (such as precipitation) and provide information about the drainage basin. Statistical analysis of the geospatial model will allow an understanding of the most important drivers of streamflow in these small basins.

Measuring streamflow in Fogarty Creek during the summer high flows. Photo by Cheryl A. Eddy-Miller, U.S. Geological Survey.

These insights will help interpret the aquatic species distribution data, as well as describe mechanisms of sustaining small streams in the upper parts of watersheds. The new methodology may provide a framework to analyze other watersheds, particularly, small headwater basins, where streamflow data do not exist. Many small streams such as these can be critical for survival of native species. Increasing our understanding of what controls streamflow will support resource management decisions in the study area.

Accomplishments in Fiscal Year 2017

- All streamflow and water-quality measurements collected from the 25 study sites are available online at https://wy-mt.water.usgs.gov/projects/wlci/gw_interaction/index.html.

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Long-Term Groundwater-Streamgage Data and Geologic Unit Description

Ongoing energy development in the northern Green River structural basin (a geologic designation) necessitates gathering information about groundwater resources that supply water to the basin's wells. Many human activities in that area, including pumping water from the aquifers for agricultural, domestic, and industrial use and the penetration of the heterogeneous (that is, complex intertonguing layers) aquifers (Bartos and others, 2015) during deeper drilling for natural gas, have the potential to affect the aquifer system that supplies water to most wells in the area.

To broaden the understanding of the geology of the water-bearing units primarily used for drinking water supplies in the hydrologic basin, the upper Green River Basin, a monitoring well was installed in the Wasatch Formation near the New Fork River in the vicinity of the Big Piney streamgage. We published a detailed description of the lithology and physical characteristics of 52 meters (m) of the core collected during well drilling in a USGS data release (Hallberg and others, 2017) in FY2017. These data add to the understanding of the complexities of the heterogeneous layers and will help managers and scientists understand the aquifer system.

In FY2015, we installed monitoring wells in both streambanks at the New Fork River near Big Piney and the Green River near LaBarge to create groundwater streamgages (Eddy-Miller and others, 2012) that record water elevation and temperature (figs. 1 and 2). We are using data from these new wells, as well as the 52-m well mentioned above, to develop a groundwater flow model to understand how groundwater contributes to streamflow in the Green River Basin.

Accomplishments in Fiscal Year 2017

- All groundwater-streamgage sites have preliminary data available in real time, as well as approved long-term data. Parameters available include the elevation of water groundwater and stream) and water temperature (table 3).

Table 3. Products published in fiscal year 2017 related to work on groundwater-streamgage elevation and temperature in the Wyoming Landscape Conservation Initiative region.

Real-time data for groundwater-streamgage sites	
Water-surface elevation	**Temperature**
New Fork River near Big Piney, Wyoming	
https://go.usa.gov/xnFAe	https://go.usa.gov/xnFAt
Green River near LaBarge, Wyoming	
https://go.usa.gov/xnFAF	https://go.usa.gov/xnFAM

- Hallberg, L.L., Eddy-Miller, C.A., and Boughton, G.K., 2017, Description of core collected during installation of a Wasatch aquifer monitoring well in the Green River Basin, Sublette County, Wyoming: U.S. Geological Survey data release, https://doi.org/10.5066/F7FQ9V2J.

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Ecology of Focal Wildlife Species Important to Wyoming Landscape Conservation Initiative Partners

Modeling Greater Sage Grouse Population Responses to Landscape Changes

In FY2017, we continued to improve our understanding of mechanisms affecting sage grouse population trends. This includes analyses evaluating population trends and potential consequences of spatial variation in resource use on population persistence. We published an analysis that evaluated the relationship between grazing (Monroe and others, 2017) and sage grouse population trends across Wyoming. Our results illustrated that grazing may have positive and negative effects on sage grouse population trends depending on grazing timing and level, possibly reflecting the sensitivity of cool season grasses to grazing during peak growth periods (Monroe and others, 2017).

We developed and published a simulation framework that spatially evaluates long-term population viability of sage grouse (Heinrichs and others, 2017). We learned that areas having lower habitat selection (that is, outside of core areas) identified from seasonal habitat models (Fedy and others, 2014) can be important in sustaining the “overflow” of sage grouse during times of periodic high density, possibly reducing the risk of population declines and extinctions. Additionally, lesser quality habitats located in proximity to high-quality habitats can be important for sustaining viable populations of sage grouse.

Despite sage grouse population cycles that are seen across large areas, as demonstrated in Wyoming (Fedy and Aldridge, 2011), individual populations may experience different population trajectories across biological or management units. We published trend analyses (1993–2015) indicating that large-scale management units may trend similarly, but individual core areas often have different trajectories (Edmunds and others, 2018). We developed hierarchical population clusters that more truly capture biologically significant population units, which will help to understand drivers of population change, similar to methods we applied for sage grouse populations in Nevada (Coates and others, 2017). We are currently preparing a manuscript on this work.

Accomplishments in Fiscal Year 2017

- 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.
- Edmunds, D.R., Aldridge, C.L., O’Donnell, M.S., and Monroe, A.P., 2018 [first published online October 2017], Greater sage-grouse population trends across Wyoming: Journal of Wildlife Management, v. 82, no. 2, p. 397–412, https://doi.org/10.1002/jwmg.21386.
- 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.

- 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.
- Completed a hierarchical clustering analysis for the State of Wyoming to link leks into biologically related groups that can be used for hierarchical evaluation of sage grouse population trends in Wyoming and developed a draft manuscript. This approach is now being applied rangewide for greater sage grouse.

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Identifying Impediments to Wyoming Mule Deer Seasonal Movements and Long Distance Migration

Increasingly, we understand that migration corridors are key habitats for migratory mule deer; however, alterations to the behavior of animals during migration has the potential to modify their ability to track plant phenology (or “greenup”) across the landscape, also known as “surfing the green wave.” In addition, long-term monitoring of migration is needed to understand how migrating animals respond to habitat alterations and conservation measures (that is, fence modifications). Our research objectives include (1) conducting a long-term study of the Red Desert to Hoback mule deer migration, (2) evaluating the effect of drought on green-wave surfing, (3) assessing the effect of fencing and other barriers on mule deer movement and migrations, and (4) sharing this information with the public, managers, and decision makers.

In FY2017, we completed our first analysis of green-wave surfing in mule deer that migrate along the Wyoming Range (Aikens and others, 2017). We found that mule deer surf spring greenup closely and that alterations to green-up patterns strongly influenced surfing. Ongoing analyses indicate that drought makes it more difficult for mule deer to surf during spring movement patterns.

