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U.S. Geological Survey
Landscape Science Strategy 2020–2030

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Cover. Silver Creek Preserve, Idaho, in 2013, where the U.S. Geological Survey is collecting information about the preserve's aquatic life and habitat to guide sound decision making. Photograph by Terry Maret, U.S. Geological Survey.

Title page. The Florida Everglades, 2010. Photograph by the U.S. Geological Survey.

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By Karen E. Jenni, Sarah K. Carter, Nicholas G. Aumen, Zachary H. Bowen, John B. Bradford, Michael A. Chotkowski, Leslie Hsu, Peter S. Murdoch, Scott W. Phillips, Kevin L. Pope, Rudy Schuster, Melanie J. Steinkamp, Jake Weltzin, and George Z. Xian

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Colorful wildflowers in the Great Basin, 2011. Photograph by Steven Schwarzbach, U.S. Geological Survey.

Chattanooga River in North Carolina, 2018. Photograph by Alan Cressler, U.S. Geological Survey.

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Sample collection for aquatic species in Grand Teton National Park, 2018. Photograph by Adam Sepulveda, U.S. Geological Survey.

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Executive Summary

Across our Nation, multiple Federal, State, Tribal, and local governments are working with stakeholders and landowners to restore, conserve, and manage lands and resources to benefit fish, wildlife, and people. One of the largest Federal efforts is led by the U.S. Department of the Interior (DOI), with multiple DOI agencies working to conserve and manage public lands, resources, and cultural heritage for the benefit and enjoyment of current and future generations. As a science provider within the DOI, the U.S. Geological Survey (USGS) has an important role in developing actionable science products that can inform decision making on public lands and across all of our Nation's landscapes.

Our landscapes and resources are undergoing continual change from a complex and interacting suite of stressors that include traditional and nontraditional land uses, a changing climate, a dynamic economy, and a culturally diverse and ever-changing society. Landscape science seeks to understand how the physical, biological, and social components of ecosystems and landscapes interact with each other and are affected by these stressors across local to global scales.

The USGS has developed this landscape science strategy to focus and strengthen the agency's efforts to inform critical conservation, restoration, and management decisions for American landscapes. The strategy directly supports the overarching 21st-century science strategy of the USGS and expands our perspective and focus on partnerships, including with internal, external, traditional, and nontraditional partners.

Agricultural fields and an abandoned farmstead in eastern Montana in the Great Plains region. Photograph by Terry Sohl, U.S. Geological Survey.

The vision for USGS landscape science is to integrate multiple disciplines and approaches to create and deliver relevant, timely, and scientifically sound products that enable our partners to make informed decisions about how to manage complex interacting natural and human systems across changing American landscapes. This strategy seeks to leverage the expertise, data, analytical capacity, and tools of the agency and to strengthen integration of science efforts across programs and scales. A cornerstone of the strategy is working closely with landowners and resource managers to identify the science that is needed to inform management actions, and then working collaboratively with those same partners to coproduce science and data products that are timely, practical, and useful for their decision making.

Many individual efforts within the USGS already embrace landscape science ideas and practices. With the development of this strategy, we are seeking to build on these efforts and to focus agency attention and expertise on expanding, connecting, and institutionalizing core practices and approaches for landscape science that produces actionable science products and tools that decision makers can use to help conserve and manage American landscapes.

The strategy has three goals that would be achieved by the USGS working in partnership with other DOI agencies and with Federal, State, Tribal, and local governments, regional conservation networks, universities, communities, and private landowners:

A. Create and deliver science and insights that can be used to manage American landscapes.

B. Understand and communicate how and why landscapes have changed and will change.

C. Engage in transdisciplinary science that creates new types of management insights.

Fog over Saint Mary Lake in Glacier National Park, Montana, 2006.
Photograph by Greg Pederson, U.S. Geological Survey.

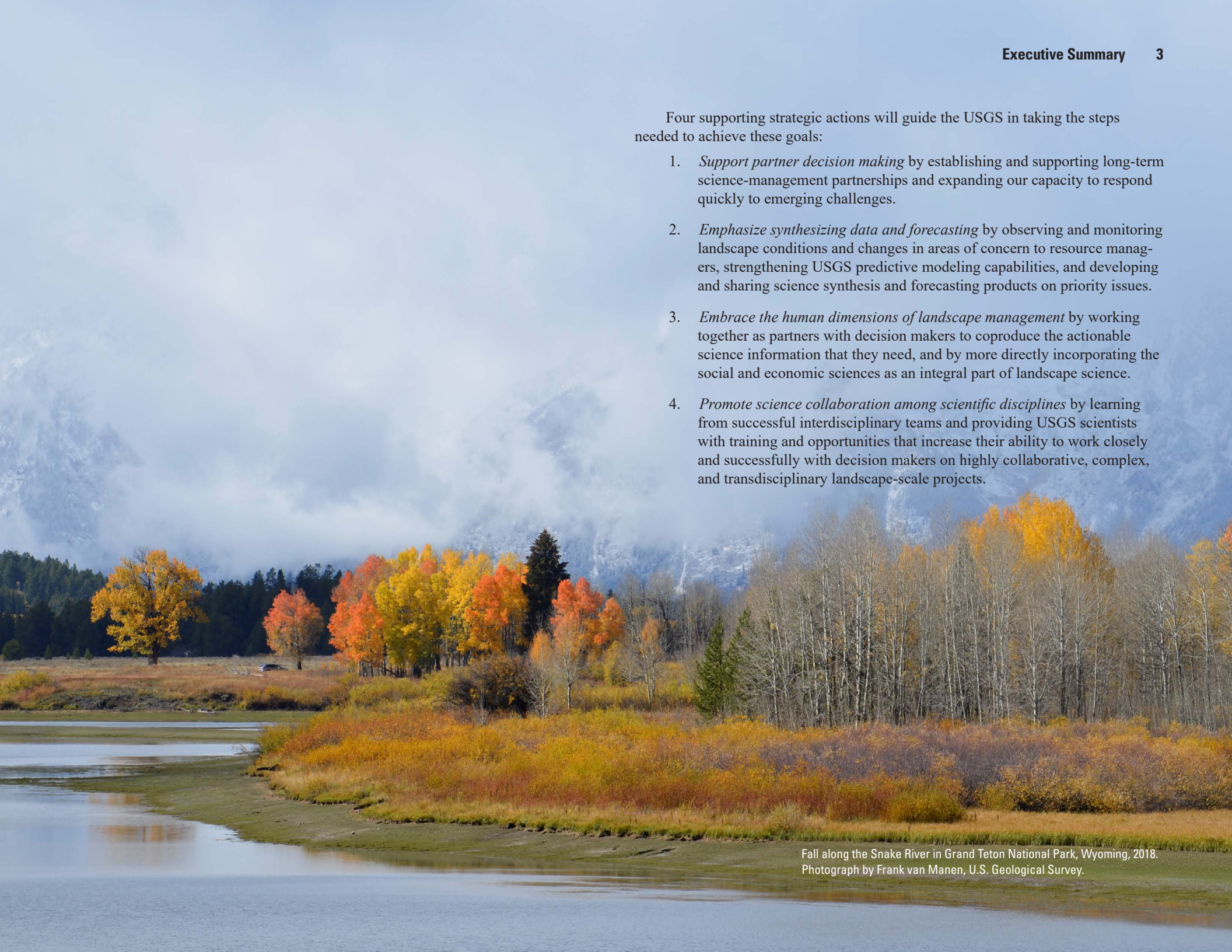
Four supporting strategic actions will guide the USGS in taking the steps needed to achieve these goals:

