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U.S. Geological Survey Science for the Wyoming Landscape Conservation Initiative—2018 Annual Report

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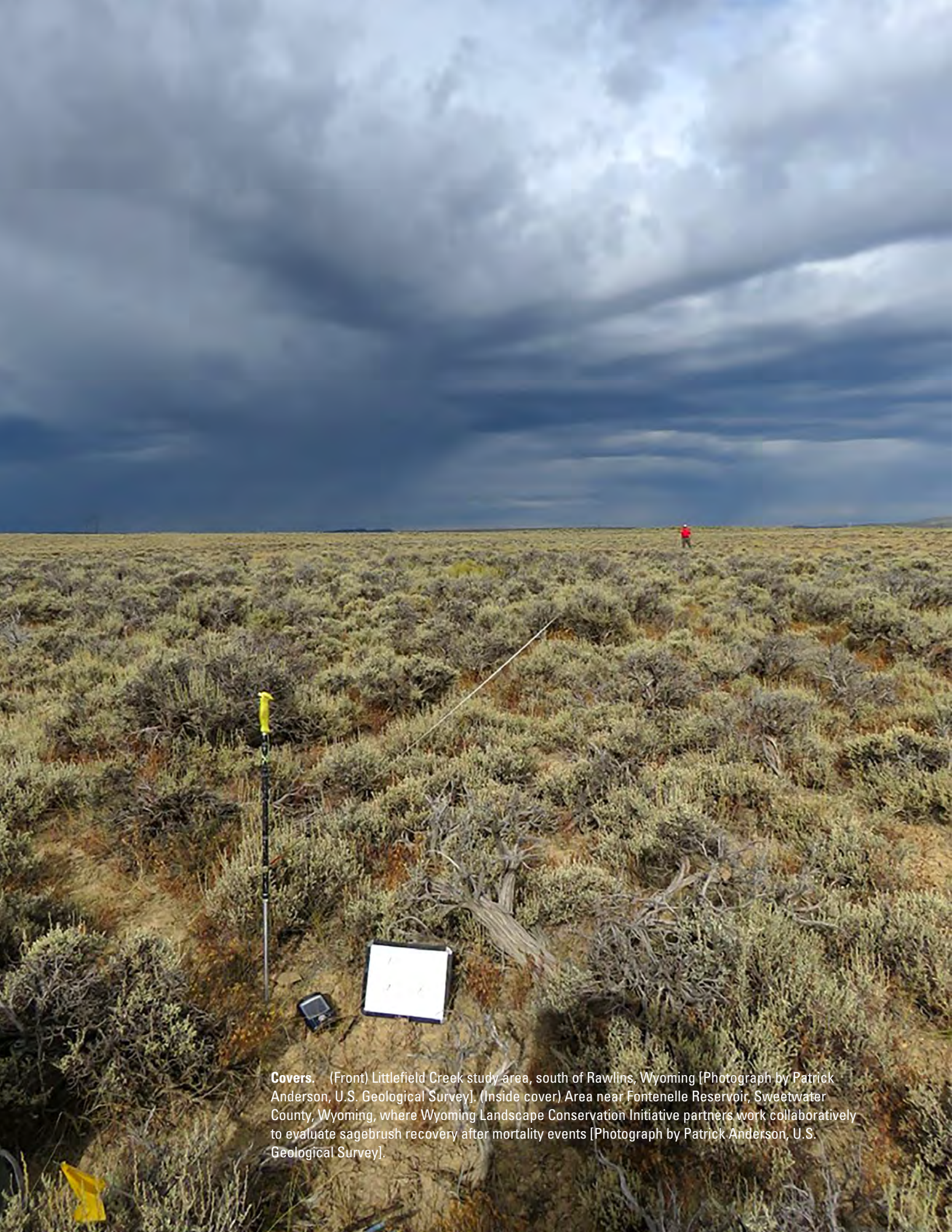
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U.S. Geological Survey Science for the Wyoming Landscape Conservation Initiative—2018 Annual Report

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Covers. (Front) Littlefield Creek study area, south of Rawlins, Wyoming [Photograph by Patrick Anderson, U.S. Geological Survey]. (Inside cover) Area near Fontenelle Reservoir, Sweetwater County, Wyoming, where Wyoming Landscape Conservation Initiative partners work collaboratively to evaluate sagebrush recovery after mortality events [Photograph by Patrick Anderson, U.S. Geological Survey].

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**U.S. Department of the Interior
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U.S. Geological Survey, Reston, Virginia: 2021

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Suggested citation:

Anderson, P.J., Aldridge, C.L., Alexander, J.S., Assal, T.J., Aulenbach, S., Bowen, Z.H., Chalfoun, A.D., Chong, G.W., Copeland, H., Edmunds, D.R., Germaine, S., Graves, T., Heinrichs, J.A., Homer, C.G., Huber, C.C., Johnston, A., Kauffman, M.J., Manier, D.J., McShan, R.R., Eddy-Miller, C.A., Miller, K.A., Monroe, A.P., O'Donnell, M.S., Ortega, A., Walters, A.W., Wieferich, D., Wyckoff, T.B., and Zeigenfuss, L., 2020, U.S. Geological Survey science for the Wyoming Landscape Conservation Initiative—2018 annual report: U.S. Geological Survey Open-File Report 2021–1067, 33 p., <https://doi.org/10.3133/ofr20211067>.

ISSN 2331-1258 (online)

Acknowledgments

The authors thank the Wyoming Landscape Conservation Initiative (WLCI) Science and Technical Advisory Committee and the WLCI Coordination Team for their ideas and guidance to the U.S. Geological Survey (USGS) on WLCI science needs and priorities and for reviewing the proposed 2018 USGS science activities and work plan. The authors also give thanks and acknowledgment to the Wyoming Game and Fish Department, the Wyoming Department of Agriculture, the Bureau of Land Management, the U.S. Fish and Wildlife Service, and other WLCI partners for supporting the USGS 2018 science efforts by meeting with our scientists to discuss science needs and priorities and for providing data and information about USGS study areas and WLCI monitoring efforts and conservation projects. The authors also wish to thank Jim Wasseen of the Wyoming Game and Fish Department, Rock Springs, Wyoming, and Benjamin Harms at the USGS Fort Collins Science Center in Colorado for their thorough reviews and informative suggestions and comments on this report.

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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)
Area		
square kilometer (km ²)	247.1	acre

Common and Scientific Species Names

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

Abbreviations

BLM	Bureau of Land Management
DOI	U.S. Department of the Interior
ET	evapotranspiration
FY	fiscal year (Federal fiscal year runs from October 1 through September 30)
GPS	Global Positioning System
LST	land-surface temperature
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
PAD-US	Protected Areas Database
SGCN	Species of Greatest Conservation Need
SO	Secretarial Order
SPEI	Standardized Precipitation Evapotranspiration Index
STAC	Science Technical Advisory Committee
USGS	U.S. Geological Survey
WGFD	Wyoming Game and Fish Department
WLCI	Wyoming Landscape Conservation Initiative
WY-TWS	Wyoming Chapter of the Wildlife Society

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Abstract

The Wyoming Landscape Conservation Initiative (WLCI) was established in 2007 as a collaborative interagency partnership to develop and implement science-based conservation actions. During the past 11 years, partners from U.S. Geological Survey (USGS), State and Federal land management agencies, universities, and the public have collaborated to implement a long-term (more than 10 years) science-based program that assesses and enhances the quality and quantity of wildlife habitats in the southwest Wyoming region while facilitating responsible development. The USGS WLCI 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 2018, the USGS initiated 3 new projects and continued efforts on 21 ongoing science and web-development projects. The first new project was initiated to support Secretarial Order 3362 which calls on the USGS to assist Western States in mapping big-game migration corridors and developing new mapping tools. During 2018, the USGS hosted a workshop in Laramie, Wyoming, which included more than 70 State and Federal wildlife experts from Colorado, New Mexico, Texas, and Wyoming. Most of the mapping and migration tool curricula used in the workshop were derived from prior WLCI studies and mapping efforts of big-game migration movement in habitats undergoing large-scale energy development.

The second new project was in response for WLCI partners to better understand sedimentation and hydrogeomorphic processes in a cold-desert headwater and the third new project was designed to improve our approach for people to access, manage, and analyze WLCI data and WLCI resource information. The USGS published 18 products (including peer-reviewed journal articles, USGS series publications, and data releases) and provided more than a dozen professional oral and poster presentations at scientific meetings and numerous informal presentations to WLCI partners at meetings and workshops. This report summarizes the objectives and status of each project and highlights the USGS 2018 accomplishments and products.

Introduction

During the early 2000s in southwestern Wyoming, expanding energy and mineral development, urban growth, and other changes in land use combined with landscape-scale drivers (such as climate change and invasive species) presented numerous challenges to resource managers and stakeholders. To address these challenges, the Wyoming Landscape Conservation Initiative (WLCI) was established in 2007 as a collaborative interagency partnership with the goals of understanding how key drivers and land-use change affect wildlife and their habitats and the development and implementation of conservation actions (Bowen and others, 2009; D'Erchia, 2016).

The WLCI is a 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. Partners associated with the WLCI include the Wyoming Department of Agriculture, Wyoming Game and Fish Department (WGFD), six counties (Carbon, Fremont, Lincoln, Sublette, Sweetwater, and Uinta), nine

¹U.S. Geological Survey.

²Kent State University.

³University of Wyoming.

⁴Colorado State University.

conservation districts, Bureau of Land Management (BLM), U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service, U.S. Forest Service, National Park Service, and the Natural Resources Conservation Service.

The WLCI area includes diverse land ownership and covers more than 19 million acres in southwest Wyoming (fig. 1). The WLCI focuses on sagebrush, mountain shrub, aspen, riparian, and aquatic communities for conservation work and science studies. Among these focal communities, increased significance is placed on those habitats associated with migration and movement corridors (terrestrial and aquatic species) and areas with designated crucial habitats (for example, winter range, parturition areas), or support important life stage needs for designated Species of Greatest Conservation Need (SGCN).

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

The primary role of the USGS in the WLCI is to conduct research and provide science information to facilitate management decisions associated with fish and wildlife and their habitats and understand cumulative effects of energy development and other drivers of ecosystem change at landscape scales. The USGS accomplishes these responsibilities through a multidisciplinary science team which includes more than 20 scientists and technological experts, graduate students, and field and laboratory technicians. The USGS Science Team follows WLCI science strategies and priorities (Bowen and others, 2009) and partner input to develop annual statements of work for the WLCI. Partner input is primarily provided by the WLCI Science Technical Advisory Committee (STAC) but also includes the WLCI Executive Committee, the WLCI Coordination Team, and WLCI local project teams.

The STAC is an interagency committee with representatives from WLCI partner agencies including the U.S. Fish and Wildlife Service, BLM, National Park Service, USGS, Wyoming Department of Agriculture, and WGFD. The STAC

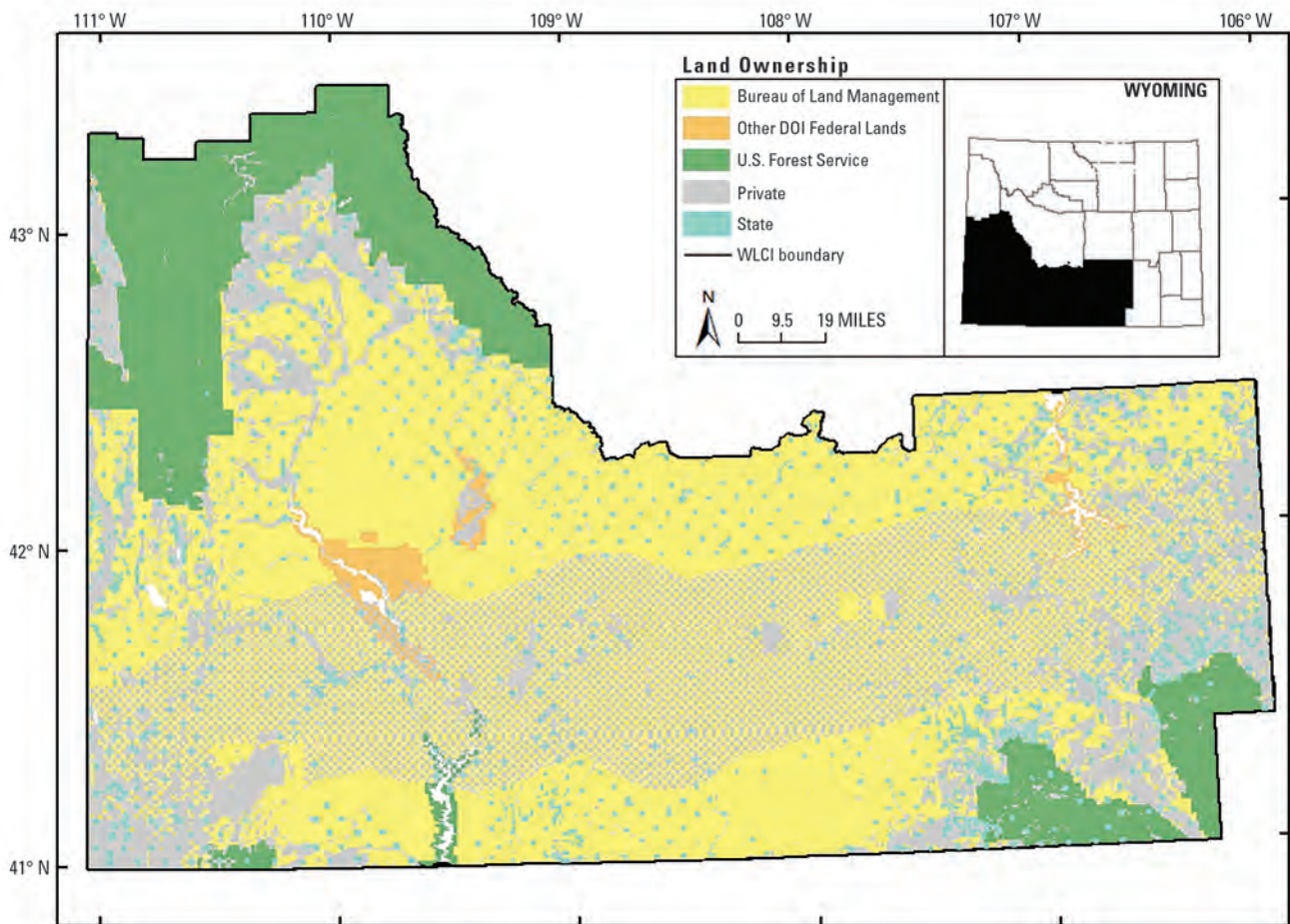


Figure 1. Map showing the boundary of and landownership in the Wyoming Landscape Conservation Initiative (WLCI) program area. (DOI, U.S. Department of the Interior)

provides guidance to the USGS by identifying and prioritizing research needs of the WLCI and by helping integrate science to inform WLCI management decisions and conservation projects. The STAC also reviews ongoing USGS studies and products and proposed annual statements of work. The USGS Science Team uses the STAC reviews and guidance to adjust existing science studies, prioritize and develop new science studies, and revise proposed annual statements of work.