Long-term monitoring of the Red Desert to Hoback mule deer migration continues. During FY2017, we increased our sample size of collared adult female mule deer to 107, which includes 52 long distance migrants. In addition, we deployed trail cameras along the migration corridor, including areas where migration routes cross fences and highways (fig. 3). We now have more than 4 years of capture and migration data, and we have begun to evaluate the fitness benefits of migration (fat dynamics, fawn survival, forage availability), fidelity to migration routes and summer range, and timing of spring and fall migration.

Figure 3. Photographs of mule deer crossing fences will help us determine behavioral responses associated with encountering different types of migration barriers. Photographs courtesy of Matthew Kauffman, U.S. Geological Survey.

Accomplishments in Fiscal Year 2017

- Aikens, E.O., Kauffman, M.J., Merkle, J.A., Dwinnell, S.P.H., Gralick, G.L., and Monteith, K.L., 2017, The greenscape shapes surfing of resource waves in a large

migratory herbivore: Ecology Letters, v. 20, no. 6, p. 741–750, https://doi.org/10.1111/ele.12772.
- Kauffman, M.J., Meacham, J.E., Sawyer, H., Steingisser, A.Y., Rudd, W.J., and Ostlind, E., 2018 [in press at the end of FY17], Wild migrations─Atlas of Wyoming's ungulates: Eugene, Oregon, Oregon State University Press.

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Mapping and Characterizing the Status and Trends of Focal Habitats

Framework and Indicators for Long-Term Monitoring

This project is aimed at development of habitat monitoring capacity, methods, and information. In FY2017, we worked with scientists from several USGS Science Centers located across the sagebrush biome, who were sampling within the Wyoming Basin Ecoregion (which includes the WLCI region), to assess postfire conditions of sagebrush communities. We collected field observations using the BLM Assessment, Inventory, and Monitoring plot design (www.landscapetoolbox.org). Sampled sites included seeded and untreated burned areas and a range of time since fire. Our analyses indicated clear evidence of recovery of herbaceous species; occasional, but not ubiquitous invasion by cheatgrass; and reestablishment of sagebrush. In addition, analysis of postfire treatment effects revealed positive effects of broadcast and drill seeding on sagebrush reestablishment and reduction of exposed bare ground (canopy gap) after aerial and broadcast seeding; however, aerial seeding was significantly and positively correlated with an increased abundance of cheatgrass. We are currently preparing a manuscript for publication.

In FY2017, we published the WLCI Monitoring Fact Sheet (Manier and others, 2017), which summarizes the purpose and value of research and monitoring of resource and wildlife across the WLCI, conducted by USGS and WLCI partners. The fact sheet explains WLCI's monitoring priorities and how they inform management, including monitoring wildlife and habitat, effectiveness monitoring and adaptive management, integrating habitat and population monitoring, monitoring energy development, and monitoring water quantity and quality.

Accomplishments in Fiscal Year 2017

- Manier, D.J., Anderson, P.J., Assal, T.J., Chong, G.W., and Melcher, C.P., 2017, Monitoring the southwestern Wyoming landscape—A foundation for management and science: U.S. Geological Survey Fact Sheet 2017–3030, 6 p., https://doi.org/10.3133/fs20163030.
- Poster—"Sagebrush Restoration for Sage-grouse Habitat Needs, Wyoming Basin," D.J. Manier—Great Basin Consortium Conference, University of Nevada; Reno, Nev., February 21–23, 2017.
- Presentation—"Invasive Plant Research─Applications for Management Restoration Activities and Lingering Questions," D.J. Manier—Wyoming Mining Natural Resource Foundation, Invasive Plant Workshop; Western Wyoming College, Green River, Wyo.; April 25, 2017.

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Time-Series Analysis of Multiresolution Imagery to Quantify Sagebrush Defoliation and Mortality in Southwest Wyoming

Sagebrush mortality and defoliation has been reported in the upper Green River Basin in the past five years (Clause and Randall, 2014). There is concern that defoliation and (or) mortality events represent additional stressors on sagebrush habitats that could have negative effects on sagebrush-obligate species. The extent, mechanism, and frequency of these events are unknown at this time, but sagebrush mortality has been reported within sage grouse core areas and pronghorn crucial winter habitat. Numerous causes have been proposed, but recent drought (2012–13) has likely played a substantial role in mortality at the landscape scale in this water-limited ecosystem. Sagebrush communities are a WLCI focal habitat, and this work seeks to expand our research capacity to monitor the status and trends of sagebrush communities, and responses to drought. In this study, we assess time-series data for detection of subtle changes in sagebrush ecosystem productivity associated with mortality at landscape and local scales.

Sagebrush mortality observed in northern Sweetwater County in September 2017. Photograph by Tim Assal, U.S. Geological Survey.

In FY2017, we completed phase I of this project. We used a 17-year record of satellite-derived productivity (for example, MODIS [moderate resolution imaging spectroradiometer] data) to address two questions: (1) how did the drought affect vegetation over space and time and (2) what is the relationship of temperature and moisture on vegetation response? Productivity was anomalously negative over large areas of the upper Green River Basin at the start of the drought in 2012 and persisted in some areas into the early part of the 2014 growing season. The effects of the drought began to subside in 2014, and significant greening trends were observed in some areas during 2015 and 2016. We hypothesized sagebrush refoliation and resprouting of other shrubs may move an area of vegetation from a negative anomaly back to a normal baseline; however, there was likely a release of resources in areas of higher sagebrush mortality, followed by a flush of herbaceous plants when increased precipitation was received in 2015 and 2016.

We assessed the relations of temperature and moisture on annual vegetation response using Daymet data (https://daymet.ornl.gov/). We also summarized a standardized precipitation evapotranspiration index for the upper Green River Basin to quantify climate variability over the last century. The standardized precipitation evapotranspiration index incorporated precipitation and temperature data and provides the capacity to include the effects of temperature variability on drought. The standardized precipitation evapotranspiration index data were produced as an approach to quantify the effects of temperature and the frequency and intensity of wet and dry patterns across the study area and to specifically place the 2012 drought in a historical perspective, and this index was published as a USGS data release (Assal, 2018b). The cumulative precipitation deficit (during fall, winter, and spring) was the most important precipitation variable related to mean growing season anomalies, whereas previous summer temperature was the most important thermal variable. The effect size of these variables differed by year; however, we determined that spring temperature and previous summer temperature have a larger effect size than cumulative precipitation deficit. Our results indicate that vegetation response is not solely affected by a lack of precipitation; temperature also has a strong effect on productivity during drought events. In FY2018, we intend to begin phase II of this project where we will investigate trends identified in phase I at local scales and assess relationships with local biophysical properties.