1. *Support partner decision making* by establishing and supporting long-term science-management partnerships and expanding our capacity to respond quickly to emerging challenges.

2. *Emphasize synthesizing data and forecasting* by observing and monitoring landscape conditions and changes in areas of concern to resource managers, strengthening USGS predictive modeling capabilities, and developing and sharing science synthesis and forecasting products on priority issues.

3. *Embrace the human dimensions of landscape management* by working together as partners with decision makers to coproduce the actionable science information that they need, and by more directly incorporating the social and economic sciences as an integral part of landscape science.

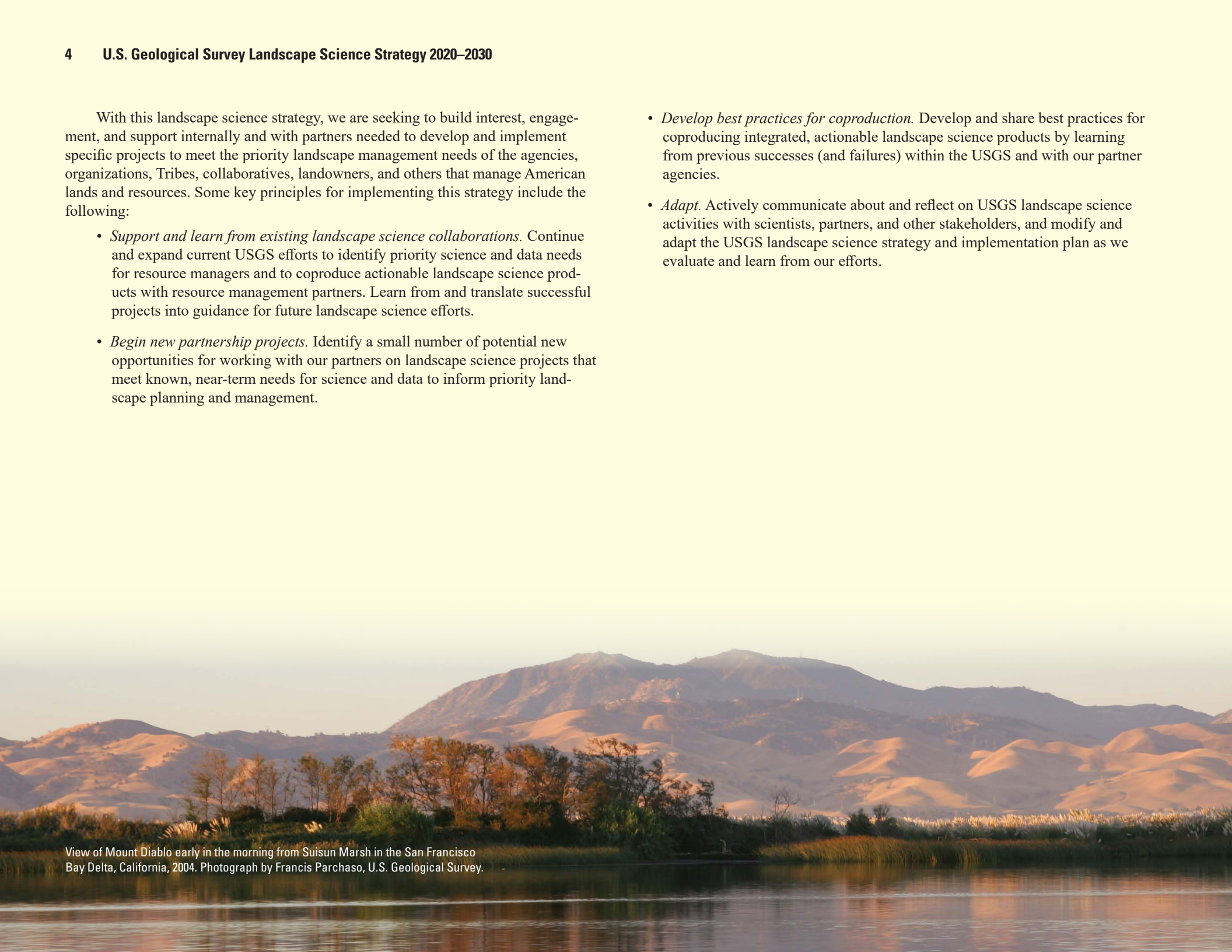
4. *Promote science collaboration among scientific disciplines* by learning from successful interdisciplinary teams and providing USGS scientists with training and opportunities that increase their ability to work closely and successfully with decision makers on highly collaborative, complex, and transdisciplinary landscape-scale projects.