A member of the USGS Science Team also serves on the WLCI Coordination Team, which manages the daily operations of WLCI. Responsibilities of the Coordination Team include coordination and communication between USGS and WLCI partners; helping WLCI partners integrate new information and technologies in their planning, decision making, and management actions; and facilitating the dissemination, interpretation, and use of USGS findings, products, and tools. The 2017 USGS WLCI annual report (Zeigenfuss and others, 2019) provides more recent information on how the USGS is implementing its science and integrating it with WLCI decisions and actions.

Purpose of this Report

Scientists with the USGS use multiple approaches to disseminate science information. These include the WLCI web page; science presentations at local team meetings, partner offices, and at the WLCI Executive Committee meetings; WLCI Science Workshops; and annual reports. The USGS has produced annual reports to highlight its WLCI science accomplishments every Federal fiscal year (FY; October 1 through September 30) since 2008. In-depth information on ongoing and completed projects can be found in earlier annual reports, which can be accessed at the web addresses listed in the box below. This report features summaries of new and ongoing projects and highlights FY 2018 science activities, accomplishments, and products.

Previous USGS Annual Reports for WLCI

2017 Annual Report: <https://doi.org/10.3133/ofr20181188>
 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/>

The USGS science activities are organized by themes which reflect WLCI landscape priorities and issues outlined by WLCI partners. When appropriate, themes overlap WLCI conservation themes, which improves the integration between WLCI science and conservation. These themes are also used on the WLCI webpage to organize science accomplishments

and enhance web delivery for WLCI partners. Most studies address multiple themes, but to keep the organization of this report simple, studies were aligned with the theme they primarily address. The following themes were addressed by USGS science projects during FY 2018:

- Big-Game Migration Corridors in Wyoming and Other Western States: USGS Implementation of Secretarial Order (SO) 3362;
- Ecology of WLCI Focal Wildlife Species;
- Status and Trends of WLCI Priority Habitats;
- Effects of Energy Development on Fish, Wildlife, and their Habitats;
- Supporting WLCI Conservation Planning and Conservation Actions; and
- Science Information and Data Management.

Individual project reports include in-depth information on each new science project. Project reports also include, where applicable, web addresses to directly access USGS and outside products published in FY 2018.

Summary of Fiscal Year 2018 Accomplishments and Activities

The USGS initiated 3 new projects and continued efforts on 21 ongoing projects during FY 2018. The first new project used approaches developed from USGS WLCI studies and mapping of big-game movements, to support other Western States with a comprehensive, standardized approach to mapping big-game migration corridors. In 2018, the U.S. Department of the Interior (DOI) directed its bureaus to work with Western States to improve the quality of big-game winter range and migration corridor habitat (DOI, 2018). Also, during 2018, the USGS Wyoming Cooperative Research Unit hosted a workshop to discuss and apply these approaches in Laramie, Wyoming. More than 70 State and Federal wildlife experts from Wyoming, Colorado, New Mexico, and Texas participated.

The second new project helped researchers better understand sedimentation and hydrogeomorphic processes in a cold-desert headwater stream. Investigators from the USGS met with biologists and resource specialists from WGFD, the BLM Rawlins Field Office, and other agencies to discuss sediment issues in the Littlefield Creek headwater priority area. This small, spring-fed stream is an important trout fishery and has been the focus of WLCI conservation projects. During the fall of 2018, USGS scientists set up instruments to monitor baseflow, stream depth, snowfall, snow melt, rainfall, runoff, and channel physical processes (such as bank erosion and ice-jamming) and to collect bed sediments. Results from these activities will help WLCI partners incorporate information about hydrogeomorphic processes into Littlefield Creek management and restoration plans.

The third new project improved the ability of USGS researchers to access, manage, and analyze WLCI data. For example, the USGS explored the use of computer algorithms and a literature database to return information from WLCI scientific literature. This effort was done to determine how well WLCI literature is currently documented in widely available literature databases. These efforts identified several WLCI publications that were not included in literature databases and (or) that were not currently included in the WLCI catalog of publications, both of which are planned to be brought up to date in FY 2019.

During 2018, USGS scientists completed and published 10 science manuscripts or reports and presented study findings at numerous conferences and meetings. Examples of our 2018 studies and findings include the following.

- Developing an energy footprint model that simulates well, pad, and road patterns for oil and gas recovery options that vary in well types (vertical and directional) and number of wells per pad. This framework was used to simulate scenario tradeoff assessments between oil and gas field development and wildlife needs and to identify approaches that best achieve both energy and conservation goals (see Garman, 2018 in the “List of 2018 Products” section).
- Investigating trends for greater sage-grouse populations at multiple spatial scales across Wyoming instead of using single-scale estimates (see Edmunds and others, 2018 in the “List of 2018 Products” section). Scientists with the USGS found that most populations of sage-grouse were declining at broad spatial scales. However, at finer spatial scales, some interspersed populations were increasing. These results indicate that broad-scale population trends can mask trends occurring at local scales.
- Investigating how disturbances from oil and gas development affect native fish species assemblages (see Girard and Walters, 2018 in the “List of 2018 Products” section). We learned that Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*) and mottled sculpin (*Cottus bairdii*) were correlated with environmental conditions that had less disturbance and that mountain sucker (*Catostomus platyrhynchus*) were persisting at more degraded sites. Degraded conditions were similar to other watershed-level disturbances (from invasive plants, fire, drought) which are usually successfully addressed through best management practices.
- Evaluating changes in vegetation after sagebrush treatments. In this case, USGS scientists used satellite imagery to quantify effects of prescribed-fire, herbicide, and mechanical treatments on vegetative cover, productivity, and phenology (see Johnston and others, 2018 in the “List of 2018 Products” section). Most treatments appeared to increase cover of grasses and

forbs, which was the primary objective for most treatments. The successful implementation of this approach indicates that the use of satellite imagery is a very effective approach to monitoring vegetation change in sagebrush ecosystems.

The USGS also released datasets and data products during 2018. One such data product is a viewable quick reference chart of a Standardized Precipitation Evapotranspiration Index (SPEI) summarized for the upper Green River Basin (see Assal, 2018 in the “2018 U.S. Geological Survey Data Products” section). The SPEI index, which incorporates both precipitation and temperature data to determine their combined effects on drought, was calculated for each water year (October–September) between 1896 and 2017. In addition to this being a quick reference for wildlife and habitat biologists, the underlying data can be used to determine how temperature and precipitation influenced treatment responses in sagebrush habitat. Other data releases include real-time water quality and streamgage data at several sites in the WLCI area (see the “2018 U.S. Geological Survey Data Products” section).

The highlight of 2018 for the USGS and WLCI was our successful joint science conference between the WLCI and the Wyoming Chapter of the Wildlife Society (WY-TWS) which was held during November 6–8 in Laramie, Wyo. More than 200 people participated in the conference representing restoration practitioners, resource specialists, researchers and scientists, managers and planners, students, industry workers, and policy staff. The conference included 45 oral presentations and 27 poster presentations that addressed 6 themes relevant to both WY-TWS and WLCI, and USGS scientists and affiliated students presented 13 oral papers and 5 poster papers. The 2018 WY-TWS WLCI Conference Program, which includes abstracts for all oral and poster presentations, is available at http://wytwsconference.org/wp-content/uploads/2018/10/2018-YTWS-WLCI-Conference-Program_CORRECTED.pdf.

The USGS FY 2018 list of projects and their relationship to WLCI science themes and other WLCI activities are summarized in [table 1](#). A list of 2018 products, which includes completed manuscripts, presentations, and data products, are provided starting on page 6 of the conference program. Some of these products that were drafted in 2018 and published in early 2019 are listed after [table 1](#) so WLCI partners are aware of them now rather than waiting for the 2019 report to be published. Individual project updates are provided in the section “Project Descriptions and FY 2018 Accomplishments” which starts on page 11 of the conference program.

For more information on USGS WLCI activities, contact 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 (USGS) science projects conducted in fiscal year (FY) 2018. Projects are organized by science theme and list focal species and (or) habitats addressed by the project. (WLCI, Wyoming Landscape Conservation Initiative)

Project title	Status during FY 2018	Focal species ¹	Focal habitat
Theme: Big-Game Migration Corridors in Wyoming and Other Western States: USGS Implementation of Secretarial Order 3362			
Big-Game Migration Corridors in Wyoming and Other Western States	New	Mule deer and pronghorn	All focal habitats
Theme: Ecology of WLCI Focal Wildlife Species			
Modeling Greater Sage-Grouse Population Responses to Landscape Changes	Ongoing	Greater sage-grouse	Sagebrush steppe, sage-grouse core areas
Identifying Impediments to Wyoming Mule Deer Seasonal Movements and Long-Distance Migration	Ongoing	Mule deer	Mixed mountain shrubland, crucial winter range
Theme: Status and Trends of WLCI Focal Habitats			
Remote Sensing and Vegetation Inventory and Monitoring	Ongoing	Sagebrush species	Sagebrush steppe
Framework and Indicators for Long-Term Monitoring	Ongoing	All focal species	All focal habitats
Long-Term Productivity of Sagebrush Ecosystems and Their Responses to Drought, Land Use, and Other Change Agents	Ongoing	Sagebrush species	Sagebrush steppe
Mapping and Monitoring Mixed Mountain Shrub Communities	Ongoing	Mountain-mahogany, western serviceberry, chokecherry, antelope bitterbrush	Shrub steppe
Status and Trends of Aspen and Willow Communities in the Bighorn Mountains	Ongoing ²	Aspen, willow	Riparian habitat
Monitoring of Surface Water, Groundwater, and Water Quality	Ongoing	No focal species	Riparian, aquatic habitat
Evaluation of Environmental Drivers of Streamflow, Including Interaction with Groundwater, in Small Streams in the Western Green River Basin to Enhance Understanding of Aquatic Communities	Ongoing	No focal species	Riparian, aquatic habitat
Theme: Relationships 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
Identifying Threshold Levels of Energy Development that Impede Wyoming Mule Deer Migration	Ongoing	Mule deer	Shrub steppe, crucial winter habitat
Wind Energy and Wildlife in Southwest Wyoming	Ongoing	At-risk birds, bats, and other wildlife	All focal habitats associated with species
Relationship Between Energy Development and Pygmy Rabbit Presence and Abundance	Ongoing	Pygmy rabbit	Sagebrush steppe
Mechanistic Understanding of Energy Resource Development Effects on Songbirds	Ongoing	Brewer's sparrow, sagebrush sparrow, sage thrasher	Sagebrush steppe
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 habitat
Theme: Supporting Conservation Planning and Conservation Actions			
Application of Comprehensive Assessment to Support Decision Making and Conservation Actions	Ongoing	All species area	All focal habitats in WLCI study
Plant Phenology Metrics to Evaluate Sagebrush in the WLCI Region	Ongoing	Sagebrush species, mule deer, elk	Sagebrush steppe, shrub steppe, aspen
Characterizing and Quantifying Dynamics of a Cold-Desert Headwater Stream, Littlefield Creek	New	Colorado River cutthroat trout	Aquatic and riparian habitats

Table 1. Summary of U.S. Geological Survey (USGS) science projects conducted in fiscal year (FY) 2018. Projects are organized by science theme and list focal species and (or) habitats addressed by the project. (WLCI, Wyoming Landscape Conservation Initiative)—Continued

Project title	Status during FY 2018	Focal species ¹	Focal habitat
Theme: Supporting Conservation Planning and Conservation Actions—Continued			
Economics of Greater Sage-Grouse Conservation Strategies	Ongoing	Sagebrush species, sage-grouse	Sagebrush steppe
Modeling Recovery of Sagebrush Across the WLCI Using Remotely Sensed Vegetation Products	Ongoing	Sagebrush species	Sagebrush steppe
Theme: Science Information and Data Management			
Information Management Framework	New	Not applicable	Not applicable

¹Scientific 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.).

²New project phase or new focus and title.

List of 2018 Products

2018 U.S. Geological Survey Publications

Carter S.K., Manier D.J., Arkle R.S., Johnston A., Phillips S.L., Hanser S.E., and Bowen Z.H., 2018, Annotated bibliography of scientific research on greater sage-grouse published since January 2015: U.S. Geological Survey Open-File Report 2018–1008, 183 p., <https://doi.org/10.3133/ofr20181008>.

Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., and Monroe, A.P., 2018, 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>.

Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., and Monroe, A.P., 2018, Erratum—Greater sage-grouse population trends across Wyoming: *Journal of Wildlife Management*, v. 82, no. 8, p. 1808, <https://doi.org/10.1002/jwmg.21560>.

Garman, S.L., 2018, A simulation framework for assessing physical and wildlife impacts of oil and gas development scenarios in southwestern Wyoming: *Environmental Modeling & Assessment*, v. 23, p. 39–56, <https://doi.org/10.1007/s10666-017-9559-1>.

Girard, C.E., and Walters, A.W., 2018, Evaluating relationships between fishes and habitat in streams affected by oil and natural gas development: *Fisheries Management and Ecology*, v. 25, p. 366–379, <https://doi.org/10.1111/fme.12303>.