Accomplishments in Fiscal Year 2017

- Presentation—"A cross-scale approach to understand drought-induced variability of sagebrush ecosystem productivity," Timothy Assal—American Geophysical Union 2016 Fall Meeting; San Francisco, Calif,; December 12–16, 2016, https://agu.confex.com/agu/fm16/meetingapp.cgi/Paper/196167.
- Presented preliminary results to WLCI partners from Natural Resources Conservation Service and WGFD to coordinate additional field observations.
- Assal, T.J., 2018, Standardized Precipitation Evaporation Index for the Upper Green River Basin (1896–2017): U.S. Geological Survey data release, https://doi.org/10.5066/P9VLM7Z6.

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Remote Sensing and Vegetation Inventory and Monitoring

The focus of this work is to use remote-sensing tools and protocols for monitoring long-term changes in vegetation cover across the WLCI region. This information is important for understanding patterns of change within sagebrush habitats across the WLCI region, including historical changes and potential future trajectories of change. We characterized vegetation by component cover quantified at 1-percent intervals. Based on samples collected in the field and from satellite imagery, we can evaluate and quantify the amount and distribution of change in these target components over time. This work and the associated products represent the operational vegetation monitoring effort for WLCI and provide input to a broad spectrum of ongoing WLCI research and applications.

During FY2017, WLCI vegetation change was monitored and analyzed using ground and satellite measurement. We measured long-term vegetation monitoring plots across 253 marked transects on the ground, and 2-m and 30-m satellite data. These transects have been ground and satellite measured every year since 2008. Preliminary analysis of ground transect measurements taken between 2008 and 2016 indicated significant shrub change on 23 percent of transects, significant sagebrush change on 14 percent of transects, significant herbaceous change on 67 percent of transects, and significant bare ground change on 41 percent of transects. Trend analysis of transect change from 2008 to 2017 revealed that the average shrub canopy has increased by 3.4 percent (from 8.6 to 12.0 percent), average sagebrush canopy has increased 2.6 percent (from 6.0 to 8.6 percent), average herbaceous canopy has increased 1.6 percent (from 10.8 to 12.4 percent), and bare ground has decreased 3.9 percent (from 62.4 to 58.5 percent). This change is likely a reflection of the changing climate, because increasing precipitation and increasing minimum and maximum temperatures were measured during this same period. Research is currently underway to analyze these changing patterns of vegetation and report findings across the WLCI area.

Permanent measurement transect 11, Boars Tusk, Wyoming, Photo by Collin Homer, U.S. Geological Survey.

During FY2017, we began production of new and updated historical mapping products for WLCI. These products will provide historical change measurements for shrub, sagebrush, herbaceous plant cover, litter, and bare ground. This process incorporates the latest methodological improvements and data to provide a complete historical analysis of component change (five components of vegetation cover—shrubs overall, sagebrush, herbaceous vegetation, litter, and bare ground—which are quantified at 1-percent intervals) back to 1985. Once completed, these data will provide an updated change analysis of vegetation components, indicate where significant change has happened, and provide insight into the source of that change. This information is now being used to evaluate recovery rates after disturbance in sagebrush habitat components from 1985 to 2015 (see "Modeling Recovery of Sagebrush across the Wyoming Landscape Conservation Initiative using Remotely Sensed Vegetation Products" section on p. 49). Similar approaches are now being explored across Wyoming to better understand vegetation recovery among a more diverse suite of disturbance types.

Accomplishments in Fiscal Year 2017

- Sustained long-term monitoring of 253 marked transect plots across 2 intensive study areas to continue ground measurement of annual vegetation change (shrub, sagebrush, herbaceousness, litter, and bare ground). These same plots have been annually measured since 2008.
- Began and partially completed a new back-in-time analysis of WLCI historical change for five components (shrub, sagebrush, herbaceousness, litter, and bare ground). This is expected to be completed for WLCI in the coming year.
- Completed initial analyses of vegetation recovery rates at well pads in Wyoming.

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Mapping Mixed Mountain Shrub Communities to Support Wyoming Landscape Conservation Initiative Conservation Planning and Monitoring of Habitat Treatments

The mixed mountain shrub community is composed of a variety of shrub species, including mountain mahogany (*Cercocarpus montanus*), curl-leaf mountain mahogany (*Cercocarpus ledifolius*), western serviceberry (*Amelanchier alnifolia*), chokecherry *(Prunus virginiana*), and antelope bitterbrush (*Purshia tridentata*). This vegetation community is one of five WLCI priority habitats and is associated with numerous WLCI conservation projects; however, very little is known about the current extent, condition, and trends of mountain shrub patches and mechanisms driving their condition. Monitoring data from selected stands indicate an overall decline in stand recruitment and vertical structure. Hypothesized causes of decline range from persistent drought to herbivory and, possibly, factors associated with increased energy development. Our objectives are to map and measure the distribution and current condition of mixed mountain shrub communities and evaluate potential effects of habitat treatments (for example, projects to improve mule deer habitat), weather-related trends, increased energy development, and other change agents. Maps and other information on the location and distribution of habitats help to support conservation planning and effectiveness monitoring of habitat treatments by WLCI partners. We shared map products and associated information with WLCI partners during two LPDT meetings.

During 2014 through 2016, we collected mountain mahogany and bitterbrush stems to evaluate ungulate browse patterns. We developed a protocol in 2016 to reconstruct browse history and browse intensity. In FY2017, we began using the protocol to measure stem productivity and browse rates. We will continue to process the remaining stems through 2018.

Accomplishments in Fiscal Year 2017

- Poster—Retrospective approaches to evaluate resilience of aspen, mountain mahogany, and sagebrush communities to drought," P.J. Anderson and T.J. Assal—Restoring the West 2016 Conference: Climate, Disturbance, and Restoration in the Intermountain West, Logan, Utah, October 18–19, 2016.

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Status and Trends of Aspen and Willow Communities in the Bighorn Mountains

New Phase of Project Previously Titled "Landscape Assessment and Monitoring of Semiarid Woodlands in the Little Mountain Ecosystem"

At the request of USGS program managers, we have begun to export approaches developed within the WLCI to areas outside of the WLCI. In FY2016, WLCI partners from the WGFD asked if we could assess the status and condition of deciduous communities in the Bighorn Mountains in northern Wyoming (outside of the WLCI; fig. 4). This request was similar to our assessment of the status and trends of semiarid woodlands in the Little Mountain Ecosystem (Bowen and others, 2016) and served as a template to apply techniques developed inside the WLCI to other systems.