Fall along the Snake River in Grand Teton National Park, Wyoming, 2018. Photograph by Frank van Manen, U.S. Geological Survey.

With this landscape science strategy, we are seeking to build interest, engagement, and support internally and with partners needed to develop and implement specific projects to meet the priority landscape management needs of the agencies, organizations, Tribes, collaboratives, landowners, and others that manage American lands and resources. Some key principles for implementing this strategy include the following:

- *Support and learn from existing landscape science collaborations.* Continue and expand current USGS efforts to identify priority science and data needs for resource managers and to coproduce actionable landscape science products with resource management partners. Learn from and translate successful projects into guidance for future landscape science efforts.
- *Begin new partnership projects.* Identify a small number of potential new opportunities for working with our partners on landscape science projects that meet known, near-term needs for science and data to inform priority landscape planning and management.
- *Develop best practices for coproduction.* Develop and share best practices for coproducing integrated, actionable landscape science products by learning from previous successes (and failures) within the USGS and with our partner agencies.
- *Adapt.* Actively communicate about and reflect on USGS landscape science activities with scientists, partners, and other stakeholders, and modify and adapt the USGS landscape science strategy and implementation plan as we evaluate and learn from our efforts.



View of Mount Diablo early in the morning from Suisun Marsh in the San Francisco Bay Delta, California, 2004. Photograph by Francis Parchaso, U.S. Geological Survey.

Introduction

Multiple Federal, State, Tribal, and local governments are working with stakeholders and landowners to restore and conserve lands and resources to benefit fish, wildlife, habitats, and people across the Nation. One of the largest Federal efforts is led by the U.S. Department of the Interior (DOI), with multiple DOI agencies working to conserve and manage the Nation's natural resources and cultural heritage for the benefit and enjoyment of current and future generations. Managing our Federal lands and resources provides tremendous benefits to our Nation: DOI activities provide critical jobs and economic output (1.8 million jobs and $315 billion in economic output in fiscal year 2018) along with clean air and water from healthy forests and grasslands, storm protection from coastal wetlands, and stewardship of our Nation's preeminent natural, historical, and cultural sites (U.S. Department of the Interior, 2019).

These valuable natural resources are undergoing constant change. Human uses and values of our lands and resources take place in the context of a changing climate and against a backdrop of hazards, such as wildfires, floods, earthquakes, and volcanic activity. Landscape science seeks to understand how the physical, biological, and social components of ecosystems and landscapes interact with each other across local to global scales and can provide science, data, and tools that landowners and resource managers can use to help manage American lands and resources sustainably and effectively in the face of these complex and interacting stressors.

The purpose of this report is to share the vision, goals, and strategic actions of the U.S. Geological Survey (USGS) for providing the integrated landscape science, data, and analytical tools needed by decision makers to help respond to today's resource management challenges. The vision and goals in this document are aligned with and directly support the overarching USGS 21st-century science strategy (U.S. Geological Survey, 2021o). In particular, the landscape science strategy expands our focus on internal and external partnerships and aligns with the goal of the USGS to "deliver actionable information in the form of integrated observations and predictions of the current and future state of Earth systems at the scales and timeframes needed to support decisions" (Jenni and others, 2017; U.S. Geological Survey, 2021o). Our aim in sharing the landscape science strategy is to build support and interest from the USGS, the DOI, other Federal, State, Tribal, and local governments, regional conservation networks, and landowners toward committing to working together as true partners to coproduce actionable landscape science and data products that are useful and can be used to inform management of our Nation's lands and resources outlining the next step: how we can work together to implement the strategy over the next decade.