Johnston, A.N., Beever, E.A., Merkle, J.A., and Chong, G., 2018, 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>.

Sanders, L.E., and Chalfoun, A.D., 2018, Novel landscape elements within natural gas fields increase densities of an important songbird nest predator: *Biological Conservation*, v. 228, p.132–141, <https://doi.org/10.1016/j.biocon.2018.10.020>.

Sanders, L.E., and Chalfoun, A.D., 2019, Mechanisms underlying increased nest predation in natural gas fields—A test of the mesopredator release hypothesis: *Ecosphere*, v. 10, no. 5, article no. e02738, <https://doi.org/10.1002/ecs2.2738>.

Walters, A.W., Girard, C.E., Walker, R.H., Farag, A.M., and Alvarez, D.A., 2019, Multiple approaches to surface water quality assessment provide insight for small streams experiencing oil and natural gas development: *Integrated Environmental Assessment and Management*, v. 15, no. 3, p. 385–397, <https://doi.org/10.1002/ieam.4118>.

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

2018 U.S. Geological Survey Data Products

Assal, T.J., 2018, Bighorn Mountains, Wyoming Forest Mapping, 2013–2017: U.S. Geological Survey data release, <https://doi.org/10.5066/P98OS2XK>.

Assal, T.J., 2018, Standardized Precipitation Evapotranspiration Index for the upper Green River Basin (1896–2017): U.S. Geological Survey data release, <https://doi.org/10.5066/P9VLM7Z6>.

Girard, C. and Walters, A., 2018, Habitat and fish field survey data from Wyoming Range streams in 2012 and 2013: U.S. Geological Survey data release, <https://doi.org/10.5066/F78S4P7Z>.

Graves, T.A., Mikle, N.L., and Olexa, E.M., 2019, West Green River elk herd locations in southwestern Wyoming, 2005–2010: U.S. Geological Survey data release, <https://doi.org/10.5066/F70K27SF>.

Real-Time and Water-Quality Data

New Fork River near Big Piney, WY: https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09205000

Green River near Green River, WY: https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09217000

Muddy Creek above Olson Draw, near Dad, WY: https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09258050

Muddy Creek below Young Draw, near Baggs, WY: https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09258980

Real-Time Groundwater—Streamgage Site Data

New Fork River near Big Piney, WY: Water-surface elevation—<https://go.usa.gov/xnFAe>, temperature—https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09205000

Green River near Green River, WY: <https://go.usa.gov/xnFAF>

Project Descriptions and Fiscal Year 2018 Accomplishments

Theme: Big-Game Migration Corridors in Wyoming and Other Western States

The primary USGS role in implementing SO 3362 is to work collaboratively with States, the Western Association of Fish and Wildlife Agencies, and DOI bureaus to facilitate data compilation and analyses necessary to map big-game migration corridors across the West. This includes the transfer of technical information on the tools and methods available to analyze migration corridor data to State wildlife agencies and other Federal biologists. Corridor maps are based on high-resolution movement data from collared animals tagged with a Global Positioning System (GPS) collar and are analyzed to create low-, medium-, and high-use corridors using standardized, peer-reviewed methods, many of which came from USGS WLCI projects. The USGS continues to provide expertise, statistical code, troubleshooting, metadata, and map templates as well as overall direction for this ongoing west-wide mapping effort.

Mapping Big-Game Migration Corridors in Wyoming and Other Western States: USGS Implementation of Secretarial Order 3362

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Wyoming's mule deer herds contribute significantly to the State's wildlife diversity, and they play a crucial role in its hunting economy. However, mule deer herds throughout Wyoming and other Western States have been declining since the 1990s. Increasingly, wildlife biologists and wildlife managers are understanding that migration corridors are key habitats for migratory ungulates. However, disturbances to habitats and land management activities that may alter the behavior of animals during migration have the potential to modify their ability to track plant phenology across the landscape. Long-term monitoring of migration is needed to understand how migrating animals respond to habitat alterations and conservation measures (for example, fence modifications). In response to SO 3362 (DOI, 2018), which calls on the USGS to assist Western States in mapping corridors and developing new mapping tools, we are applying our knowledge and expertise on mapping and tracking big game that we developed from our years of research in Wyoming and WLCI projects. Our research objectives include (1) assessing the effect of fencing and other barriers on mule deer migrations; (2) conducting Brownian Bridge Movement Models of existing GPS movement data for mule deer, pronghorn, and elk within Wyoming and other Western States and providing these polygons to the respective State wildlife agencies; (3) creating compelling cartographic map products of migrations in Wyoming and other Western States and making associated corridor polygon data available to land and wildlife managers; and (4) sharing this information with the public and State and Federal agency managers and decision makers.

A primary focus for the USGS researchers at the Wyoming Cooperative Research Unit in 2018 was to assemble a Corridor Mapping Team to work with individual State wildlife agencies and DOI partners to facilitate mapping of migration corridors. In collaboration with the Western Association of Fish and Wildlife Agencies mule deer working group, USGS conducted four workshops between October 2017 and September 2018 to train State and Federal biologists throughout the West. These workshops introduced wildlife managers to recent migration research and trained them to analyze GPS movement data using the new Migration Mapper software the Wyoming team developed for corridor analyses. The Wyoming team will continue to update and refine the Migration Mapper software as the science and technology improves. Science performed by the USGS in support of SO 3362 was presented at the WY-TWS and WLCI joint meeting November 6–8, 2018, in Laramie, Wyo.

Accomplishments and Products Completed FY 2018

Manuscript: Kauffman, M.J., Meacham, J.E., Sawyer, H., Steingisser, A.Y., Rudd, W.J., Ostlind, E., and Proulx, A., 2018, Wild migrations—Atlas of Wyoming’s ungulates: Corvallis, Oreg., Oregon State University Press.

Presentation: Ortega, A.C., Sawyer, H., Aikens, E.O., Merkle, J.A., Burke, P., Zornes, M., Monteith, K.L., and Kauffman, M.J., 2018, One herd, many migrations—A test of the fitness-balancing hypothesis with mule deer, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Ortega, A.C., Sawyer, H., Aikens, E.O., Merkle, J.A., Burke, P., Zornes, M., Monteith, K.L., and Kauffman, M.J., 2018, One herd, many migrations—A test of the fitness-balancing hypothesis with mule deer, *in* Biennial Scientific Conference on the Greater Yellowstone Ecosystem, 14th, Big Sky, Mont.

Theme: Ecology of WLCI Focal Wildlife Species

Southwest Wyoming encompasses vast areas of high-quality, crucial wildlife habitat for many high-profile game and nongame species. The core of the WLCI mission is to understand how land use, drought, and other drivers of change affect priority species and their habitats, and to enhance the quality and quantity of aquatic and terrestrial habitats for priority wildlife in southwest Wyoming. Partners of the WLCI have identified five focal wildlife species or species assemblages (all of the wildlife species that exist in a particular habitat of concern) that are priorities for conservation and research. These are pygmy rabbits, large ungulates (mule deer and pronghorn), sage-grouse, native fish (for example, Colorado River cutthroat trout), and songbird assemblages (especially assemblages with designated SGCN). The USGS addresses this theme by evaluating focal wildlife species habitat requirements, habitat use, seasonal movements, population status and trends, and species’ direct and indirect responses to landscape-scale disturbances. Our studies during 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); assessing aspects of habitat use and requirements for all five priority species or assemblages; assessing migratory songbird use of aspen stands (Bowen and others, 2013); and evaluating 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 (Sawyer and Kauffman, 2011; Allen and Kauffman, 2012). The results of our studies have many practical applications, such as prioritization of areas for conservation, restoration, and mitigation, and forecasting the future extent and condition of wildlife habitat.

Modeling Greater Sage-Grouse Population Responses to Landscape Changes

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In FY 2018, work continued to improve project scientists’ understanding of mechanisms affecting sage-grouse population trends. Through past efforts supported by the WLCI, we developed and published a simulation framework for spatially evaluating long-term population viability of sage-grouse (Heinrichs and others, 2017). We illustrated that areas with lower habitat selection (that is, outside of Core Areas) identified from seasonal habitat models (Fedy and others, 2014) can be important in sustaining higher numbers of sage-grouse during times of periodic high density, possibly reducing the risk of population declines. Additionally, lesser-quality habitats located in proximity to high quality habitats can be important for sustaining viable populations of sage-grouse. More recently, these simulation approaches were applied to assess the potential future effects of climate-induced habitat changes on sage-grouse habitat (see Homer and others, 2015) and increasing oil and gas development (see Garman, 2018, WLCI energy simulations) on sage-grouse demography and habitat use. Results indicate that both climate-induced vegetation changes and oil and gas development are important potential stressors that affect long-term population viability (Heinrichs and others, 2019). The combined influences during the coming decades could cause strong population declines. The pattern and intensity of oil and gas development could also result in the isolation of local sage-grouse populations in areas protected from development.

Efforts continued during FY 2018 to relate analyses linked to sage-grouse population viability. In contrast with projected sage-grouse population cycles that occur across large areas, as demonstrated in Wyoming (Fedy and Aldridge, 2011), individual populations may experience different population trajectories across biological or management units. In FY 2018, we published results from our trend analyses (1993–2015), which indicate that large-scale management units may trend similarly, but individual units often have different trajectories (Edmunds and others, 2018a, b). Hierarchical population clusters (O’Donnell and others, 2019) were developed to capture biologically significant population units more accurately, which will help to understand drivers of population change. Hierarchical population clusters were applied for sage-grouse populations in Nevada (Coates and others, 2017) and a similar population viability analysis was applied by individual core areas across the State of Wyoming. Together, these efforts increase our understanding of mechanisms that drive sage-grouse population trends, which directly inform conservation and management efforts being undertaken by WLCI partners.

Accomplishments and Products Completed FY 2018

Manuscript: Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., and Monroe, A.P., 2018, Greater sage-grouse population viability analyses across Wyoming core and management areas: *Journal of Wildlife Management*, v. 82, p. 397–412, <https://doi.org/10.1002/jwmg.21386>.

Manuscript: Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., and Monroe, A.P., 2018, Erratum—Greater sage-grouse population trends across Wyoming: *Journal of Wildlife Management*, v. 82, p. 1808, <https://doi.org/10.1002/jwmg.21560>.

Presentation: Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., Monroe, A.P., Coates, P.S., and Cade, B.S., 2018, Population trends of Wyoming greater sage-grouse across hierarchical population clusters, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Heinrichs, J.A. O'Donnell, M.S., Aldridge, C.L., Garman, S.L., Homer, C.G., and Schumaker, N.H., 2018, Simulating the potential consequences of future development and climate on sage-grouse in Wyoming, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Monroe, A.P., Aldridge, C.L., O'Donnell, M.S., Manier, D.J., Homer, C.G., Anderson, P.J., 2018, Estimating vegetation recovery following energy development using a long-term remote sensing dataset, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Monroe, A.P., Wann, G.T., Aldridge, C.L., and Coates, P.S., 2018, The importance of repeated counts when estimating population trends with dynamic n-mixture models, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: O'Donnell, M.S., Edmunds, D.R., Aldridge, C.L., Heinrichs, J.A., Coates, P.S., Prochazka, B.G., and Hanser, S.E., 2018, A new multi-scaled approach for designing population monitoring frameworks using graph theory—A case study of greater sage-grouse, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

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

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Increasingly, scientists and land managers understand that migration corridors are key habitats for migratory mule deer; however, alterations to the behavior of animals during migration have the potential to modify an animal's ability to track plant phenology (or “green-up”) across the landscape. Following greening plant phenology is 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. For example, mule deer wintering in Wyoming's Red Desert have been observed using three different migratory strategies (Sawyer and others, 2014). These include long-distance migrants that travel 241.4 kilometers (km) (150 miles) to the Hoback Basin for the summer, medium-distance migrants that migrate nearly 112.7 km (70 miles) to the southern Wind River Range for the summer, and short-distance migrants that either migrate less than 48.3 km (30 miles) north for the summer or live year-round in the Red Desert. Although these different types of migration have been observed for several years, little is known about the costs or benefits associated with each migratory strategy and how varying vegetation or weather conditions or landscape changes like habitat treatments, fire, or fencing may affect each strategy. 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; and (3) sharing this information with the public, land and wildlife managers, and decision makers.

Long-term monitoring of mule deer migration along the Red Desert to Hoback corridor continued during FY 2018 to learn more about these different migration strategies. In FY 2018, we increased our sample size of collared adult female mule deer to $n = 116$, up from $n = 107$ the previous year. FY 2018's count of $n = 116$ includes $n = 49$ long-distance migrants, $n = 31$ medium-distance migrants, and $n = 36$ short-distance migrants (Zeigenfuss and others, 2019). In addition, we deployed trail cameras along the migration corridor, including in areas where migration routes cross fences and highways (fig. 2). With more than 5 years of capture and migration data, we have begun to evaluate the fitness benefits of migration (for example, fat dynamics, fawn survival, forage availability), fidelity to migration routes and summer range, and timing of spring and fall migration.

In FY 2017, we completed our first analysis of green-wave surfing in mule deer that migrate along the Wyoming Range (Aikens and others, 2017). Results indicate that mule deer surf spring green-up closely and that alterations to green-up patterns strongly influenced surfing. Results also indicated that drought makes it more difficult for mule deer to surf



Figure 2. Photographs taken by trail cameras show mule deer behavioral responses such as *A*, leaping over fences; and *B*, crawling under fences. Photographs by Matt Kauffman, USGS Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, 2018.

during spring migration. In FY 2018, researchers involved with this project published a study that was designed to help researchers understand how development influences the ability of mule deer to track green-up phenology by evaluating movement relative to three different types of development (energy, residential, and dispersed rural) in southwestern Wyoming. Results indicate that, when signs of development are present, mule deer maintain their fidelity to migration routes but increase their rate of movement along their route and reduce their time at stopover sites. Mule deer also shifted stopover locations away from intense development. The most dramatic alterations to mule deer migratory behavior in the Atlantic Rim project area led to a reduction in the ability of mule deer to track green-up phenology through time, linking development to the loss of the foraging benefits of migration. By

understanding how different types and intensities of development influence migration, land managers and habitat biologists can use this information to help inform land-use planning and identify steps to maintain or improve movement corridors and known stopover sites.