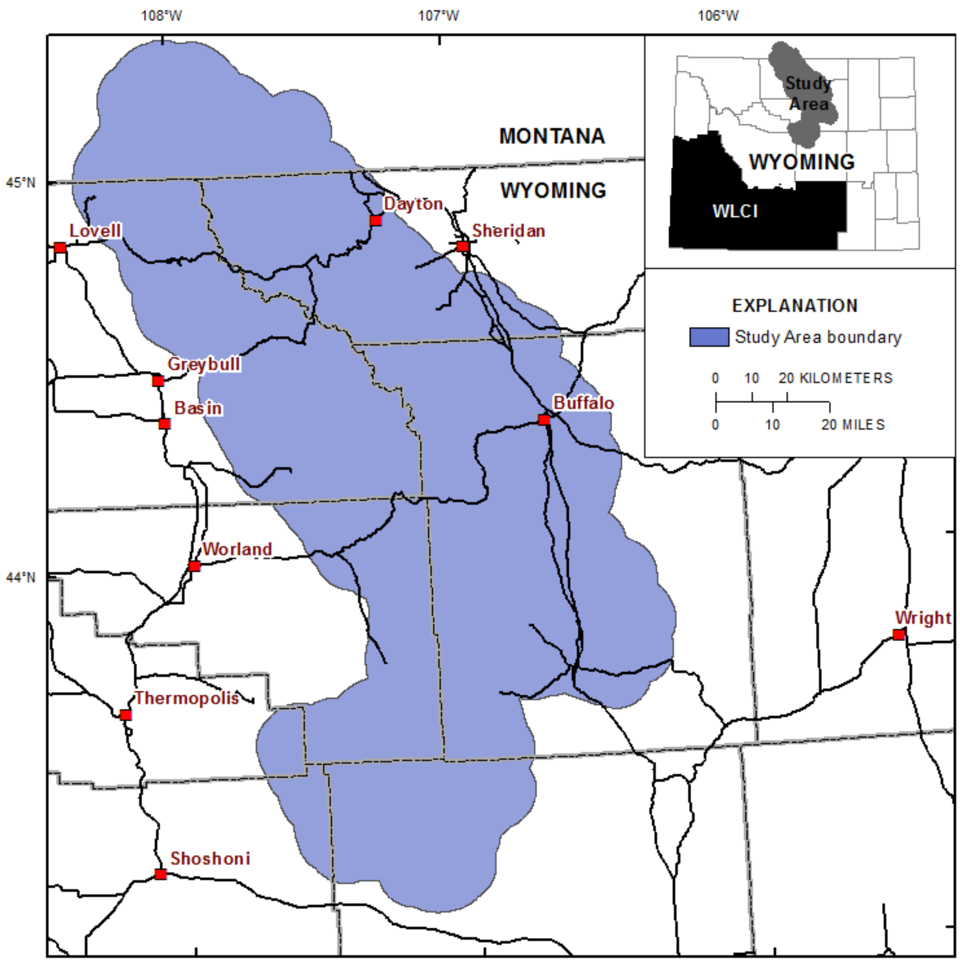

Figure 4. Location of the Bighorn Mountains study area in north-central Wyoming and south-central Montana.

In the Bighorn Mountains of north-central Wyoming, deciduous communities dominated by aspen and willow species are an integral part of the life cycles of many wildlife species, including large ungulates. These communities face a plethora of issues in the Bighorns, including drought, conifer encroachment, overbrowsing, and lack of natural disturbance. The WGFD and the Bighorn National Forest have begun research with USGS to assess the current trends of deciduous communities. The work will also benefit the BLM and Wyoming State Forestry Division and is expected to inform management options within the City of Buffalo's Municipal Watershed project.

In phase I of this project, completed in FY2017, we created a synthesis map of coniferous and deciduous communities in the Bighorn Mountains of Wyoming using a species distribution modeling approach developed in the WLCI (Assal and others, 2015). The modeling framework utilized several topographic covariates and temporal remote-sensing data from the early, middle, and late growing season to capitalize on phenological differences in vegetation types. The synthesis map (Assal, 2018a) is an improved data product that represents baseline conditions of the amount and extent of each forest type. In phase II of this project (intended completion FY2018 and 2019), we will conduct a preliminary assessment on the baseline condition of riparian deciduous communities. This will be a proof-of-concept study where the USGS will apply a framework used in prior research in upland aspen and sagebrush communities to detect trends in riparian vegetation condition from the mid-1980s to 2015. We will conduct trend analysis in a subset of priority drainages identified by the WGFD. We will also work with agency partners to develop a rapid assessment field protocol to measure riparian community condition. This information will be used to validate trends measured through remote sensing.

Accomplishments in Fiscal Year 2017

- Presented initial findings and WLCI outreach at the 2017 Aspen Days Workshop, Sheridan, Wyo.
- Assal, T.J., 2018, Bighorn Mountains, Wyoming Forest Mapping, 2013–2017: U.S. Geological Survey data release, https://doi.org/10.5066/P98OS2XK.

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Relationships Between Energy Development and Fish, Wildlife, and Their Habitats

Investigating the Influences of Oil and Gas Development on Greater Sage Grouse

The overall focus of this project is to evaluate sage grouse responses to landscape changes in Wyoming. This entails evaluating population-level responses, developing models to understand how population demographics and distributions are affected by change, and assessing potential effects of future change on sage grouse habitat resources and population viability. One of the main drivers of change we have been investigating is the rapid oil and gas development within and adjacent to sage grouse core areas in Wyoming. During 2017, we published an article about our investigation of oil and gas development, and environmental and habitat conditions, on sage grouse populations in Wyoming using male lek counts from 1984 to 2008 (Green and others, 2017). Sage grouse population declines from 1984 to 2008 in Wyoming were correlated to oil and gas development. We found that increasing density of oil and gas development within 6.4 km of leks resulted in declining attendance of male sage grouse at those leks.

We have also been working on spatially explicit simulation approaches to assess the potential future effects of climate-induced habitat changes on sage grouse habitat (Homer and others, 2015) and of increasing oil and gas development (Garman, 2018) on sage grouse demography and habitat use. Our results indicate that climate-induced vegetation changes and oil and gas development are important potential stressors to sage grouse populations.

Accomplishments in Fiscal Year 2017

- Green, A.W., Aldridge, C.L., and O'Donnell, M.S., 2017, Investigating impacts of oil and gas development on greater sage-grouse: Journal of Wildlife Management, v. 81, no. 1, p. 46–57, https://doi.org/10.1002/jwmg.21179.
- Developed initial, spatially explicit, individually based population viability analyses models for WLCI to evaluate the effects of future energy development and climate change on sage grouse populations.