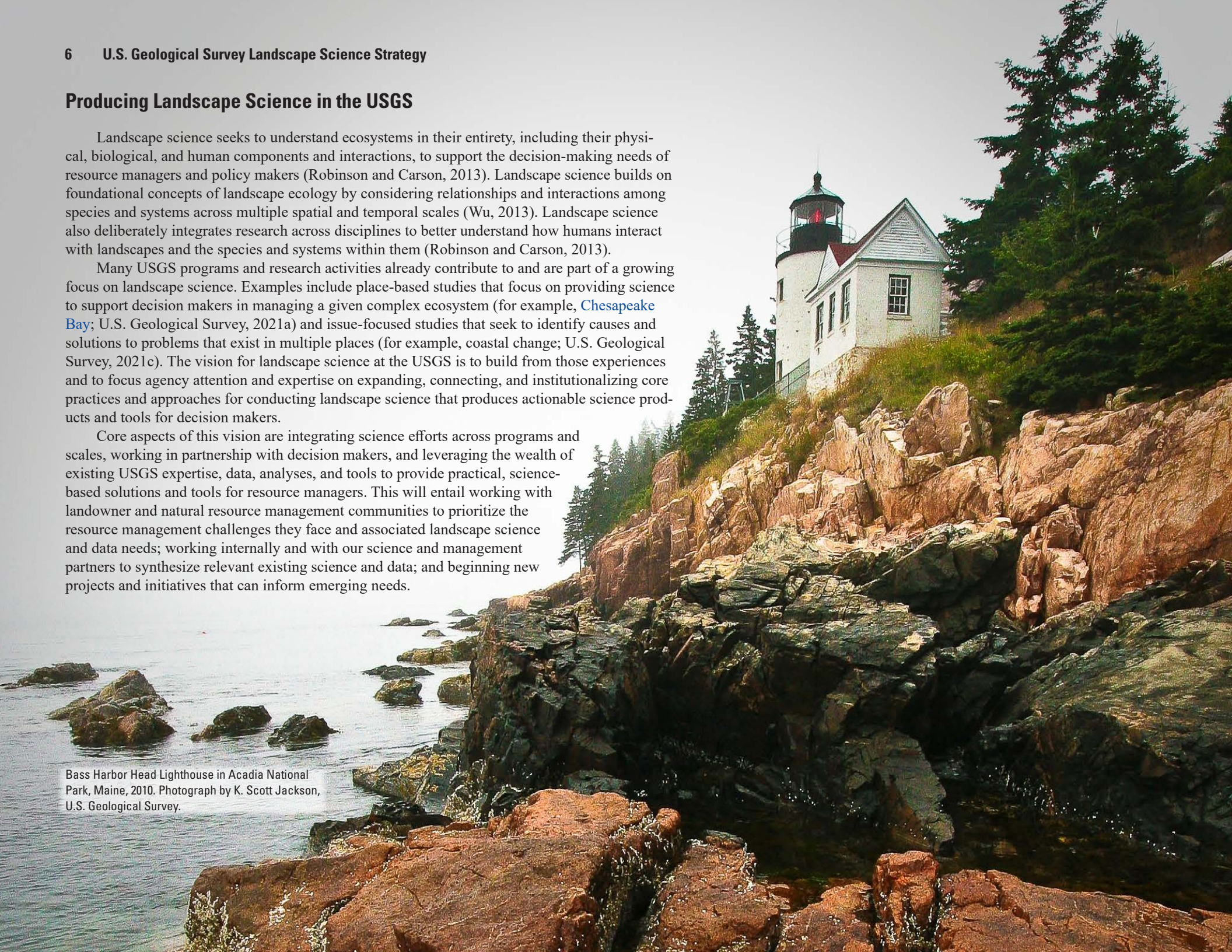
Recording information on tree mortality, fuel consumption, and vegetation communities after a fire to better understand and predict effects of fires in Kenai National Wildlife Refuge, Alaska, 2015. Photograph by Rachel Loehman, U.S. Geological Survey.

Producing Landscape Science in the USGS

Landscape science seeks to understand ecosystems in their entirety, including their physical, biological, and human components and interactions, to support the decision-making needs of resource managers and policy makers (Robinson and Carson, 2013). Landscape science builds on foundational concepts of landscape ecology by considering relationships and interactions among species and systems across multiple spatial and temporal scales (Wu, 2013). Landscape science also deliberately integrates research across disciplines to better understand how humans interact with landscapes and the species and systems within them (Robinson and Carson, 2013).

Many USGS programs and research activities already contribute to and are part of a growing focus on landscape science. Examples include place-based studies that focus on providing science to support decision makers in managing a given complex ecosystem (for example, Chesapeake Bay; U.S. Geological Survey, 2021a) and issue-focused studies that seek to identify causes and solutions to problems that exist in multiple places (for example, coastal change; U.S. Geological Survey, 2021c). The vision for landscape science at the USGS is to build from those experiences and to focus agency attention and expertise on expanding, connecting, and institutionalizing core practices and approaches for conducting landscape science that produces actionable science products and tools for decision makers.

Core aspects of this vision are integrating science efforts across programs and scales, working in partnership with decision makers, and leveraging the wealth of existing USGS expertise, data, analyses, and tools to provide practical, science-based solutions and tools for resource managers. This will entail working with landowner and natural resource management communities to prioritize the resource management challenges they face and associated landscape science and data needs; working internally and with our science and management partners to synthesize relevant existing science and data; and beginning new projects and initiatives that can inform emerging needs.



Bass Harbor Head Lighthouse in Acadia National Park, Maine, 2010. Photograph by K. Scott Jackson, U.S. Geological Survey.

Delivering Landscape Science

Successfully addressing today's land and resource management challenges requires that scientists and decision makers find increasingly better ways to work together across organizations and geographies to identify, produce, and deliver relevant, timely, practical, and useful science, data, and tools. The USGS is well positioned and organized to help meet this challenge (see "USGS Landscape Science Capabilities and Strengths" sidebar). The USGS has a wide range of expertise with a robust history of research and monitoring over the full range of scales from specialized laboratories to ecoregions and from short-duration (days to months) abrupt change to long-term (years to decades and centuries) global trends. The USGS also has experience and ongoing activities in data collection and integration, assessing landscape change using multiscale and multidisciplinary metrics, building the high-caliber data processing and analysis capacity needed for real-time analyses across large areas, and delivering science and information on priority management topics to decision makers.

USGS Landscape Science Capabilities and Strengths

The USGS is a multidisciplinary science organization with a national and international reputation in a variety of disciplines supported by an extensive scientific infrastructure and capacity. Some of the strengths that make the USGS well suited to begin a landscape science initiative include:

- expertise across the spectrum of physical, biological, and social science disciplines and a strong history and ethic of multidisciplinary and integrated science;
- extensive long-term observational systems and datasets, from land cover to stream flow to organismal abundance and migration, that can be combined to understand and project future landscape changes;
- powerful technical capacity and expertise for applying advanced machine learning algorithms to large datasets for the real-time analysis and forecasting needed to understand potential resource futures;
- offices and employees distributed across the Nation with the expertise, experience, methods, and tools needed to produce respected, unbiased, high-quality science needed for science-based decision making; and
- established relationships and mutual trust with our many stakeholders, including DOI partner agencies, and an institutional commitment to working with other decision makers, science providers, stakeholders, and the public to identify and deliver locally, regionally, and nationally relevant science for managing natural resources

Measuring the elevation of the Tule Slough wetlands, California, 2018. Photograph by Erika Sanchez-Chopitea, U.S. Geological Survey.