Accomplishments and Products Completed FY 2018

Manuscript: Wyckoff, T.B., Sawyer, H., Albeke, S.E., Garman, S.L., and Kauffman, M.J., 2018, Evaluating the influence of energy and residential development on the migratory behavior of mule deer: *Ecosphere*, v. 9, no.2, article no. e02113, <https://doi.org/10.1002/ecs2.2113>.

Presentation: Ortega, A.C., Sawyer, H., Aikens, E.O., Merkle, J.A., Burke, P., Zornes, M., Monteith, K.L., and Kauffman, M.J., 2018, One herd, many migrations—A test of the fitness-balancing hypothesis with mule deer, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Ortega, A.C., Sawyer, H., Aikens, E.O., Merkle, J.A., Burke, P., Zornes, M., Monteith, K.L., and Kauffman, M.J., 2018, One herd, many migrations—A test of the fitness-balancing hypothesis with mule deer, *in* 14th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, Big Sky, Mont.

Theme: Mapping and Characterizing the Status and Trends of Wyoming Landscape Conservation Initiative Focal Habitats

Large, open landscapes support a wide variety of wildlife species in southwestern Wyoming. The WLCI's five priority habitats—sagebrush, mountain shrub, aspen, riparian, and aquatic communities—provide crucial habitat for deer, elk, pronghorn, sage-grouse, nongame bird and mammal species, and native fish. Land and wildlife managers need information on the condition and distribution of priority habitats and of wildlife populations that rely on these habitats to inform resource and conservation planning. The WLCI habitat conservation projects aim to preserve or improve conditions in these priority habitats, but it is important to know which conservation-management projects work and how well. 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 across space and time. Scientists with the USGS are also developing new and innovative techniques to combine field data with remotely sensed data to monitor vegetation changes more efficiently and with greater accuracy. The WLCI studies that the USGS conducts are helping WLCI local project teams to better understand the status and trends—as well as important ecological

functions—of semi-arid woodlands, the extent and trends of sagebrush die-off, and the interactions between groundwater, surface water, and streamflow on aquatic communities.

During past and ongoing studies, USGS scientists have identified condition trends in aspen-dominated woodlands (Assal and others, 2015), mapped mixed mountain shrublands (Bowen and others, 2014), and continued to investigate the extent and trends in sagebrush die-off and recovery (Assal and others, 2016). To support habitat and movement analyses, USGS ecologists and biologists continue to develop 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 green-up 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, USGS scientists have been using satellite imagery and data to monitor long-term changes in vegetation cover (Homer and others, 2009; Xian and others, 2011, 2012). Information gained from historical data is combined with future climate projections to assess potential changes in sagebrush habitats during the next three decades (Homer and others, 2015). The results of these studies have many practical applications and information about habitat distribution, quality, use, and occupancy for individual species can assist in prioritization of areas for conservation and restoration.

Remote Sensing and Vegetation Inventory and Monitoring

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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 crucial for understanding patterns of change within sagebrush habitats across the WLCI region, including historical changes and potential future trajectories of change. By comparing field samples with data from satellite imagery, USGS scientists 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 FY 2018, vegetation change in the WLCI region was monitored and analyzed using both ground and satellite measurement. Long-term vegetation-monitoring plots were measured across 60 marked transects on the ground, along with 2-meter (m) and 30-m satellite data. These transects have been ground and satellite measured every year since 2008 (fig. 3). Preliminary analysis of ground transect measurements taken from 2008 to 2017 reveal that average shrub canopy has increased by 3.2 percent (from 10.4 to 13.6 percent), average sagebrush canopy has increased by 2.7 percent (from 8.5 to 11.2 percent), average herbaceous canopy has decreased by

0.5 percent (from 16.0 to 15.5 percent), and bare ground has decreased by 2.3 percent (from 56.0 to 53.7 percent). This change is likely a reflection of the changing climate, with generally increasing precipitation and increasing minimum and maximum temperatures measured during this same period. Research is currently underway to analyze these changing vegetation patterns to further understand the influence of soils, climate, and shrub species on change patterns. Results will be reported in a new manuscript.

During FY 2018, USGS scientists updated historical mapping products for the WLCI project area. These products provide measurements of historical changes for shrubs, sagebrush, herbaceous grasses and forbs, litter, and bare ground. This process incorporates the latest methodological improvements and data to provide a complete historical analysis of component change back to 1985. Using these products, change trends from 1985 to 2018 are being evaluated to understand flora recovery rates after disturbance. We recently developed a framework for modeling changes in sagebrush cover and have tested this approach for well-pad disturbances using our time-varying remote-sensing products across the WLCI (Monroe and others, 2020). This approach allows for predicted rates of sagebrush recovery across broad scales and the ability to assess the influence of factors such as weather, soils, and disturbance type on recovery outcomes. Similar approaches are now being explored across Wyoming to better understand vegetation recovery among a more diverse suite of disturbance types, using data from sources such as the Land Treatment Digital Library and the Monitoring Trends in Burn Severity databases.

Accomplishments and Products Completed FY 2018

Draft Manuscript: Initiated a manuscript to evaluate the use of remote sensing imagery to quantify recovery of vegetation across space and time following energy development.

Draft Manuscript: Initiated a new manuscript to detail ground measured change patterns from 2008–2018.

Sustained long-term monitoring of 60 marked transect plots across Site 1 study area to continue ground measurement of annual change. These same plots have been annually measured since 2008.

Completed a new back-in-time analysis of WLCI historical change for five components (shrub, sagebrush, herbaceous grasses and forbs, litter, and bare ground).

Completed analyses of vegetation recovery rates at well pads in Wyoming.

Initiated new work to evaluate vegetation recovery for other types of disturbances from sources such as the Land Treatment Digital Library and the Monitoring Trends in Burn Severity databases.

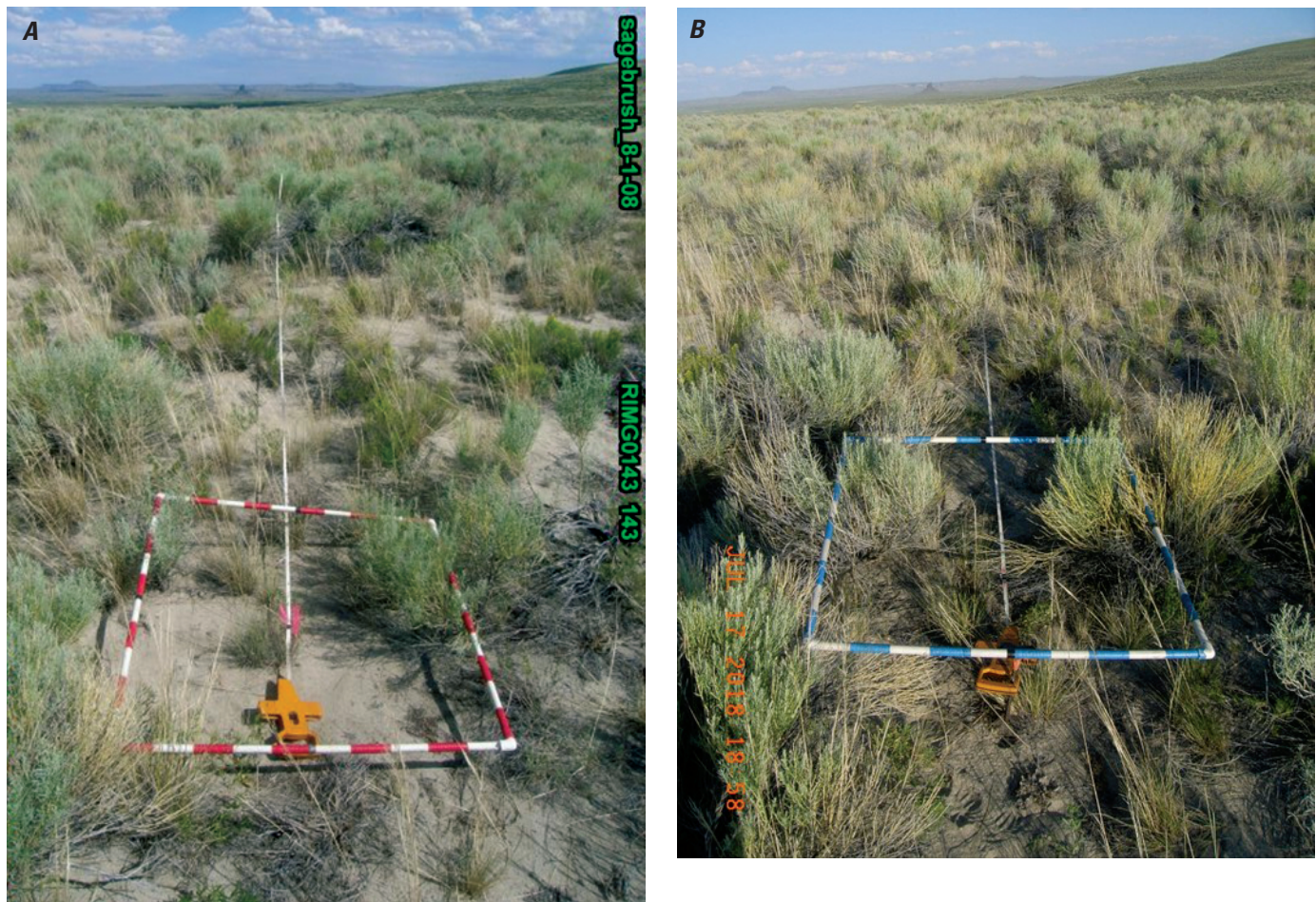


Figure 3. Photographs showing 10 years of rubber rabbitbrush (*Ericameria nauseosa*) growth change (1-meter by 1-meter plot frame for scale) on permanent transect 61, Boars Tusk, Wyoming. *A*, Photograph taken in 2008. *B*, Photograph taken in 2018. Photographs by Collin Homer, U.S. Geological Survey.

Framework and Indicators for Long-Term Monitoring

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This project is designed to develop habitat-monitoring information and methods, as well as the capacity to support future long-term monitoring. In FY 2018, USGS ecologists incorporated information from the Natural Resources Conservation Service’s soil model to refine estimates of the soil-climate classification that forms the backbone of the resistance and resilience framework. A team of collaborators created the resistance and resilience framework to help guide understanding of differences in habitat conditions and restoration outcomes based on soil temperature and moisture patterns (soil-climate) identified in the Soil Survey Geographic database (see https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053631). This framework describes relations of soil-climate classes with post-disturbance recovery and potential for weedy invasions.

Partners of the WLCI recognized the benefits of this framework but indicated challenges for local applications because of the low resolution of the data.

The analytical approach used by the USGS uses continuous spatial grids of climate (temperature and precipitation), soils (available water capacity), and snowpack variables as inputs to the Newhall Soil Simulation Model (Van Wambeke, 2000). This model calculates soil-water conditions to improve the resolution of the model output. Estimates of monthly and seasonal soil-water balances and conditions are calculated using the Keys to Soil Taxonomy (Soil Survey Staff, 2014). Results from these efforts complement the resistance and resilience framework and were customized to evaluate southwest Wyoming using local data to describe relationships between dominant vegetation types, sagebrush cover, and cheatgrass abundance. Seasonal and monthly water-balance estimates offer additional discrimination and allow planners and managers to evaluate areas where moisture limitations may affect project outcomes (fig. 4). Because soil-climate factors—especially moisture availability—have an important effect on current vegetation and habitat patterns (as well as on

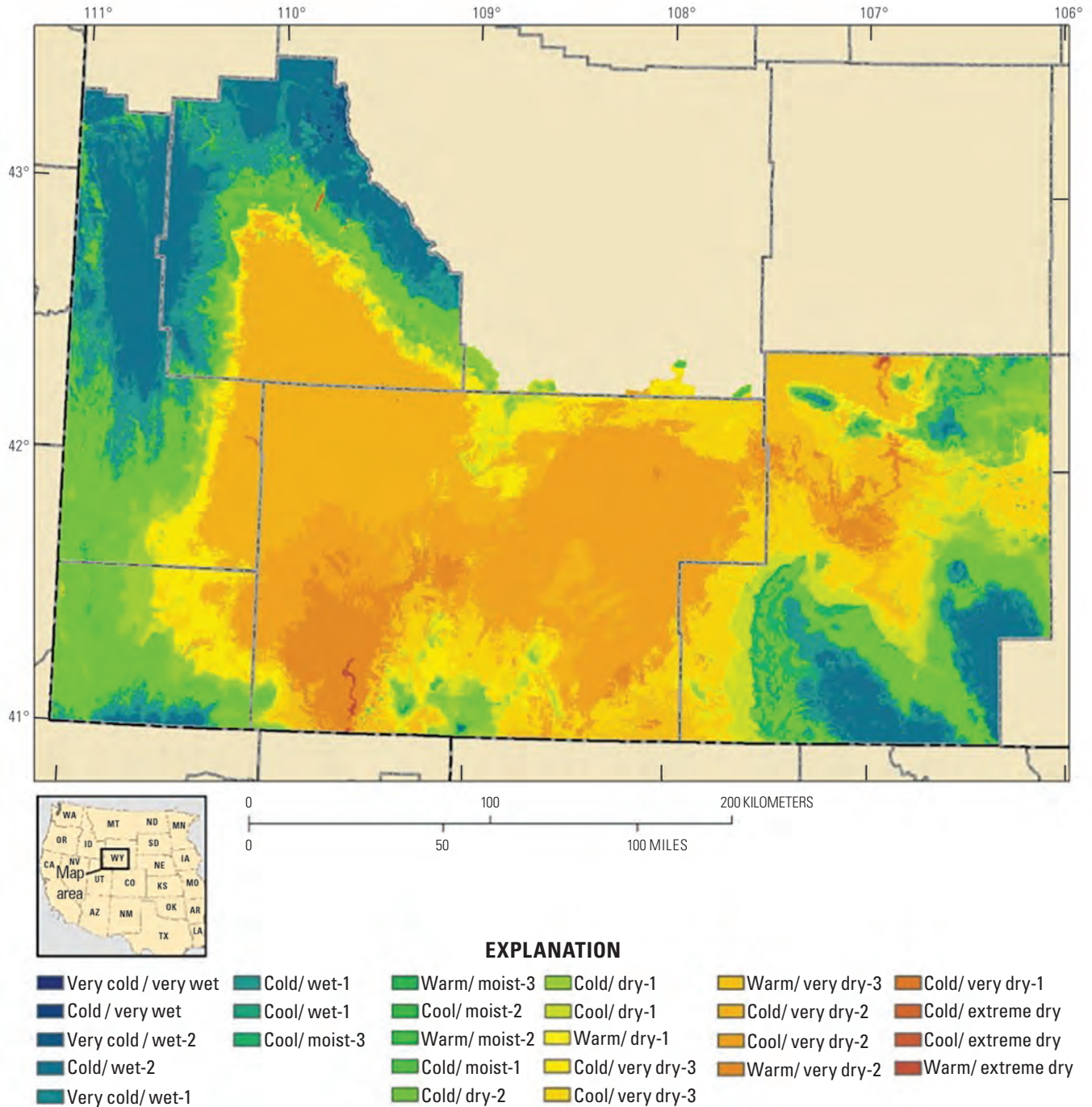


Figure 4. Map showing the current classification of the soil-climate subdivisions (classes) based on the Natural Resources Conservation Service “Keys to soil taxonomy” (Soil Survey Staff, 2014) using the Newhall Soil Simulation Model and gridded inputs for climate, soil, and snowpack.

post-fire and post-restoration recovery rates), these data are useful for planning appropriate restoration actions as well as monitoring habitat conditions and dynamics. A manuscript and data release of these results are in preparation and anticipated to be released in 2020. By collaborating with other USGS scientists working on WLCI studies, we developed an approach to predict the rate of sagebrush cover recovery across large landscapes and the ability to assess the influence of factors such as weather and soils on recovery outcomes.