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Identifying Threshold Levels of Energy Development that Impede Wyoming Mule Deer Migrations

Migratory ungulates are susceptible to development along their migration routes (Lendrum and others, 2012; Sawyer and others, 2013). Understanding the influence of current development on migratory routes, including stopover sites used for foraging, can provide insights on the effects of future landscape changes. It has been proposed that impermeable barriers (like tall fences) have apparent and detrimental effects to migratory ungulates (Flesch and others, 2010); however, the effect of semipermeable barriers (like an energy field)—where connectivity is maintained but the benefits of migration routes are compromised—remains unclear (Sawyer and others, 2013). We are using data collected from mule deer radiomarked using Global Positioning System collars to evaluate the influence of development on the migratory behavior of individual deer in western Wyoming (Wyckoff and others, 2018). Specifically, we are evaluating the effects of development on movement rate, stopover use, and fidelity to migration routes for each individual, by season and year.

In FY2017, we completed a study to understand how development affects the ability of mule deer to track phenology by evaluating movement relative to three types of development (energy, residential, and dispersed rural) in southwest Wyoming (Wyckoff and others, 2018). We found that mule deer shift their stopovers away from most types of development. In the rapidly developing Atlantic Rim project area, we observed the most dramatic alterations to deer migratory behavior. Deer increased their rate of movement, reduced time at stopover sites, and shifted stopovers in areas of intense development.

Accomplishments in Fiscal Year 2017

- Wyckoff, T.B., Sawyer, H., Albeke, S.E., Garman, S.L., and Kauffman, M.J., 2018 [in press at end of FY2017], Evaluating the influence of energy and residential development on the migratory behavior of mule deer: Ecosphere, v. 9, no. 2, article e02113, https://doi.org/10.1002/ecs2.2113.

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Wind Energy and Wildlife in Southwest Wyoming

Wyoming is rich in wind resources and has experienced substantial growth in the development of wind energy (Godby and others, 2016), including development of the largest wind farm in North America in terms of power capacity (http://www.powercompanyofwyoming.com/). Many existing and proposed wind farms are located on public lands and present challenges to managers responsible for conservation of wildlife because of inherent disturbances to wildlife habitat and collisions of flying animals with turbines. The goal of this project is to assess wildlife conflicts with wind energy in Wyoming and provide map products for further investigations of wind and wildlife interactions.

In FY2017, we compiled information on existing and proposed wind farms throughout Wyoming to determine their status, distribution, and overlap with areas of conservation concern, including core areas for greater sage grouse and crucial range for ungulates. To identify pressing research needs specific to the WLCI focal area, a member of the research team attended the Wind Wildlife Research Meeting XI and consulted BLM and WGFD managers regarding research needs. Several managers expressed concern over effects of wind farms on habitat use by ungulates (especially pronghorn, mule deer, and elk) and greater sage grouse. Within the WLCI focal area, most existing and proposed wind farms are within seasonal habitats for pronghorn, mule deer, and elk; at least five proposed farms are within areas identified as crucial range for pronghorn by WGFD. Several wind farms are proposed for construction around existing farms near Medicine Bow and have raised questions about cumulative effects on wildlife. We assembled spatial data to quantify disturbances at wind farms across Wyoming from pre- to postconstruction. Analyses of these data are expected to be completed in 2018 to inform managers of ground disturbances across space and time that can be expected from proposed wind farms within landscapes of Wyoming. New map products that depict infrastructure of wind farms will provide useful data to support analyses of wildlife interactions with wind energy infrastructure.

Accomplishments in Fiscal Year 2017

- Assessment of research needs and assembly of spatial data for investigation of disturbances from wind developments.

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Relationship Between Energy Development and Pygmy Rabbit Presence and Abundance

Pygmy rabbits are a species of conservation concern throughout their occupied range. They are established throughout southwest Wyoming, and they are sensitive to development and disturbance in sagebrush habitats (Larrucea and Brussard, 2008). Gas and oil extraction is taking place on more than 6,000 square kilometers of land in the WLCI area. This activity disturbs sagebrush vegetation, but little information exists on the relationship between energy development and the health of pygmy rabbit populations. Understanding this relationship in more detail will allow more responsible resource management planning and help conserve one of Wyoming's sensitive nongame wildlife species while continuing to produce domestic energy. Our goal in this phase of pygmy rabbit research was to better understand the relationship between gas field development and pygmy rabbit populations.

We surveyed pygmy rabbits on four major gas energy fields (Continental Divide/Creston, Jonah, Moxa Arch, and Pinedale Anticline Project Area) during 2011–13, collecting detailed information on where pygmy rabbits were present and estimating their abundance. Throughout our survey area, we used satellite imagery to map how much land had been converted to gas field elements such as roads, well pads, and pipeline corridors. We then statistically related the amount of land area converted to each gas field element with pygmy rabbit presence and abundance levels. We found gas field infrastructure to be negatively associated with pygmy rabbits; pygmy rabbits became more likely to be absent than present once 1–2 percent of the area on a gas field was converted to roads, well pads, and pipelines, and pygmy rabbit abundance declined sharply once 2 percent of the area was developed (fig. 5; Germaine and others, 2017a, b).