USGS Landscape Science Strategy

The current USGS science portfolio includes many projects and activities that contribute to understanding the complex interactions among natural and human systems and that focus on supporting resource management decisions within and outside the DOI. The USGS landscape science strategy has been created to recognize the commonalities and connections among these efforts, to learn from them, and to identify productive areas of intersection and focus that can increase the effectiveness and usefulness of USGS science for land and resource management.

A set of three goals and four strategic actions have been developed to help the USGS realize the vision for landscape science in the USGS (see "Vision" sidebar). The three goals describe what this strategy aims to achieve. The four interconnected strategic actions identify areas where focused efforts can help the USGS reach those goals (fig. 1).

Vision

USGS landscape science integrates multiple disciplines and approaches to create and deliver relevant, timely, and scientifically sound products that enable our partners to make informed decisions about how to manage complex interacting natural and human systems across changing American landscapes

An inundated floodplain in the Delaware River watershed. Photograph by U.S. Geological Survey.

Figure 1. Goals and supporting strategic actions for achieving the vision of the U.S. Geological Survey landscape science strategy.

Landscape science is inherently integrative. It is distinguished by the explicit merging of insights from many individual studies across a variety of disciplines and by the creation of new multiscale and transdisciplinary studies to gain understanding of the complex and changing natural and human systems that make up American landscapes. The vision of the USGS is for landscape science to be coproduced (Meadows and others, 2015; Beier and others, 2017): designed and executed with decision makers and stakeholders to deliver the actionable science products that they need. Landscape science supports decision makers as they seek to understand and manage lands and resources over broad areas within and across jurisdictional boundaries and addresses current and future conditions. By actively engaging with decision makers to coproduce actionable landscape science products, the USGS can continue its strong contribution to delivering science-based solutions to today's resource management challenges

Cattle grazing in a sabebrush ecosystem. Photograph by Steve Hanser, U.S. Geological Survey.

Goals

Landscape science can provide a strong foundation for managers and stakeholders to develop options, make decisions, and implement actions that are most likely to be effective in our changing world. The three goals described below are key to achieving the USGS vision for landscape science and emphasize delivering decision-relevant transdisciplinary science.

Monitoring fire effects at archaeological sites in Santa Fe National Forest, New Mexico, 2014. Photograph by Rachel Loehman, U.S. Geological Survey.

Goal A

Create and Deliver Science and Insights To Manage American Landscapes

A fundamental goal for USGS landscape science is to be useful and used to inform and support management of American landscapes. Achieving this goal requires work on two fronts. First, the USGS must work together with landowners and managers from the start in a process of mutual learning, to understand their information needs and to distill the complexity of landscape science—interacting resources and stressors, diverse disciplines, and multiscale questions—into accessible, practical, and useful tools that present clear analyses of management options and their results. This level of collaboration has been a focus of USGS efforts with multiple partners at levels from local to national, including the Bureau of Land Management and the U.S. Fish and Wildlife Service, and will be a critical foundation for this strategy to build upon if it is to be successful.

Second, the USGS must continue to work to better understand the complex organizational, social, and governance systems within which landowners and managers make policies and management decisions. Multiple jurisdictions and stakeholders with diverse or even oppositional policy preferences are commonplace. Clear opportunities exist for understanding these perspectives and decision contexts, for identifying key points in decision processes where landscape science can inform and improve resource outcomes, and for communicating information in ways that can increase the engagement and understanding of all stakeholders (Carter and others, 2020).

Campsite at Thousand Island Lake along the Pacific Crest Trail in California. Photograph by Jeffrey Marion, U.S. Geological Survey.

Goal B

Understand and Communicate Landscape Change

Resource managers often have to make decisions without information that could improve their understanding of likely decision outcomes. In some cases, scientists may not yet have researched these questions. In other cases, pertinent information exists, but it may not have been compiled, summarized, or shared with managers in a format that is freely and easily accessible. USGS landscape science aims to bridge this gap between science and management (Meffe, 1998; Pullin and others, 2004) by consistently working closely with landowners and land management partners to identify, create, and share actionable landscape science products that provide a clear understanding of the forces affecting our landscapes and the vulnerability and resilience of those systems to different stressors. Core activities will include USGS scientists working with resource managers to monitor, assess, and anticipate, the status, trend, condition, and vulnerability of aquatic and terrestrial systems, species within those systems, and nearby communities across our American landscapes. Key to accomplishing these activities will be predicting potential future changes, especially changes to resources, species, habitats, and communities, that may be associated with different management actions and potential climate change scenarios.

Collecting alpine insects below a small seep on a slope above a tributary to the Dry Fork, north of the Two Medicine area in Glacier National Park, 2015. Photograph by Joe Giersch, U.S. Geological Survey

Goal C

Create New Types of Management Insights Through Transdisciplinary Science

The complexities of interconnected and changing landscapes have created problems and questions that are not confined to a single scientific discipline. For example, human and social systems are strong drivers of change in natural systems, and adaptability in natural systems drives and limits change in social systems. USGS landscape science will move beyond simply recognizing that human and natural systems are dependent upon each other and integrate social and natural science analyses to understand change in these coupled human and natural systems. Regularly engaging scientists from multiple USGS programs, along with landowners, resource managers, and other stakeholders, in the science formulation and discovery process will help ensure that USGS landscape science integrates multiple perspectives, resources, datasets, and analyses to more accurately understand and convey the complex and interconnected nature of our landscapes.