Accomplishments and Products Completed FY 2018

Presentation: O'Donnell, M.S., and Manier, D.J., 2018, Locally variable seasonal soil moisture budgets for sagebrush ecosystem conservation—A new look at resistance and resilience, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Completed Newhall Soil Simulation Model development and implementation across the WLCI area.

Long-Term Productivity of Sagebrush Ecosystems and their Responses to Drought, Land Use, and Other Change Agents

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Sagebrush mortality and defoliation have been reported in the upper Green River Basin in recent 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 suggested, but recent drought (2012–2013) has likely played a significant role in mortality at the landscape scale. 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 with respect to drought. In this study, time series data were assessed for detection of subtle changes in sagebrush ecosystem productivity associated with mortality at local scales and landscape scales.

In FY 2017, a 17-year record of satellite-derived productivity Moderate Resolution Imaging Spectroradiometer (MODIS) data was used to address two questions: (1) how did the 2012–2013 drought affect vegetation over space and time; and (2) what is the relationship of temperature and moisture to vegetation response? The MODIS data shows that 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 that sagebrush refoliation and resprouting of other shrubs may have moved an area of vegetation productivity from a negative anomaly back to a normal baseline. However, with increased precipitation in 2015 and 2016, there was likely a release of resources in areas of higher sagebrush mortality, followed by a flush of herbaceous plants.

The relationship of temperature and moisture on the annual vegetation response was assessed using Daymet data (<https://daymet.ornl.gov/>) in 2017. In 2018, a SPEI index was developed for the upper Green River Basin to quantify climate variability during the last century. The SPEI incorporated both precipitation and temperature data and provides the capacity to include the effects of temperature variability on drought (fig. 5). The SPEI 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 2012–2013 drought in a historical perspective. This index was published as a USGS data release (Assal, 2018). 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 found spring temperatures and previous summer temperatures to have a larger effect size on vegetation response to drought than cumulative precipitation deficit. Our results indicate that vegetation response is not solely affected by a lack of precipitation; temperature also has a strong influence on productivity during drought events. Site visits were conducted during 2018 at 10 sites that were affected by drought and 10 sites that did not appear to be affected by drought to develop sampling protocols designed to discern patterns of vegetation anomalies at multiple scales. These protocols are intended to be applied during 2019 and 2020 across the affected area.

Accomplishments and Products Completed FY 2018

Data Product Release: Assal, T.J., 2018, Standardized Precipitation Evapotranspiration Index for the Upper Green River Basin (1896–2017): U.S. Geological Survey data release, <https://doi.org/10.5066/P9VLM7Z6>.

Mapping and Monitoring Mixed Mountain Shrub Communities

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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

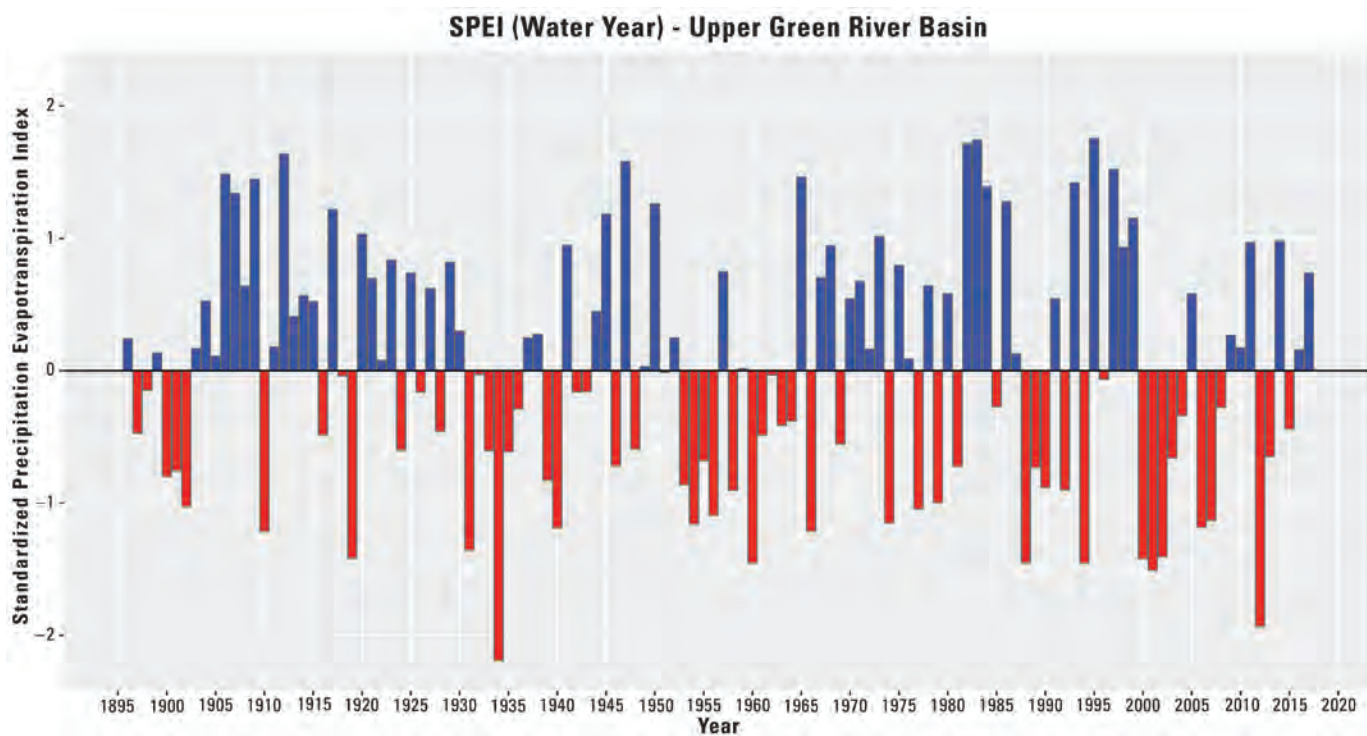


Figure 5. Graph showing the Standardized Precipitation Evapotranspiration Index (SPEI) for the upper Green River Basin to quantify climate variability during the last century. Blue indicates a higher SPEI than the long-term mean and red indicates a lower SPEI than the long-term mean.

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, drought and land use.

The objectives for this study are to map mixed mountain shrub communities associated with crucial winter and transitional range northwest of La Barge, Wyo., and to evaluate potential effects of habitat treatments (for example, projects to improve mule-deer habitat), weather-related trends (drought), energy development, and herbivory. 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. During 2014, maps of mixed mountain shrub communities within the Big Piney-La Barge area were completed (Bowen and others, 2014). Mountain-mahogany and bitterbrush stems were collected by USGS staff between 2014 and 2016 to reconstruct histories of intense browsing (Bowen and others, 2016). Stems were collected at sites within 25 m and 100 m and at sites greater than 250 m from oil and gas well pads. During 2017, we developed a protocol to reconstruct periods of intense browsing and stem-growth patterns. This protocol required numerous measurements and stem samples for ring analysis at primary and all

secondary and tertiary stem joints. Although more informative, this protocol was too difficult and time consuming to implement. To address this, we revised the protocol in 2018 to only include measurements and stem samples along the primary stem and one secondary stem.

Accomplishments and Products Completed FY 2018

Protocol Development: Revised protocol to reconstruct intense browsing of mountain-mahogany at three different distances from oil and gas well pads on big game crucial and transitional winter range.

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

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At the request of USGS program managers, we have begun to export approaches developed within the WLCI to areas outside of the WLCI. In FY 2016, WLCI partners from the WGFD asked if we could assess the status and condition of deciduous communities in the Bighorn Mountains in northern Wyoming (for map and other details, see Zeigenfuss and others, 2019). This request was for an assessment 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.

In the first phase of this project, completed in FY 2017, 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 is an improved data product that represents baseline conditions of the amount and extent of each forest type. During the final phase of this project, 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 the present.

We plan on conducting a trend analysis on a subset of priority drainages identified by the WGFD and work with agency partners to develop a rapid assessment field protocol to measure the condition of riparian communities during 2019. This information will be used to validate vegetation phenology trends measured through remote sensing. In FY 2018, we developed a rapid assessment field protocol to assess the intensity of ungulate browse pressure on riparian vegetation. We led a field trip in the Bighorn National Forest to demonstrate the protocol to collaborators from the U.S. Forest Service, WGFD, Wyoming State Forestry Division, and the University of Wyoming. Cooperatively, we collected data from more than 50 locations, which we will use in conjunction with satellite data to assess trends in riparian condition.

Accomplishments and Products Completed FY 2018

Data Product Release: Assal, T.J., 2018, Bighorn Mountains, Wyoming Forest Mapping, 2013–2017: U.S. Geological Survey data release, <https://doi.org/10.5066/P98OS2XK>.

Protocol Development: USGS and study partners developed field protocols and datasheets to assist with field measurements during 2018.

Monitoring Surface Water, Groundwater, and Water Quality

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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 riparian and aquatic ecosystems (fig. 6). With WLCI funding, streamflow, surface-water quality, and groundwater levels have been monitored at four sites (table 2).

Monitoring sites were selected to provide baseline characterization of the upper Green River Basin and the Muddy Creek watershed. Data collected at Muddy Creek sites where streamflow is intermittent during most years are especially important because few continuous, long-term datasets exist to help us understand the hydrology of these types of streams which are very common in the semi-arid WLCI area.

We continued to monitor water elevation and temperature at groundwater streamgages at near-stream groundwater at the New Fork River near Big Piney and Green River near La Barge (table 3). Data from these wells, along with data from a nearby 170-foot flowing well, are being used to understand how groundwater contributes to streamflow in the Green River Basin and the data will be important for land managers overseeing the basin's water resources. When combined with other WLCI monitoring activities, these data support resource management and research in the WLCI study area and support BLM and other land and resource managers with planning and decision-making responsibilities.

Accomplishments and Products Completed FY 2018

Data Release: Real time preliminary data release annual report summaries with links, see tables 2 and 3.

Evaluation of Environmental Drivers of Streamflow and Interaction with Groundwater in Small Streams

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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. In order to assist with the understanding of how aquatic communities in the area respond to land use (see project “Drivers of Native Fish Community Response to Oil and Gas Development”), there is a need for a better understanding of the environmental drivers of streamflow. Streamflow can vary greatly along the length of a stream and throughout the year, requiring data collection at different places and times for a reliable assessment of where and when aquatic communities may be most affected by changes in streamflow. During 2012–2017, streamflow measurements were collected by study teams at 125 sites (fig. 7).

Traditional methods of evaluating how groundwater interacts with streamflow, namely seepage runs, proved inconclusive. Consequently, a novel approach has been developed to assess streamflow in relation to the surrounding environment by using geospatial data for many environmental variables,



Figure 6. Photograph showing a U.S. Geological Survey hydrologist (from the Wyoming-Montana Water Science Center) using surveying equipment to measure elevations on Muddy Creek near Baggs to ensure accurate data collection. Photograph by Cheryl A. Eddy-Miller, U.S. Geological Survey, 2018.

Table 2. Real-time surface-water quality data and associated annual report summaries for four locations in the Wyoming Landscape Conservation Initiative area.

[WY, Wyoming]

Site	Real-time and water-quality data	Annual report
New Fork River near Big Piney, WY	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, WY	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, WY	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, WY	https://waterdata.usgs.gov/wy/nwis/uv/?site_no=09258980	https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=09258980

Table 3. Online sources of real-time data for groundwater streamgauge sites. The table provides online sources of water-surface elevation of water (both groundwater and stream) and water temperature data for two groundwater-streamgauge sites in the Wyoming Landscape Conservation Initiative area. Both sites have preliminary data available in real-time, as well as approved long-term data.

[WY, Wyoming]

Site	Water-surface elevation	Temperature
New Fork River near Big Piney, WY	https://go.usa.gov/xnFAe	https://go.usa.gov/xnFAt
Green River near Green River, WY	https://go.usa.gov/xnFAF	https://go.usa.gov/xnFAM

including climate, geology, topography, vegetation, soils, and human infrastructure, such as roads and diversions. The geospatial data are processed into variables that can be analyzed in relation to the streamflow observations. This analysis is used to (1) explain which environmental variables are most influential on streamflow in the small streams and (2) predict average streamflow in the small streams on a monthly basis. Findings of this analysis show that some of the more important environmental drivers of streamflow include average precipitation, evapotranspiration (ET), and snowpack during the 3 to 6 months preceding a streamflow measurement; average depth to the water table and a restrictive soil layer; and the presence of diversions and irrigated land. This information is helpful for interpreting the mechanisms that drive streamflow in these small streams and can help with the understanding of how changes in climate and land use may affect streamflow, which in turn may influence the distribution and abundance of aquatic species. Comparisons of the mean monthly streamflow predictions from this analysis with the streamflow observations show a reasonable accuracy (fig. 8).