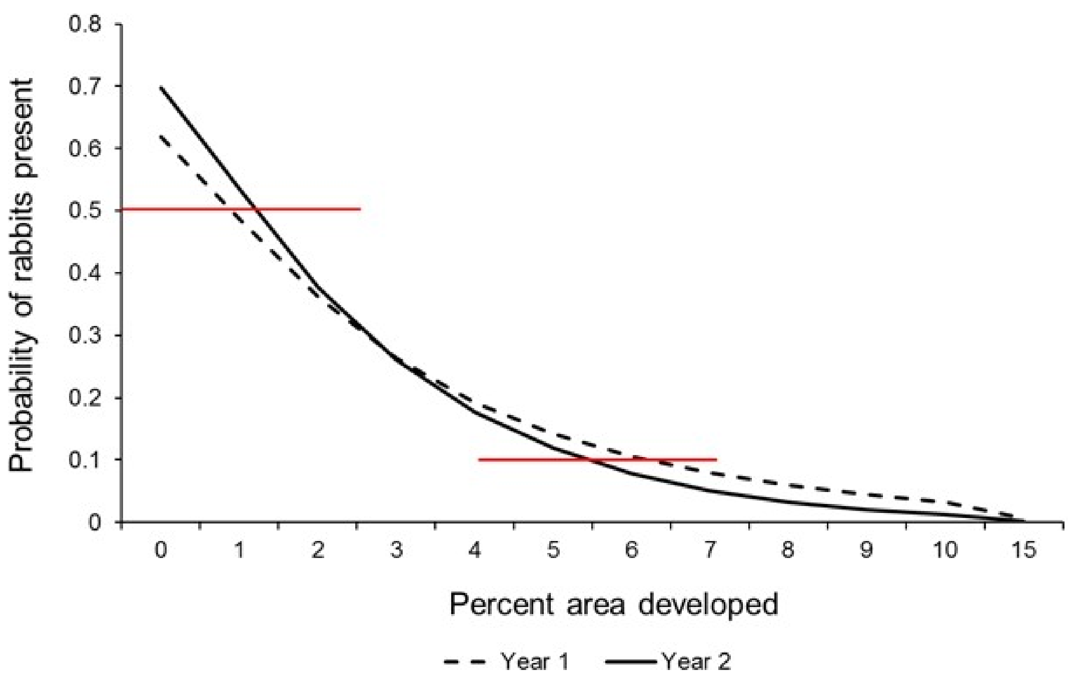

Figure 5. Probability of pygmy rabbits being present (y axis) as gas field development density increases (x axis). Red bars indicate development levels at which probability of presence is 0.5 and 0.1.

This is the first study of its kind to relate gas energy development and pygmy rabbits. Based on our results, we are now examining if future gas fields might be developed in a manner that maximizes distances between development and pygmy rabbit habitat. We are also studying the potential effect future gas field development may have on pygmy rabbit population distributions across the WLCI landscape.

Accomplishments in Fiscal Year 2017

- Germaine, S.S., Carter, S.K., Ignizio, D.A., and Freeman, A.T., 2017, Relationships between gas field development and the presence and abundance of pygmy rabbits in southwestern Wyoming: Ecosphere, v. 8, no. 5, article e01817, https://doi.org/10.1002/ecs2.1817.
- Germaine, S.S., Carter, S.K., Ignizio, D.A., and Freeman, A.T., 2017, Analysis of land disturbance and pygmy rabbit occupancy values associated with oil and gas extraction in southwestern Wyoming, 2012: U.S. Geological Survey data release, https://doi.org/10.5066/F7BR8QDD.

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Mechanistic Understanding of Energy Resource Development Effects on Songbirds

Three species of sagebrush-obligate songbirds (Brewer's sparrow [*Spizella breweri*], sagebrush sparrow [*Artemisiospiza nevadensis*], and sage thrasher [*Oreoscoptes montanus*]) nest within the WLCI area. All are declining rangewide because of widespread habitat conversion and change (Gilbert and Chalfoun, 2011; Sauer and others, 2017). In collaboration with the WGFD, we started this multiphase project to address the need to identify the condition and distribution of sagebrush songbird habitats and key drivers of change for these habitats.

In phase I (2008–09), we documented decreased nest survival of all three songbird species as natural gas well density increased in the Jonah and Pinedale Anticline Project Area. An average decrease of 0.3 individuals was observed for each additional well per square kilometer (Gilbert and Chalfoun, 2011). In phase II (2011–12), infrared video cameras confirmed that rodents were responsible for most depredation events, the smallest of which (the deer mouse [*Peromyscus maniculatus*]) was the most prevalent (Hethcoat and Chalfoun, 2015a, b). Deer mouse and ground squirrel abundances were higher in areas having more surrounding habitat loss due to natural gas extraction, and nest survival of Brewer's and sagebrush sparrows was negatively associated with increased rodent abundance (Hethcoat and Chalfoun, 2015b).

Brewer's sparrow perched on sagebrush in the Jonah Field. Photo by Tayler LaSharr, University of Wyoming.

During phase III (2013–16), we continued monitoring nests and nest predators to determine the spatial and temporal consistency of these relationships. We also examined alternative hypotheses for why the abundance of rodent nest predators increases with natural gas development. First, we tested if lower abundance of the primary predators (raptors, canids, badgers) of rodents could explain higher small mammal abundance; however, raptors, coyotes, and badgers were also more abundant in areas with more natural gas extraction. Second, we conducted spatial analyses to determine which components of landscape change (well pads, roads, reclaimed areas) within gas fields were most associated with increased rodent predator numbers and determined that rodent densities were strongly and positively related to reclaimed (reseeded) areas. Dietary analysis of deer mice and powder tracking efforts in 2016 confirmed that mice utilize reclaimed areas, which were usually differ in composition from adjacent sagebrush patches, for foraging. Several nonnative species of plants, located exclusively within reclaimed areas, were found in mouse diets.

Collectively, our results indicate that energy development in southwest Wyoming increases songbird nest predation by attracting rodents to areas reseeded using forbs and grasses not typically established within native sagebrush steppe. Decreased nesting success is a concern because it can strongly decrease populations; moreover, none of the bird species have demonstrated a habitat preference for areas having less development, yet they produce fewer young there, indicating that they are experiencing an "ecological trap." An ecological trap is a situation where, under rapid environmental change, animals become "trapped" by their evolutionary responses to formerly reliable environmental cues, often leading them to select lower quality habitats that decrease their survival or reproductive fitness (Schlaepfer and others, 2002). Management and mitigation efforts targeted towards more efficient habitat restoration back to sagebrush habitats that contain only grass and forb species associated with local undisturbed sagebrush patches will likely help maintain songbird populations in the WLCI area.

Our current research focuses on the combined effects of physical habitat change caused by development and weather conditions on avian nesting success.

Accomplishments in Fiscal Year 2017

- Presentation—"Natural gas fields as ecological traps for breeding birds," A.D. Chalfoun, M.G. Hethcoat, and L.E. Sanders—American Ornithological Conference, East Lansing, Mich., July 31–August 5, 2017.
- Presentation—"What is sustaining higher nest predator abundance within natural gas fields?" L.E. Sanders and A.D. Chalfoun—American Ornithological Conference, East Lansing, Mich., July 31–August 5, 2017.
- We are currently drafting two manuscripts intended for peer-reviewed journals on mechanisms underlying nest predation near natural gas development and on how novel landscape elements within natural gas fields increase densities of an important songbird nest predator

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Drivers of Native Fish Community Response to Oil and Gas Development

The rapid expansion of natural gas development in southwest Wyoming has raised concerns about potential effects on key wildlife species and habitats. Our goals are (1) to evaluate potential mechanisms through which oil and gas development can affect fish and (2) to assess physiological and immunological effects of oil and gas development for fish. Our approach is a comparative study examining sites having differing levels of oil and gas development.