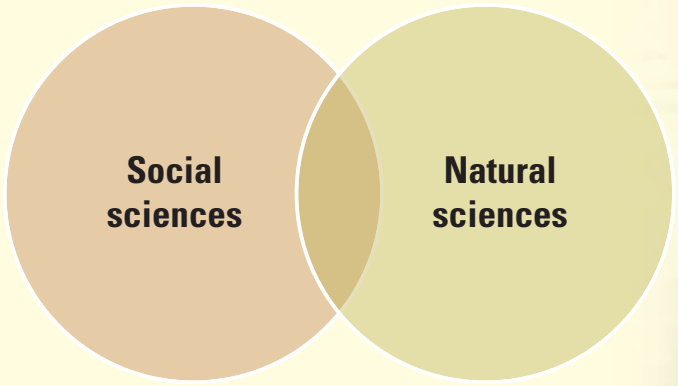


Figure 2. A goal of the U.S. Geological Survey landscape science strategy is to generate new management insights through the integration of social and natural science analyses.

Collecting water monitoring data at Seal Beach National Wildlife Refuge, California, 2015. Photograph by Katharine Lovett, U.S. Geological Survey.

Supporting Strategic Actions

Each of the supporting strategic actions described in this section starts with existing USGS strengths and outlines specific steps that the USGS can take in pursuit of the three goals described in the "Goals" section of this report. The strategic actions are mutually reinforcing and identify areas where we can leverage and expand existing capabilities to provide high-quality, high-impact landscape science information delivered in forms and on schedules that enable our partners to use that information to help manage American landscapes.

Colorado Plateau native plant community dominated by globe mallow, Indian ricegrass, and sand dropseed west of Los Lunas, New Mexico. Photograph by Rob Massatti, U.S. Geological Survey

Strategic Action 1

Build Approaches That Support Partner Decision Making

A core strategic action for increasing the usefulness of landscape science is to build and strengthen approaches that bridge the research-management gap to support the decision-making needs of landowners and resource managers now and into the future.

Support long-term partnerships between science and resource management. One of the fundamental mechanisms for ensuring that USGS landscape science is relevant to decision making is to establish and support relationships between research teams and resource owners, planners, managers, and policy makers. Long-term partnerships foster trust and the ability to successfully navigate the surprises and challenges that are an inevitable part of coproduction. Long-term partnerships also provide the capacity, experience, and perspective to ask and answer key questions across the entire span of the management decision space. This includes working with planners, managers, and policy makers to prioritize their short- and long-term science needs, structure investigations to produce results that reduce uncertainty for them, understand exactly how and where they are ultimately able to use that science to inform their decisions, and evaluate the effects and effectiveness of those decisions on resources and people. A focus on institutionalizing relationships through teams and working groups can make partnerships more resilient to changes in personnel.

Long-term research-management partnerships can benefit from the use of different decision-making frameworks and approaches. These include the use of decision scenarios early in the research planning process, structured decision-making (Runge, 2011) to help frame management questions and identify the most relevant science, adaptive management (Williams and Brown, 2012) to ensure ongoing relevance of science and better outcomes in practice, and translational ecology (Enquist and others, 2017) to improve communication between the USGS and managers. The use and effect of landscape science products developed through these partnerships can be quantified using traditional (such as academic and program performance) and outcome-based (such as effect and significance) performance measures that are selected or developed with input from partners during implementation planning.

Promote existing and establish new structures that facilitate interaction among scientists and decision makers. To provide ongoing decision support and build and sustain the relationships described in the first aspect of this strategic action, the USGS will need to work with other DOI agencies and with external partners, agencies, and organizations to establish institutional structures and incentives for USGS scientists and resource owners, managers, and policy makers to interact. The landscape science initiative of the USGS can link research teams to existing management units (for example, through DOI regions; fig. 3; U.S. Department of the Interior, 2021) and partnerships (for example, the U.S. Fish and Wildlife Service's Science Applications Program [U.S. Fish and Wildlife Service, 2021], the Bureau of Land Management National Science Committee [Bureau of Land Management, 2016], and the Network for Landscape Conservation [2021]) and recognize and reward the contributions of scientists to such efforts, for example, through performance incentives.

The USGS can leverage lessons learned from existing multiorganization collaborative groups in which the USGS already plays a role, such as priority ecosystems science activities through the Ecosystems Mission Area science centers (U.S. Geological Survey, 2018), climate adaptation science centers (U.S. Geological Survey, 2021b), cooperative research units (U.S. Geological Survey, 2021e), the Energy and Minerals Mission Area (U.S. Geological Survey, 2021h), and the National Geospatial Program (U.S. Geological Survey, 2021n), about how to best provide effective scientific leadership within such groups and how to structure and support research-management teams to promote sustained, positive, and productive relationships.

Prepare to respond quickly to new challenges. In a world of increasingly rapid environmental change, policy makers and resource managers are coping with new challenges that can emerge and require informed responses over relatively short timeframes. These challenges include algal blooms, invasive species and disease outbreaks, droughts, wildfires, and rapid expansion of natural resource extraction. To respond quickly to such changes, the USGS must expand its capacity for rapid response and expand core partnerships to include State, Tribal, and local governments, who often play key roles in responding to such events. Just as the Natural Hazards Mission Area (U.S. Geological Survey, 2021l) responds quickly with relevant science and information in the wake of natural disasters, so too should landscape science teams be able to quickly provide the science needed to inform responses to new and novel land management issues when they arise.

Such responsiveness requires an ability to anticipate future issues as well as respond quickly to near-term change. The USGS is well situated to help anticipate such changes across a wide range of resources, geographies, and scales. Strong, collaborative relationships between the USGS and resource management partners can help identify the type and relevant attributes (for example, spatial or temporal resolution) of information that may be needed before a specific challenge emerges and ensure that results can be conveyed directly to those in need. Utilizing these relationships, along with sustained, programmatic investments in relevant data collection, analytical capacity, and communication frameworks, will position the USGS to consistently deliver timely information that can help landowners and managers respond to emergent challenges.