There are more sophisticated techniques to predict streamflow than this approach of geospatial analysis; however, other techniques require abundant streamflow data which are not available for these small streams in the Wyoming Range. This simplified analytic method may prove useful for predicting streamflow in small streams in other watersheds with sparse data on streamflow.

Accomplishments in FY 2018

Presentation: McShane, R.R., and Miller, C.E., 2018, Machine learning and geospatial approach to modeling streamflow in ungaged small streams in the Wyoming range, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Database Completed: All geospatial data processed and analyzed, and methods to predict streamflow developed.

Theme: Effects of Energy Development on Fish, Wildlife, and their Habitats

To facilitate responsible energy development while minimizing negative effects on wildlife, it is important to understand what mechanisms drive the effects of energy development on fish, wildlife, and their habitats. 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). Since the early 2000s, rapid energy development has happened in the region's sagebrush steppe, mountain shrublands, and watersheds that support many SGCN (Headwaters Economics, 2009; Biewick, 2011). Our research efforts have focused on (1) documenting wildlife distributions, population trends, habitat requirements, and seasonal movements and (2) conducting research on how energy development influences the habitats, behaviors, reproduction, and survival of native wildlife. Collaborators in this research include the USGS Fort Collins Science Center, the USGS Northern Rocky Mountain Science Center, the USGS Wyoming-Montana Water Science Center, the Wyoming Cooperative Fish and Wildlife Research Unit at the University of Wyoming, the Wyoming Natural Diversity Database, the BLM, and the WGFD. Understanding the mechanisms that underlie the effects of energy development on native wildlife will allow scientists to better inform managers and lead to more specific mitigation recommendations for maintaining healthy wildlife populations in locations where energy extraction is taking place.

Investigating the Influences of Oil and Gas Development on Greater Sage-grouse

Contact: Cameron L. Aldridge, aldridgec@usgs.gov

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



Figure 7. Photograph of a U.S. Geological Survey researcher (associated with the Wyoming-Montana Water Science Center) using survey and Global Positioning System (GPS) equipment to verify streamflow measurements in South Beaver Creek in Wyoming during February 2018. Photograph by Cheryl A. Eddy-Miller, U.S. Geological Survey, 2018.

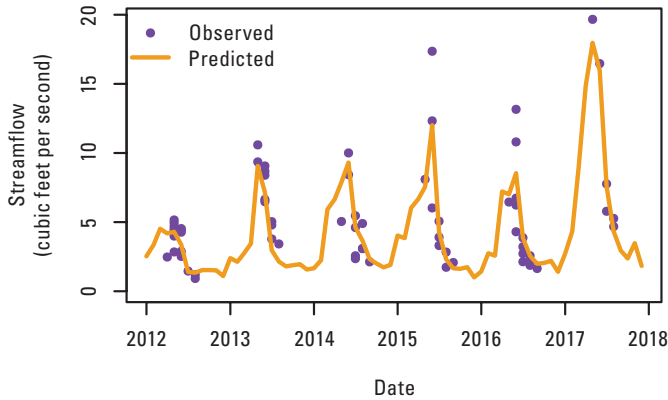


Figure 8. Graph showing a comparison of predicted mean monthly streamflow to observed streamflow for a site on South Beaver Creek in Wyoming.

effects of future landscape changes on sage-grouse habitat resources and population viability. One of the main drivers of change USGS scientists have been investigating is the rapid oil and gas development within and adjacent to sage-grouse core areas in Wyoming. During FY 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 (approximately 4 miles) of leks resulted in declining attendance of male sage-grouse at those leks.

In FY 2018, we continued work to improve our understanding of mechanisms affecting sage-grouse population trends. This included a variety of analyses evaluating either (1) population trends or (2) variation in resource use in addition to potential consequences on spatial population persistence. Through past efforts supported by the WLCI, we developed and published a simulation framework for spatially evaluating long-term population viability of sage-grouse (Heinrichs and others, 2017). We illustrated that areas with lower habitat selection (that is, outside of Core Areas) identified from seasonal habitat models (Fedy and others, 2014) can be important in sustaining increased numbers 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.

More recently, we applied these simulation approaches to assess the potential future effects of climate-induced habitat changes on sage-grouse habitat (see Homer and others, 2015) and future effects of increasing oil and gas development (Garman, 2018) on sage-grouse demography and habitat use. Results indicate that both climate-induced vegetation changes and oil and gas development are important potential stressors that affect long-term population viability (Heinrichs

and others, 2019). The combined influences over the coming decades could cause strong population declines. The pattern and intensity of development could result in the isolation of local populations in areas protected from development.

Accomplishments and Products Completed FY 2018

Manuscript: Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., and Monroe A.P., 2018, Greater sage-grouse population viability analyses across Wyoming core and management areas: *Journal of Wildlife Management*, v. 82, p. 397–412, <https://doi.org/10.1002/jwmg.21386>.

Manuscript: Edmunds, D.R., Aldridge, C.L., O'Donnell, M.S., and Monroe A.P., 2018, Erratum—Greater sage-grouse population trends across Wyoming: *Journal of Wildlife Management*, v. 82, p. 1808, <https://doi.org/10.1002/jwmg.21560>.

Manuscript: Garman, S.L., 2018, A simulation framework for assessing physical and wildlife impacts of oil and gas development scenarios in southwestern Wyoming: *Environmental Modeling and Assessment*, v. 23, p. 39–56, <https://doi.org/10.1007/s10666-017-9559-1>.

Manuscript: Heinrichs, J.A., O'Donnell, M.S., Aldridge, C.L., Garman, S.L., Homer, C.G., and Schumaker, N.H., in press, Simulating the influences of future climate and oil and gas development on sage-grouse population outcomes: *Ecological Applications*.

Manuscript: Heinrichs, J.A., O'Donnell, M.S., Aldridge, C.L., Garman, S.L., Homer, C.G., and Schumaker, N.H., 2018, Simulating the potential consequences of future development and climate on sage-grouse in Wyoming, in *The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference*, Laramie, Wyo., November 6–8, 2018.

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

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Migratory ungulates are susceptible to the effects caused by energy 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 obvious and detrimental effects on migratory ungulates (Flesch and others, 2010); however, the influence of semi-permeable barriers (like an energy field)—where connectivity is maintained, but the benefits of migration routes are compromised—remains unclear. We are using data collected from mule deer

radio-marked with GPS 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 influence of development on movement rate, stopover use, and fidelity to migration routes for each individual by season and year.

In FY 2018, we completed and published a study to understand how development influences the ability of mule deer to track green-up phenology by evaluating movement relative to three different types of development (energy, residential, and dispersed rural) in southwestern 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, deer showed the most dramatic alterations to their migratory behavior. The continued development led to a reduction in the ability of mule deer to track phenology through time, linking development to the loss of the foraging benefits of migration.

Accomplishments and Products Completed FY 2018

Manuscript: Wyckoff, T.B., Sawyer, H., Albeke, S.E., Garman, S.L., and Kauffman, M.J., 2018, Evaluating the influence of energy and residential development on the migratory behavior of mule deer: *Ecosphere*, v. 9, no. 2, article no. e02113, <https://doi.org/10.1002/ecs2.2113>.

Presentation: Ortega, A.C., Sawyer, H., Aikens, E.O., Merkle, J.A., Burke, P., Zornes, M., Monteith, K.L., and Kauffman M.J., 2018, One herd, many migrations—A test of the fitness-balancing hypothesis with mule deer, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Wind Energy and Wildlife in Southwest Wyoming

Contact: Aaron Johnston, ajohnston@usgs.gov

Wyoming is rich in wind resources and has experienced substantial growth in the early 2000s but had no wind development between 2010 and 2016 (Godby and others, 2016). However, in 2017 and 2019, Phase I and Phase II of the Chokecherry and Sierra Madre Wind Energy Project were approved and the project has the potential of being one of the largest onshore wind farms in North America in terms of power capacity when completed (<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. We mapped ground disturbances at all 17 wind farms in Wyoming that were in operation as of 2017. We used aerial imagery to

map disturbances that existed prior to construction, immediately following construction, and several years after construction. Then, we evaluated the influence of landscape and turbine features on disturbance amounts. We also used Landsat and MODIS to measure changes to vegetation (fig. 9), land-surface temperature (LST), and ET from pre- to post-construction.

We detected slight differences in LST and ET around turbines, but changes to vegetation were confined to areas of ground disturbance from the initial construction of the wind farms. We documented results of these analyses in a manuscript for publication in a peer-reviewed journal. New map products that depict infrastructure of wind farms will provide useful data to support analyses of wildlife interactions with wind-energy infrastructure. 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 wind 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, Wyo., and have raised questions about cumulative effects of wind-energy development on wildlife.

Therefore, in FY 2017 and FY 2018, we evaluated wind development on wildlife habitat before and after wind farm construction. We mapped land-surface disturbances at wind farms across Wyoming from pre- to post-construction and evaluated changes in satellite-based metrics of vegetation, LST, and ET to (1) quantify vegetation disturbances and recovery, (2) determine whether wind farms inhibit vegetative growth, and (3) evaluate potential mechanisms that can affect vegetative growth. We predicted that any reductions in vegetation following construction of wind farms would be attributed to land conversion, rather than vegetation growth being impeded by increases in LST and ET. Following the construction of wind farms, nighttime LST increased around the wind turbines; however, ET decreased across the farms. The Normalized Difference Vegetation Index (NDVI) from MODIS (250-m resolution) decreased strongly after construction, suggesting that the wind farms impeded vegetative growth. Landsat imagery (30-m resolution) revealed slight increases in NDVI within undisturbed areas around turbines, which coincided with large decreases in NDVI in disturbed areas after construction.

Vegetation recovery, based on increases in NDVI several years after wind-farm construction, was evident in areas of temporary disturbances caused by buried power lines and construction staging. Despite increases in LST from wind turbines, changes to vegetation at wind farms in Wyoming appear largely confined to surface disturbances caused by construction. Lower ET may increase the growth of vegetation in undisturbed areas around wind turbines; however, species-specific data is needed to determine whether changes in NDVI reflect outcomes that support management objectives.

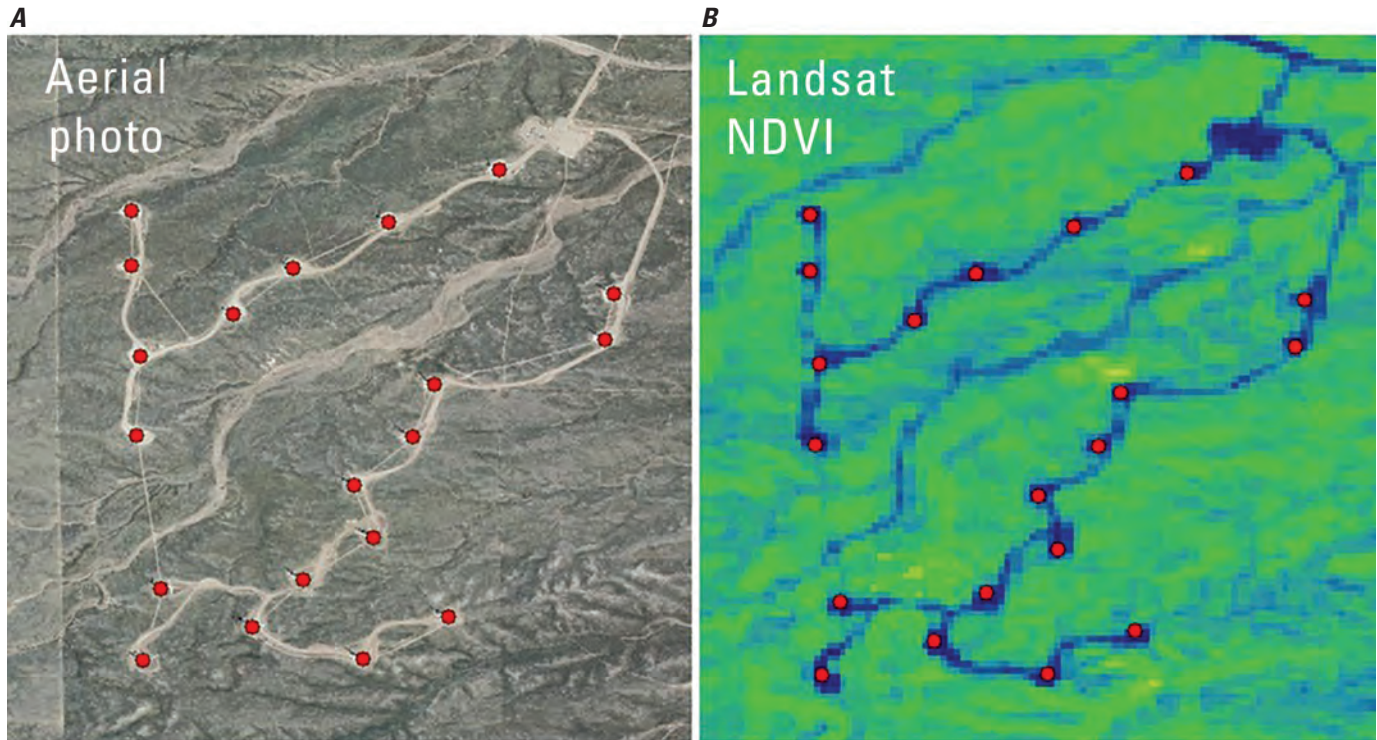


Figure 9. Images showing disturbances from wind farms in Wyoming that are visible from *A*, aerial and *B*, satellite imagery. These images facilitate analyses of changes to vegetation, micro-climate, and wildlife habitat. Red dots indicate turbine locations. Aerial photograph accessed January 31, 2018, at <https://earthexplorer.usgs.gov/> and Landsat satellite image accessed June 29, 2018, at <http://climateengine.org/>. (NDVI, Normalized Difference Vegetation Index).