We have determined that habitat is an important mechanism driving fish species' tolerance to oil and gas development. Important habitat variables for fish included suspended sediment, willow cover, and water quality. This is information land managers can use to target their conservation efforts towards reducing sediment loads, maintaining stream cover, and reducing spills. In FY2017, we collected our sixth year of fish community data and started analyzing our data on two other important potential mechanistic pathways by which oil and gas development can affect fish: hydrology and resource availability. The hydrology work is in conjunction with USGS Wyoming-Montana Water Science Center (see "Evaluation of Groundwater Interactions with Small Streams" section on p. 21). In addition, we measured physiological and immunological responses for two species: mountain sucker and mottled sculpin. Preliminary results indicate differing physiological responses of the species to temperature and salinity.

Accomplishments in Fiscal Year 2017

- Girard, C.E., and Walters, A.W., 2018 [in press in FY17], Evaluating relationships between fishes and habitat in streams affected by oil and natural gas development: Fisheries Management and Ecology, v. 25, no. 5, p. 366–379, https://doi.org/10.1111/fme.12303.
- Prepared manuscript on approaches for surface water quality assessment in small streams experiencing oil and natural gas development for submission to peer-reviewed journal.
- Prepared draft USGS data release of habitat and fish field survey data from Wyoming Range streams in 2012 and 2013.
- Four presentations/poster at scientific conferences:
  - Presentation—"Context dependent effects of flow on fish," Annika Walters and Richard Walker—Society for Freshwater Science annual meeting, Raleigh, N. Car., June 4–8, 2017 (invited presentation).
  - Presentation—"Physiological responses of fishes to stressors associated with oil and natural gas development," Richard Walker, Geoff Smith and Annika Walters—Society for Freshwater Science annual meeting; Raleigh, N. Car., June 4–8, 2017
  - Presentation—"Physiological responses of fishes to stressors associated with oil and natural gas development," Richard Walker, Geoff Smith and Annika Walters—Western Division American Fisheries Society, Missoula, Mont., May 22–25, 2017.
  - Poster—"Physiological responses of fishes to stressors associated with oil and natural gas development," Richard Walker, Geoff Smith, and Annika Walters—Colorado/Wyoming/Utah American Fisheries Society meeting, Grand Junction, Colo., February 21–24, 2017, https://utah.fisheries.org/wp-content/uploads/2017/02/2017AFSProgram.pdf.

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Supporting Conservation Planning and Conservation Actions

Application of Comprehensive Assessment to Support Decision Making and Conservation Actions

The comprehensive assessment is a collaborative, two-part effort to support WLCI data needs and efforts used to support the WLCI conservation planning process. Part 1 entails directing data synthesis and assessment activities to support LPDTs and the WLCI Coordination Team in their efforts to develop conservation priorities and strategies, identify priority areas for future conservation actions, support evaluation and ranking of conservation projects, and evaluate the ways in which proposed habitat projects relate to WLCI priorities, spatially and ecologically. WLCI partners provide information on past conservation projects and identify issues and geographic locations where they anticipate future conservation projects. USGS incorporates this information with additional information (such as WLCI focal habitat maps, species distribution maps, oil and gas maps, partner assessment data) to provide context to proposed conservation projects. This new information is used by LPDTs and the WLCI Coordination Team to prioritize and rank proposed conservation projects, identify other conservation issues, and compile WLCI accomplishments for WLCI annual reports and the WLCI web page. Part 2 of the comprehensive assessment entails a multidisciplinary IA of (1) data relating to WLCI priorities and (2) resources designed to support decisions at the WLCI programmatic level and conservation planning at landscape scales. The IA includes identifying areas of high conservation and restoration value and areas having high development potential, based on the current landscape. The IA may be used to consider scenarios of potential future development for evaluating the conservation and restoration potential of large landscapes.

In FY2017, we assisted the WLCI Coordination Team on updating the WLCI Conservation Action Plan and the associated habitat treatment spatial database with information from FY2016 habitat projects. We linked the WLCI Conservation Project Database to project location boundaries so WLCI accomplishments and funding attributes can be presented as maps. We also assisted in preparation of the 2016 BLM WLCI annual report and provided maps and other materials to support evaluations and rankings of WLCI conservation projects. We updated the USGS product list and distributed it to USGS management and WLCI partners.

Accomplishments in Fiscal Year 2017

- Updated WLCI Conservation Action Plan using WLCI 2015 and 2016 accomplishments.
- Linked 2015 and 2016 WLCI project location information with the WLCI Conservation Project Database.
- Provided maps and other information to support the evaluation and ranking of proposed 2018 conservation projects.
- Participated in workshops and conference calls associated with the Southern Rockies and Great Northern Landscape Conservation Cooperative's Green River Basin Landscape Conservation Design project. Provided spatial information on WLCI landscape priorities and geographic priority areas. This information was incorporated in their analysis to understand change agents, focal areas and habitats, and vulnerability analysis for the Green River Basin.\

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Plant Phenology Metrics to Evaluate Sagebrush in the Wyoming Landscape Conservation Initiative Region

Plant phenology and productivity are fundamental habitat components for many wildlife Species of Greatest Conservation Need in Wyoming. Plant phenology—the timing of life-history events such as greenup, flowering, and senescence—affects animal distribution and migration because the nutritional value of forage varies across phases of plant growth. Time series of vegetation indices from satellite imagery provide indicators of plant phenology and productivity that can explain animal distributions and may be useful for evaluating habitat management activities.

In FY2017, we continued research at the intersection of wildlife, plant phenology, and habitat management with projects that evaluated (1) effects of drought on the ability of mule deer to track plant phenology (Aikens and others, 2017); (2) effects of sagebrush-reduction treatments on phenology, productivity, and habitat use by mule deer; (3) interacting effects of phenology, grazing patterns, and prescribed fire on elk calving and habitat selection; and (4) hunting effects on fall elk migration. Drought affects the ability of mule deer to track plant phenology during spring migration, which has important implications for identifying migration routes and habitats for conservation (Aikens and others, 2017). Sagebrush reduction by prescribed fire, herbicide, and mechanical treatments can expedite senescence in land-surface phenology and increase primary productivity through changes in species abundance (Johnston and others, 2018). Our satellite-based assessment corroborated findings of field studies that prescribed fire has the most enduring effects on sagebrush communities (Johnston and others, 2018). Phenology strongly affects elk calving locations, and changes correlate declines in calf to cow ratios. In fall, elk move to a protected area having less forage, concurrent with the onset of archery hunting.

An elk with a radio collar on the Fossil Butte National Monument. Photo courtesy of the National Park Service.

In 2018, we expect to complete our assessment of mule deer responses to habitat treatments and begin evaluation of habitats along deer migration routes. We intend to continue collaborative efforts with the Wyoming Cooperative Fish and Wildlife Research Unit, Wyoming Migration Initiative, BLM, National Park Service, and WGFD to refine research questions and ensure development of useful products for management of wildlife and their habitats.