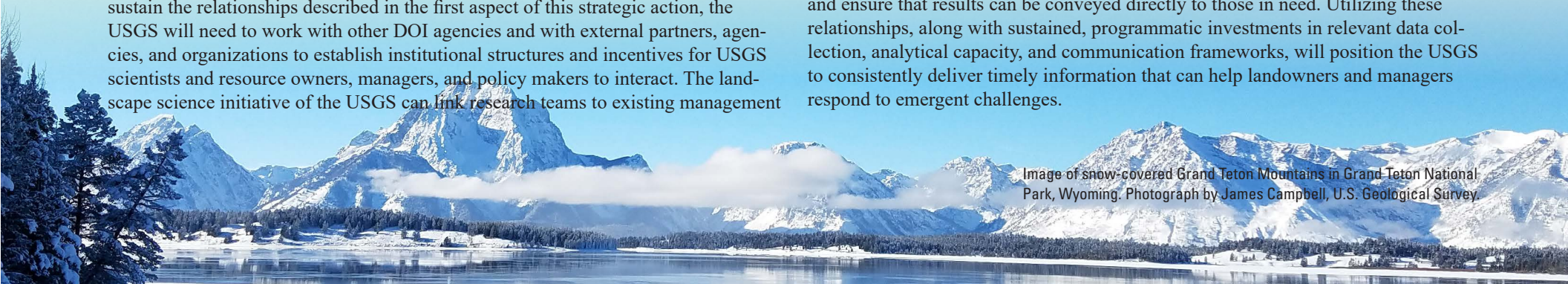


Image of snow-covered Grand Teton Mountains in Grand Teton National Park, Wyoming. Photograph by James Campbell, U.S. Geological Survey.

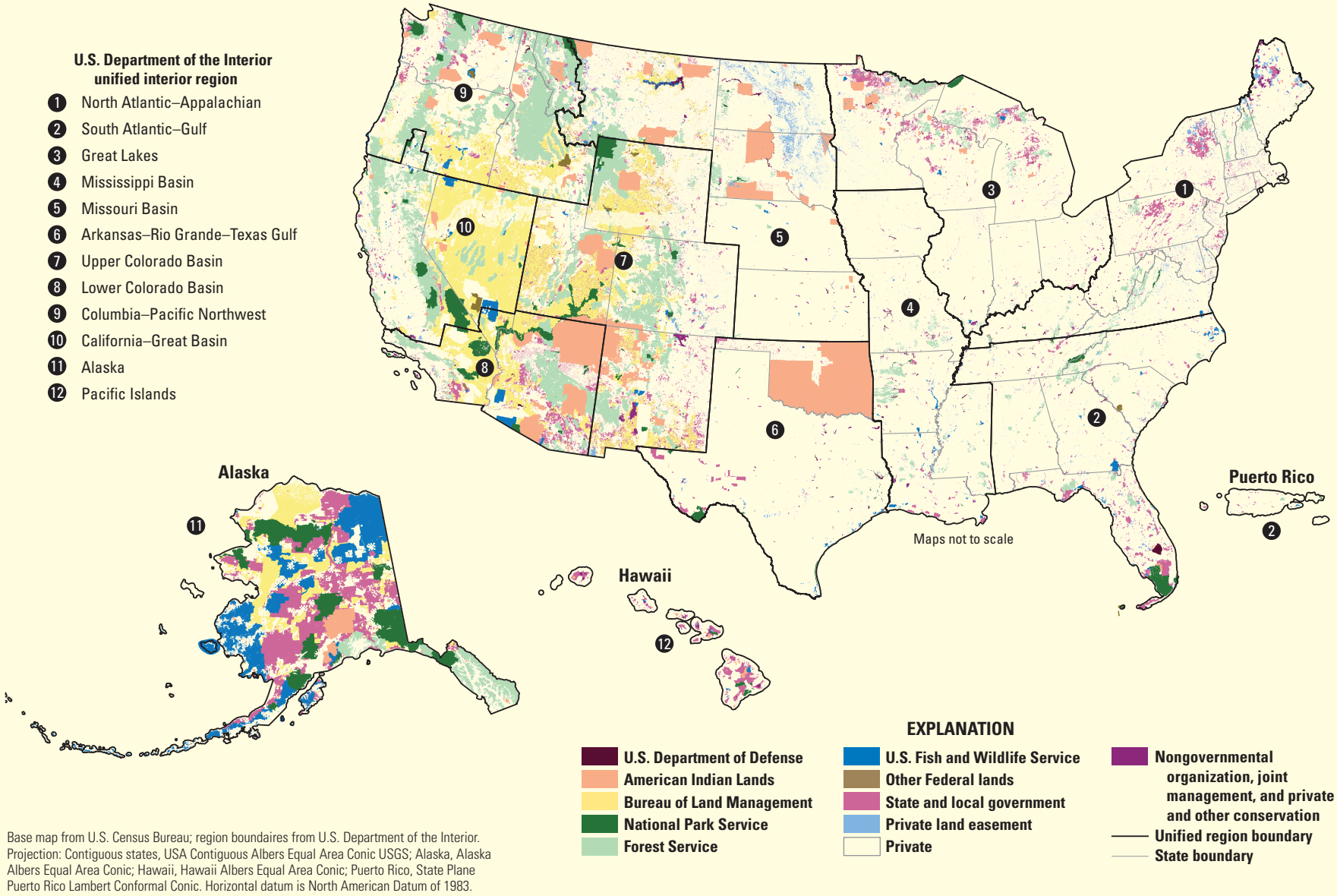


Figure 3. Lands managed by Federal, State, Tribal, local, private, and nongovernmental entities in the United States and territories, and U.S. Department of the Interior unified interior regions. These land management entities, private landowners, and others will be critical partners in implementing the landscape science strategy of the U.S. Geological Survey. Data are from U.S. Geological Survey (2020).