Accomplishments and Products Completed FY 2018

Presentation: Johnston, A.N., Bowen, Z.H., Fancher, T., and O'Donnell M., 2018, Ecological disturbances at wind farms in Wyoming, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Johnston, A., Wind energy and wildlife in Wyoming, at USGS Energy Community of Practice, June 2018, invited by USGS Energy Lead, Mona Khalil.

Relationship between Energy Development and Pygmy Rabbit Presence and Abundance

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Pygmy rabbits are a species of conservation concern throughout their occupied range. They occur throughout south-west Wyoming, and they are sensitive to development and disturbance in sagebrush habitats (Larrucea and Brussard, 2008). 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 the first 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 2011–2013, 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 the presence and abundance levels of pygmy rabbits. We found gas-field infrastructure to be negatively associated with pygmy rabbits; pygmy rabbits became more likely to be absent than present after 1–2 percent of the area on a gas field was converted to roads, well pads, and pipelines. Pygmy rabbit abundance declined sharply after 2 percent of the area was developed (Germaine and others, 2017a, b).

In the final phase of our studies, we were interested in the relationship between the presence and abundance of pygmy-rabbit transects with the distance from the nearest gas field elements and how much surface area on gas fields would be

affected. We observed that pygmy rabbit numbers declined within 1–2 km (0.6–1.2 miles) from the nearest gas field element such as roads and well pads. Buffering a digital layer of roads and well pads on our least-densely developed gas field (Continental Divide-Creston-Blue Gap Gas Field) revealed that nearly 82 percent of the surface area was within 1 km (0.6 miles) of these elements and more than 95 percent of the gas field surface area was within 2 km (1.2 miles). Based on these distance effects, we determined that 95 percent of the surface area on gas fields was compromised for pygmy rabbits. During 2018, we completed our analysis and drafted a manuscript that reports on the distance effects of gas field infrastructure on pygmy rabbits in southwestern Wyoming.

Accomplishments and Products Completed FY 2018

Draft Manuscript: Completed a draft manuscript that documents distance effects of gas field infrastructure on pygmy rabbit occurrence and distribution in southwestern Wyoming.

Mechanistic Understanding of Energy Resource Development Effects on Songbirds

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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. Abundance of these species are declining range-wide because of widespread habitat conversion and change (Gilbert and Chalfoun, 2011; Sauer and others, 2017). In phase I of this project (2008–2009), 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 of range (Gilbert and Chalfoun, 2011). In phase II (2011–2012), 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 abundance was higher in areas with more surface disturbance, and nest survival of Brewer's and sagebrush sparrows was negatively associated with increased rodent abundance (Hethcoat and Chalfoun, 2015b).

During phase III (2013–2016), we determined that rodent densities increased with the amount of surrounding reclaimed (reseeded) area (Sanders and Chalfoun, 2019). Dietary analysis of deer mice and powder tracking confirmed that mice utilized reclaimed areas, which differ in structure and composition from adjacent sagebrush patches, for foraging. Several nonnative species of plants, located exclusively within reclaimed areas, were found in mouse diets. Collectively, energy development in southwest Wyoming increases songbird nest predation by attracting rodents to areas that are reseeded

following surface disturbance. Songbirds do not appear to preferentially select habitat in areas with less development. As a result of this lack of habitat preference, gas field habitats function as ecological traps potentially impacting songbird recruitment.

In phase IV (2017–2019), we are incorporating the effects of weather conditions (temperature and precipitation) on avian nesting decisions and productivity, with implications for changing climate. Preliminary results suggest that sagebrush songbirds select nest sites that modulate temperature variation. Moreover, the number of young fledged per nest decreases with temperature and precipitation extremes.

Accomplishments and Products Completed FY 2018

Manuscript: Sanders, L.E., and Chalfoun, A.D., 2018, Novel landscape elements within natural gas fields increase densities of an important songbird nest predator: Biological Conservation, v. 228, p. 132–141, <https://doi.org/10.1016/j.biocon.2018.10.020>.

Manuscript: Sanders, L.E., and Chalfoun, A.D., 2019, Mechanisms underlying increased nest predation in natural gas fields—A test of the mesopredator release hypothesis: Ecosphere, v. 10, no. 5, article no. e02738, <https://doi.org/10.1002/ecs2.2738>.

Presentation: Chalfoun, A.D., Hethcoat, M.G., Johnson T., and Scherr, T., 2018, Sagebrush songbird responses to density and proximity of energy development, in The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Chalfoun, A.D., Hethcoat, M.G., Johnson T., and Scherr, T., 2018, Are natural gas field for the birds? An update on WLCI songbird research, in The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Chalfoun, A.D., Hethcoat, M.G., and Sanders, L.E., 2017, Natural gas fields as ecological traps for breeding birds, in Wyoming Chapter of The Wildlife Society Conference, Jackson, Wyo., December 6, 2017.

Presentation: Sanders, L.E., and Chalfoun, A.D., 2017, What is sustaining higher nest predator abundance within natural gas fields?, in Wyoming Chapter of The Wildlife Society Conference, Jackson, Wyo., December 6, 2017.

Presentation: Scherr, T.M., and Chalfoun, A.D., 2017, The effects of multiple forms of habitat change on songbird nest site selection and reproductive, in Wyoming Chapter of The Wildlife Society Conference, Jackson, Wyo., December 6, 2017.

Presentation: Wagler, B., Sanders, L.E., and Chalfoun, A.D., 2018, Do reclaimed areas within natural gas fields augment deer mouse fitness and abundance?, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Wagler, B., Sanders, L.E., and Chalfoun, A.D., 2017, Do reclaimed areas within natural gas fields augment deer mouse fitness and abundance?, *in* Wyoming Chapter of The Wildlife Society Conference, Jackson, Wyo., December 6, 2017.

Presentation: Chalfoun, A.D., Sanders, L.D., and Scherr, T.M., 2018, Thy neighbor's matter—An experimental test of the prey-site partitioning hypothesis, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Chalfoun, A.D., Sanders, L.D., and Scherr, T.M., 2018, Thy neighbor's matter—An experimental test of the prey-site partitioning hypothesis, *in* American Ornithological Society Conference, Tucson, Ariz., April 12, 2018.

Presentation: Chalfoun, A.D., and Scherr, T.M., 2018, Taming the temperature—Do birds select nest sites that modulate microclimatic variation?, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Chalfoun, A.D., and Scherr, T.M., 2018, Taming the temperature—Do birds select nest sites that modulate microclimatic variation?, *in* American Ornithological Society Conference, Tucson, Ariz., April 12, 2018.

Drivers of Native Fish Community Response to Oil and Gas Development

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The rapid expansion of natural gas development in southwest Wyoming has raised concerns about the effects of development 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 on fish. These correspond to two of WLCI's management needs: (1) identify condition and distribution of key wildlife species/habitats and species habitat requirements, and (2) evaluate wildlife responses to development. Our approach is a comparative study examining subwatersheds with differing levels of oil and gas development. Our study examines the native fish community in southwestern Wyoming's streams whose presence typically indicates good water quality. We focus on three

fish species: Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*), a Wyoming SGCN and a highly valued sport fish that brings revenue to local economies; mottled sculpin (*Cottus bairdii*), which serves an important role as trout prey; and mountain sucker (*Catostomus platyrhynchus*), which helps to clear algae from streambeds. Keeping this fish community intact supports the overall health of streams and entire watersheds. Our approach is a comparative study examining subwatersheds with differing levels of oil and gas development.

In FY 2018, we collected our seventh year of fish population data and analyzed this data to evaluate the mechanisms underlying fish responses to development. We first evaluated the interaction between surface disturbance associated with oil and gas development and streamflow for fish using both repeated state (temporal trends in abundance) and rate (that is, colonization and persistence) approaches. Overall, fish abundance, colonization, and persistence declined with low flows. We found the effect of increased surface disturbance either intensified the effect of flows or led to greater variability in responses from fish. We also used structural equation modeling to examine the major mechanistic pathways underlying individual fish species responses. We found support for the importance of water quality (two out of three species), food availability (two out of three species), and habitat availability (one out of three species). In both analyses, fish species differed in responses, which is likely because of dissimilarities in their physiological tolerances and behavioral adaptations to disturbance. Lastly, we measured physiological and immunological responses of fish to temperature and salinity in the field and laboratory and are still analyzing that data.

Accomplishments and Products Completed FY 2018

Manuscript: Girard, C.E., and Walters, A.W., 2018, Evaluating relationships between fishes and habitat in streams affected by oil and natural gas development: Fisheries Management and Ecology, v. 25, no. 8, p. 366–379, <https://doi.org/10.1111/fme.12303>.

Manuscript: Walters, A.W., Girard, C.E., Walker, R.H., Farag, A., and Alvarez, D., 2019, Multiple approaches to surface water quality assessment provide insight for small streams experiencing oil and natural gas development: Integrated Environmental Assessment and Management, v. 15, no. 3, p. 1–13, <https://doi.org/10.1002/ieam.4118>.

Data Release: Girard, C., and Walters, A., 2018, Habitat and fish field survey data from Wyoming Range streams in 2012 and 2013: U.S. Geological Survey data release, <https://doi.org/10.5066/F78S4P7Z>.

Presentation: Walker, R.H., and Walters, A.W., 2018, It takes two to tango—Interactive effects of hydrology and energy development on fish abundance, *in* Colorado-Wyoming American Fisheries Society Annual Meeting, Laramie, Wyo.

Presentation: Alford, S., and Walters, A., 2018, Evaluating factors influencing movement rates of mottled sculpin and mountain sucker in the Wyoming Range, *in* Colorado Wyoming American Fisheries Society Annual Meeting, Laramie, Wyo.

Presentation: Walker, R., and Walters, A., 2018, Mechanisms underlying ecological responses to surface disturbance in headwater streams, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Walters, A., Walker, R., and Alford, S., 2018, Evaluating the resiliency of fish populations to stochastic disturbances, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Theme: Supporting Conservation Planning and Conservation Actions

The WLCI conservation approach includes the 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 Local Project Development Teams 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).

Integration of science with conservation management is a key principle of the USGS WLCI program. Science performed by the USGS supports conservation planning and actions of WLCI partners through several approaches. We compile and synthesize data from WLCI partners, the 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 development, drought, and other habitat drivers. We use data, maps, tools, and findings from studies designed to address other USGS WLCI science themes to further assess the effectiveness of conservation actions and to 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

Application of Comprehensive Assessment to Support Decision Making and Conservation Actions

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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 direct-ing data synthesis and assessment activities to support Local Project Development Teams 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 spatially and ecologically to WLCI priorities. Partner agencies with the WLCI provide information on past conservation projects and identify issues and geographic locations where they anticipate future conservation projects. The USGS incorporates this information with additional information (such as WLCI focal habitat maps, species-distribution maps, oil and gas maps, and partner assessment data) to provide context to proposed conservation projects. This new information is used by Local Project Development Teams 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 I of the comprehensive assessment entails a multidisciplinary Integrated Assessment 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 Integrated Assessment includes identifying areas of high conservation and restoration value and areas having high development potential based on the current landscape. The Integrated Assessment may be used to consider scenarios of potential future development for evaluating the conservation and restoration potential of large landscapes.

Accomplishments and Products Completed FY 2018

WLCI Report: Updated the WLCI Conservation Action Plan and the associated habitat treatment spatial database with information from FY 2017 conservation progress reports.

WLCI Report: Working with the WLCI Coordination Team, we analyzed and summarized WLCI conservation accomplishments and funding contributions and co-authored the WLCI 10-year report.

WLCI Project Tracking Database: Collaborated with U.S. Fish and Wildlife Service to update the WLCI Conservation Project Tracking Database.

WLCI Ranking of Conservation Projects: Overlaid project maps and other information to support the evaluation and ranking of proposed 2019 conservation projects.

WLCI Science Prioritization and Feedback: Met with the WLCI Science and Technical Advisory Committee to discuss 2018 science activities and products.

Co-organized the WYTWS/WLCI Science Conference (November 6–8) and co-developed conference program. The joint conference program with abstracts is available at http://wytwsconference.org/wp-content/uploads/2018/10/2018-WYTWS-WLCI-Conference-Program_CORRECTED.pdf.

Plant Phenology Metrics to Evaluate Sagebrush in the WLCI Region

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Plant phenology, the timing of life-history events such as green-up, flowering, senescence, and productivity, are fundamental habitat components for many SGCN in Wyoming. Plant phenology influences 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 previous activities, we combined studies 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 and productivity; and (3) interacting effects of phenology, grazing patterns, and prescribed fire on elk calving and habitat selection. During 2018, we published a paper (Johnston and others, 2018, <https://doi.org/10.1016/j.ecolind.2017.12.033>) that reported on the use of satellite imagery to detect phenology and productivity of habitat treatments designed to reduce sagebrush. In the report, we compared how prescribed fire, herbicide, and mechanical treatments on BLM lands changed plant phenology over time. Treatments appeared to increase herbaceous cover and productivity, which coincided with signs of earlier senescence; these signals are expected of grass-dominated systems, relative to sagebrush-dominated systems.

Metrics associated with plant phenology indicate that spring migrations of ungulates were mostly unaffected by sagebrush treatments. Fire had the strongest effect on vegetative cover and yielded the least evidence for sagebrush recovery. Overall, treatment effects were small relative to those reported from field-based studies for reasons most likely related to sagebrush recovery, treatment specification, and untreated patches within mosaicked treatment applications. Results indicate that cumulative productivity indices, late-season phenology measurements, and spatial heterogeneity of several phenological measurements may serve as useful indicators of vegetative change in sagebrush ecosystems.

We also continued our assessment of mule deer responses to habitat treatments and shared results from our study of elk and phenology in southwest Wyoming with the Wyoming Cooperative Fish and Wildlife Research Unit and WLCI partners. We initiated efforts to evaluate the use of remote-sensing tools for assessing trends in phenology across the state and possible development of a corresponding decision support tool.