Accomplishments in Fiscal Year 2017

- Presentation—"Plant phenology and productivity at sagebrush treatments in Wyoming," A.N. Johnston, E.A. Beever, J.A. Merkle, and G. Chong—Great Basin Consortium, Reno, Nev.; February 21–23, 2017.

- Aikens, E.O., Kauffman, M.J., Merkle, J.A., Dwinnell, S.P.H., Fralick, G.L., and Monteith, K.L., 2017, The greenscape shapes surfing of resource waves in a large migratory herbivore: Ecology Letters, v. 20, no. 6, p. 741–750, https://doi.org/10.1111/ele.12772.
- Johnston, A.N., Beever, E.A., Merkle, J.A., and Chong, Geneva, 2018 [in press at the end of FY17], Vegetation responses to sagebrush-reduction treatments measured by satellites: Ecological Indicators, v. 87, p. 66–76, https://doi.org/10.1016/j.ecolind.2017.12.033.

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Economics of Greater Sage Grouse Conservation Strategies

Understanding the effects of land use changes on sage grouse has been an important research question in the USGS WLCI science strategy for many years (Bowen and others, 2009b). Due to a decline in abundance of sage grouse across the American West, a great amount of effort has been directed at conservation actions to help avoid Federally listing the species as threatened. From an economic perspective, it can be useful to think about the return on investment from these efforts, especially if they are costly. Unlike oil and gas products, the economic value of preserving sage grouse is not reflected in conventional markets, and thus requires nonmarket valuation approaches commonly used by environmental economists. Our research seeks to develop a better understanding of the full costs (that is, foregone economic benefits of sage grouse preservation) of energy development and grazing patterns. One area of particular interest is the effect of nontraditional oil and gas development technologies, including horizontal and directional drilling, on predicted energy development scenarios and how those outcomes may affect sage grouse from an economic perspective.

In FY2017, we compiled existing economic value estimates for similar species to qualitatively describe the social benefits from sage grouse protection (fig. 6). We reviewed existing studies on anticipated effects from alternative grazing strategies on ranching profits. These predicted values (fig. 6) are based on the metaregression analysis of rare, threatened, and endangered species conducted by Richardson and Loomis (2009). Consistent with economic theory, this figure displays decreasing returns in total economic value with changes to sage grouse populations. For example, a 1 percent increase in sage grouse for the year 2010 results in a predicted total economic value of roughly $2 per nonvisiting household. The predicted value increases to $109 per household per year when the change in sage grouse populations increases to 100 percent. At this point, the total economic value represents the predicted average household's total willingness to pay to prevent sage grouse extinction.

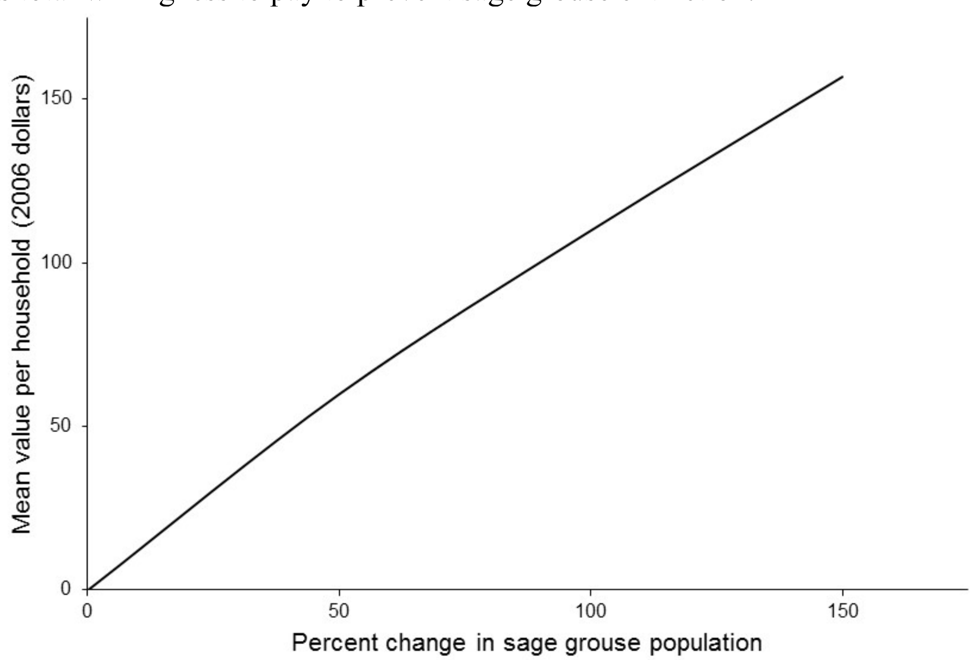

Figure 6. Preliminary economic benefits per household as it relates to a percent change in sage grouse populations.

We will use this combined information to describe the possible effects to sage grouse from USGS modeled forecasts of energy development in the region. Short of gathering new economic data, which can be costly, the implications of this body of research indicate that sage grouse conservation strategies may be best framed as a "lowest-cost" economic problem. This can be helpful when deciding how to proceed when a management objective is already stated. For example, if managing sagebrush density is the stated objective, a least-cost framework will help decide which treatment options (for example, chemical, mechanical) will meet the stated goal in the cheapest way.

Accomplishments in Fiscal Year 2017

- Prepared manuscript on economic considerations of sage grouse conservation for submission to peer-reviewed journal or USGS report.

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Modeling Recovery of Sagebrush Across the Wyoming Landscape Conservation Initiative Using Remotely Sensed Vegetation Products

The ability to predict sagebrush recovery after disturbance is limited by a paucity of research quantifying the spatial and temporal factors influencing recovery across landscapes. Scientists from Colorado State University, in cooperation with USGS Fort Collins Science Center scientists, are developing a framework for modeling changes in sagebrush cover on reclaimed well pads across the WLCI. We are using time-varying remote-sensing products developed for the WLCI to model rates of change in sagebrush cover at 2- to 5-year intervals (1988−2015; see “Remote Sensing and Vegetation Inventory and Monitoring” section on p. 30) and evaluating effects of static and time-varying factors such as soils, topography, and weather. This information will improve our practical understanding of environmental effects on postdisturbance recovery. Consideration of predicted recovery rates could identify areas that are particularly slow at recovery or could inform mitigation by identifying sites and regions that have similar potential, and therefore similar anticipated response to disturbance.

Accomplishments in Fiscal Year 2017

- Initial analyses of vegetation recovery rates at well pads in Wyoming.
- Prepared manuscript on estimating recovery of vegetation on reclaimed well pads using time-varying remote sensing products for submission to peer-reviewed journal.

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