Accomplishments and Products Completed FY 2018

Manuscript: Johnston, A.N., Beever, E.A., Merkle, J.A., and Chong, G., 2018, 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>.

Manuscript: Mikle, N.L., Graves, T.A., and Olexa, E.M., 2018, West Green River elk herd locations in southwestern Wyoming, 2005–2010: U.S. Geological Survey data release, <https://doi.org/10.5066/F70K27SF>.

Presentation: Aikens, E.O., Kauffman, M., Merkle, J., Dwinell, S., Fralick, G., and Monteith, K., 2017, Surfing the green wave in a variable environment—Not all migration routes are affected equally in drought, *in* Wyoming Chapter of the Wildlife Society Annual Meeting, Jackson, Wyo., December 5–7, 2017.

Presentation: Johnston, A., Beever, E., Merkle, J., and Chone, G., 2018, Sagebrush removal alters vegetation dynamics for migrating ungulates, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Presentation: Johnston, A., Beever, E., Merkle, J., and Chong, G., 2018, Sagebrush removal alters vegetation dynamics for migrating ungulates, *in* Greater Yellowstone Coordinating Committee Migration Symposium, Jackson, Wyo., June 6, 2018.

Presentation: Johnston, A., 2018, Sagebrush removal alters vegetation dynamics for migrating ungulates, *in* Greater Yellowstone Coordinating Committee Migration Symposium, Jackson, Wyo., June 2018.

Presentation: Graves, T., Mikle, N., and Olexa, E., 2018, To follow the forage or flee from fear—Lessons from a large ungulate migration near a protected area, *in* Ecological Society of America Annual Meeting, New Orleans, La., August 6–10, 2018.

Characterizing and Quantifying Dynamics of a Cold-Desert Headwater Stream, Littlefield Creek

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Headwater streams have important roles in determining water quality and quantity across a river basin; these streams are important sources of water for migratory species and provide diverse habitats for fish and amphibians. Importantly, the small size of headwater streams makes them especially vulnerable to changes in climate and to human-related land-use changes such as water depletions, livestock grazing, road-construction, and energy development.

Muddy Creek, a headwaters tributary to the Colorado River in the WLCI area, has been subject to substantial changes in land use including intensive grazing and, more recently, energy development. The headwaters network of Muddy Creek is one of two stream systems in Wyoming where sympatric populations of native bluehead suckers (*Catostomus discobolus*), flannelmouth suckers (*C. latipinnis*), and round-tail chub (*Gila robusta*) persist. Additionally, native Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*) were reintroduced on a tributary to Muddy Creek, Littlefield Creek. These four fish have been largely extirpated from their native ranges and are of general conservation concern to local, State, and Federal wildlife managers. Recent observations of fine sediment accumulations on the bed of Littlefield Creek have raised concerns that increased sedimentation may be a threat to trout populations and, eventually, to fish populations in

reaches downstream. The sediment accumulation has occurred despite implementation of a large best management practices program (fig. 10).

Littlefield Creek can be used as a representative of the hundreds of small, cold-desert streams in the WLCI area and is being studied to understand how the combination of natural and anthropogenic stressors affect stream geomorphology and fine sediment dynamics in headwater streams. Initial data collection includes field observations of direct fine-sediment sources, characterization of channel dynamics by geospatially analyzing channel changes over time using digital historical maps and aerial images, and development of a fluvial geomorphic framework using a digital elevation model and bedrock geology maps.

The geospatial analyses of Littlefield Creek channel geomorphology identified locations of several historical and recent meander loop cutoffs (oxbows) (fig. 11) and recent increases in beaver-pond density. Instrumentation was installed at three sites on Littlefield Creek in FY 2018 to measure how stream stage (which provides the energy to move sediment) changes during the year. Two time-lapse cameras were located at each of the three sites to capture the geomorphic processes, such as channel ice accumulation and melt, overbank flooding, and bank erosion and sediment movement, occurring at the sites. Additionally, several sediment fences were installed to capture direct fine-sediment contributions from rodent burrows or other slope sediment runoff.



Figure 10. Photograph showing how fine sediment, potentially mobilized from rodent burrows or weakened streambanks (black arrows), has moved into Littlefield Creek and accumulated on the streambed (red arrow) or moved downstream. Photograph by Cheryl A. Eddy-Miller, U.S. Geological Survey, 2018.

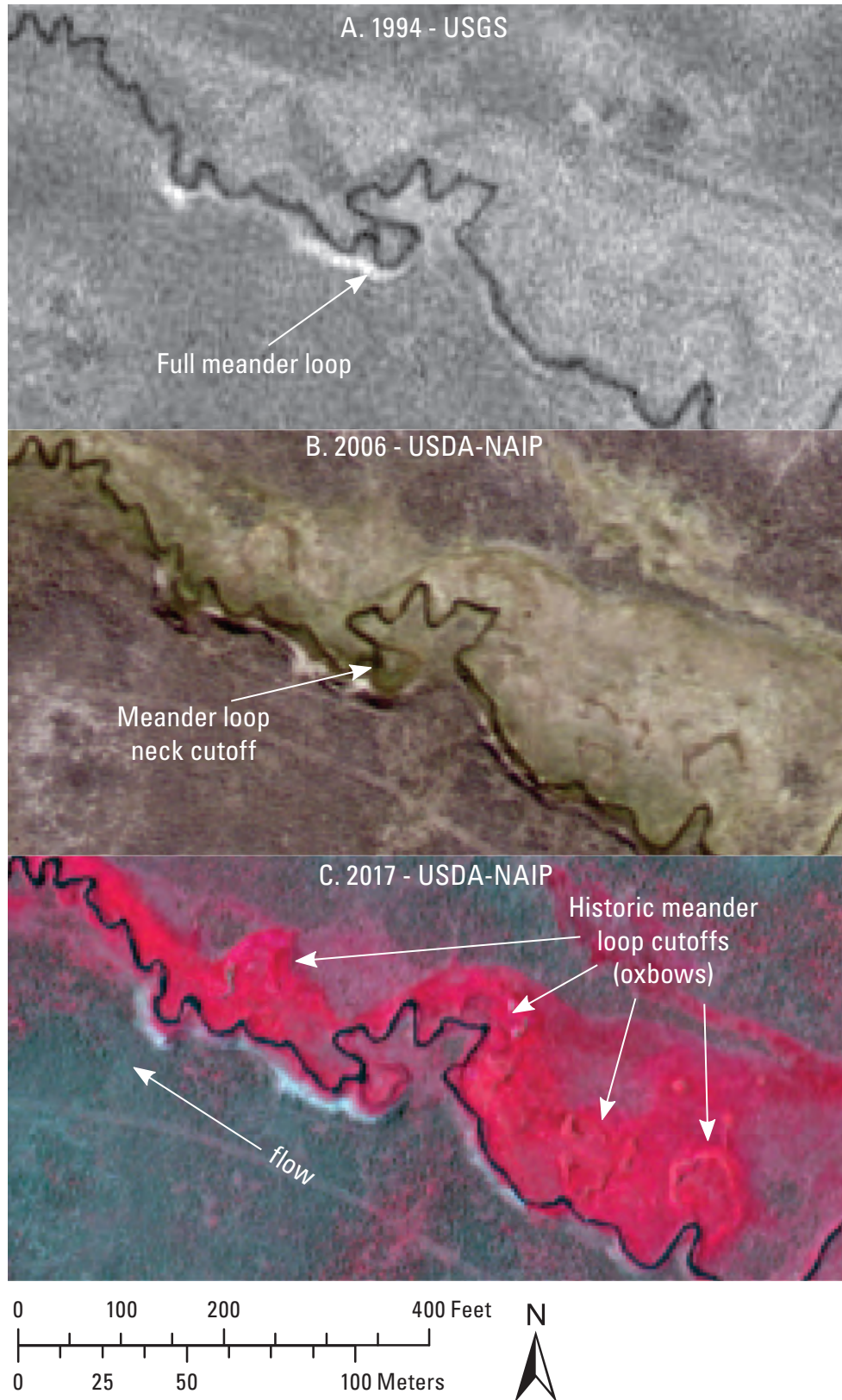


Figure 11. Aerial photographs of geospatial images to illustrate the changes in Littlefield Creek during a 23-year period and assist with the understanding of how quickly and to what degree the channel moves. *A*, Image taken in 1994 by the U.S. Geological Survey (USGS). *B*, Image taken in 2006 by the U.S. Department of Agriculture National Agriculture Imagery Program (USDA-NAIP). *C*, Image taken in 2017 by the USDA-NAIP.

Accomplishments and Products Completed FY 2018

Installation of time-lapse cameras, sediment traps, and other equipment to capture streamflow and other geomorphic processes during the next year.

Economics of Greater Sage-Grouse Conservation Strategies

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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, 2009). Because of 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 endangered. An economic perspective can be used to consider the return on investment from these efforts. Unlike oil and gas products, the economic value of preserving sage-grouse is not reflected in formal markets, and thus requires nonmarket valuation approaches commonly used by environmental economists. This research has sought to develop a better understanding of the full costs (that is, foregone economic benefits of sage-grouse preservation) of energy development and grazing patterns.

Several accomplishments have been made in support of this research. First, we have compiled and reviewed existing estimates of economic value from published research on species similar to sage-grouse. Although estimates provide some context on the existence and magnitude of similar economic values held for the preservation of sage-grouse, these estimates are not amenable for use within a cost-benefit analysis framework. Second, we reviewed existing research on ecosystem service benefits of sagebrush systems in addition to sage-grouse preservation. A feature of this step was meeting with University of Wyoming economics professors who have studied agricultural practices, grazing values, and sage-grouse. We will use this combined information to describe the possible effects to sage-grouse from forecasts of energy development in the region modeled by the USGS.

Modeling Recovery of Sagebrush Across the WLCI Using Remotely Sensed Vegetation Products

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The ability to predict sagebrush recovery following landscape disturbance is limited by a scarcity of research quantifying the spatial and temporal factors influencing recovery across landscapes. Scientists with 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. USGS scientists are using time-varying remote-sensing products developed for the WLCI to model rates of change in sagebrush cover at 2–5 year intervals between 1988–2015 and are evaluating effects of static and time-varying factors such as soils, topography, and weather on sagebrush cover. This information will improve our practical understanding of environmental effects on post-disturbance recovery. Consideration of predicted recovery rates could identify areas that are particularly slow at recovery or could inform mitigation by identifying sites and regions with similar potential, and therefore similar anticipated response to disturbance. Preliminary results indicate that sagebrush cover generally increased with moisture and temperature especially at higher elevations and the rate of change in sagebrush cover increased with greater percentage of sand and decreased with larger well pads.

Accomplishments and Products Completed FY 2018

Draft Manuscript: Completed a draft manuscript that documents the use of remote sensing to quantify recovery of vegetation across space and time following energy development.

Presentation: Monroe, A.P., Aldridge, C.L., O'Donnell, M.S., Manier, D.J., Homer, C.G., and Anderson, P.J., 2018, Estimating vegetation recovery following energy development using a long-term remote sensing dataset, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

Theme: Science Information and Data Management

This theme addresses the need to access, manage, and analyze WLCI data and information resources by providing online tools for (1) cataloging and archiving data and information; (2) discovering and using these resources; and (3) making the resources available to WLCI partners, researchers, decisionmakers, and the public through the WLCI website. In cooperation with other WLCI partners, USGS scientists developed a WLCI web framework and the WLCI web page (<http://www.wlci.gov>) which provides information about ongoing activities and allows users to discover WLCI resources, including publications, annual reports, newsletters, and information about both habitat conservation and science projects. The WLCI web page is maintained and updated by the WLCI Coordination Team and the USGS Fort Collins Science Center to ensure that resources are current and relevant.

Information Management Framework

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This project addresses the need to access, manage, and analyze WLCI data and information resources to help address important questions for WLCI and, where applicable, to facilitate cohesive integration of WLCI information at larger regional and national scales and efforts. In FY 2018, the Information Management team explored how wildlife corridor efforts within Wyoming that are documented in the Protected Areas Database (PAD-US) could inform science, restoration, and management actions in the WLCI region and how the report “Th Red Desert to Hoback Mule Deer Migration Assessment” by Sawyer and others (2014) could help WLCI partners understand existing data needs related to protected areas. Although many attributes needed for the corridor assessments (for example, protection status and land ownership) are currently included in the PAD-US, some attributes such as information on management plans and information on private lands are not captured in PAD-US. This effort highlights opportunities to work with WLCI scientists and managers to help inform future versions of the PAD-US database and to identify the benefits of using PAD-US in future assessments.

Collaborative efforts with the University of Wisconsin-Madison were leveraged to explore the use of computer algorithms and literature databases to return information from scientific literature to help direct and support future science and management efforts. These efforts focused on (1) understanding how well WLCI literature was documented in literature databases and the WLCI catalog of publications and (2) identifying literature corresponding to select WLCI focal species. These efforts identified several WLCI publications that were not included in literature databases and (or) that were not currently included in the WLCI catalog of publications. A data analyst with the USGS developed an application programming interface to allow WLCI users to identify summaries of literature that mention species of interest. This application programming interface was tested using 24 species that are studied in the WLCI from GeoDeepDive, which is a digital library and associated infrastructure that facilitates the discovery and utilization of data and knowledge in published documents. During this exercise, more than 80,000 mentions of these species were identified in the literature by GeoDeepDive.

Accomplishments and Products Completed FY 2018

Repository documenting and visualizing corridor and species efforts (see <https://github.com/usgs-bcb/wlci-regional-to-national-exploratory-analyses>).

GeoDeepDive public application programming interface endpoint for searching species references in the literature based on Integrated Taxonomic Information System terms: <http://geodeepdive.org/api/dictionaries?dict=ITIS>.

Presentation: Wiefelich, D., Aulenbach, S., and Bristol, S., 2018, Algorithm-based compilation of species information, *in* The Wyoming Chapter of the Wildlife Society Wyoming Chapter Annual Meeting and WLCI 2018 Joint Conference, Laramie, Wyo., November 6–8, 2018.

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Publishing support provided by the Science Publishing Network,
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