Emphasize Synthesis and Forecasting

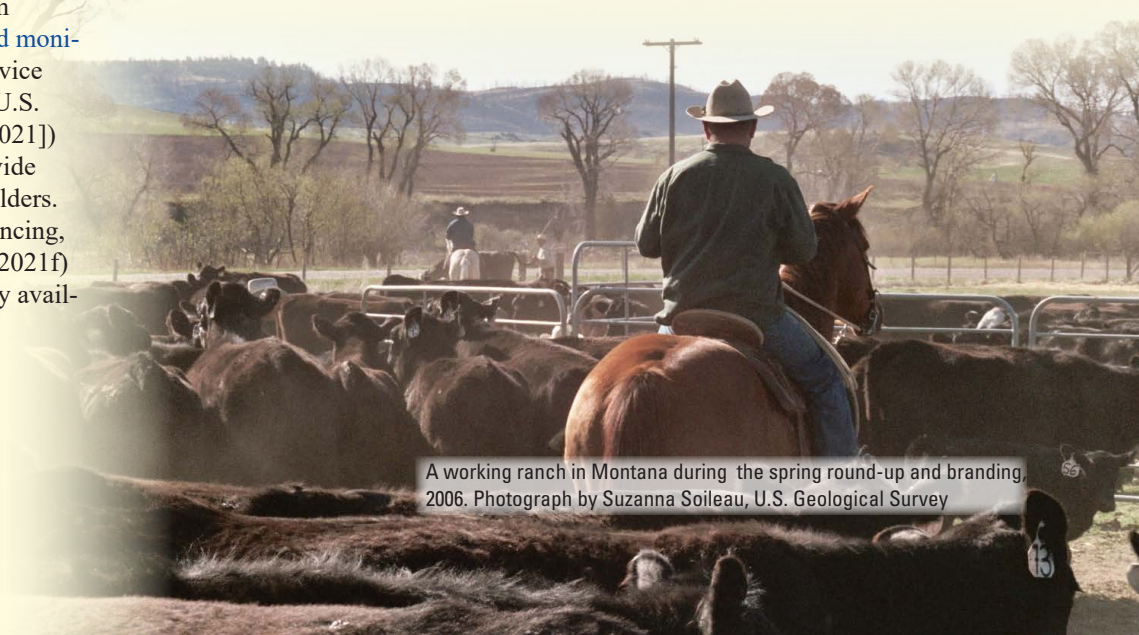
Successful resource management requires understanding what has changed, what is currently changing and why, the effects and interdependencies of those changes, and what can be done to manage or adapt to those changes. Managers also need to understand their decision space, range of viable management alternatives, the predicted effects of the alternatives, and how to monitor for those effects and outcomes. Two important focus areas for successful landscape science are to synthesize existing science to strengthen our understanding of the dynamics of landscapes and the species and communities they contain and to further develop our predictive science capacity. Combined, these actions can lead to powerful new products and services that support vulnerability detection, early warning systems, and accurate forecasting of potential futures.

Observe and monitor landscape condition and change in areas of management concern. Through place-based studies, landscape science can connect critical variables—such as land managers and their proposed management actions, the specific parcels being managed, and past stressors or changes to those parcels—to improve understanding of how management actions in specific contexts can affect the structure and function of those landscapes. The USGS has studied specific landscapes through priority ecosystem science programs (for example, see the "Informing Management and Restoration in Iconic American Landscapes" sidebar).

The long history of the USGS as a leader in remote sensing can also provide critical information on land use and land cover change at local to global scales to support such assessments. Combining the remote sensing expertise and products of the USGS with direct field observations and monitoring programs (such as the Bureau of Land Management Assessment, Inventory, and Monitoring Program [Bureau of Land Management, 2021], the National Park Service inventory and monitoring networks [National Park Service, 2021], the U.S. Fish and Wildlife Service National Wetlands Inventory [U.S. Fish and Wildlife Service, 2021], and the U.S. Forest Service Forest Inventory and Analysis program [U.S. Forest Service, 2021]) in a landscape science framework can leverage these data even further to provide multiscale insights and decision support information to managers and stakeholders. Moreover, technologies such as those used in remote sensing are rapidly advancing, and the USGS Core Science Systems Mission Area (U.S. Geological Survey, 2021f) can ensure that the data and tools developed from these technologies are freely available to all stakeholders through trusted, public-facing outlets.

Strengthen USGS predictive modeling capabilities. Understanding, describing, and predicting the status and trends of the biological and physical systems of the Earth is a critical part of landscape science and a priority for the USGS. Research on biological threats such as disease, invasive species, and harmful algal blooms; natural hazards such as earthquakes, wildland fire, landslides, volcanic eruptions, and floods; impacts of coastal and climate change; health threats from environmental contaminants and pathogens; and prediction and forecasting of water quality, quantity, and use are all likely to play key roles in USGS landscape science. Consideration of multiple spatial and temporal scales is particularly important in understanding how resource uses and values may be affected by these and other natural and human-influenced changes.

Develop and promote USGS synthesis and forecasting products. A major challenge to the use of science in resource management decisions is a lack of easy access to and awareness of that science (Seavy and Howell, 2010; Cvitanovic and others, 2014). Past work with partners has shown that synthesizing existing science and its resource management implications (for example, Hanser and others, 2018), facilitates integration of that science into the land use planning and management decisions of our partners. Examples of forecasting products might include "famine early warning," "invasive organism forecasting," and "water quantity and quality prediction" systems or tools. Creating and sharing high-quality, actionable science products such as these with our resource management partners through reliable, public-facing outlets can also raise awareness of the USGS as a trusted source of relevant landscape science, data, and tools.

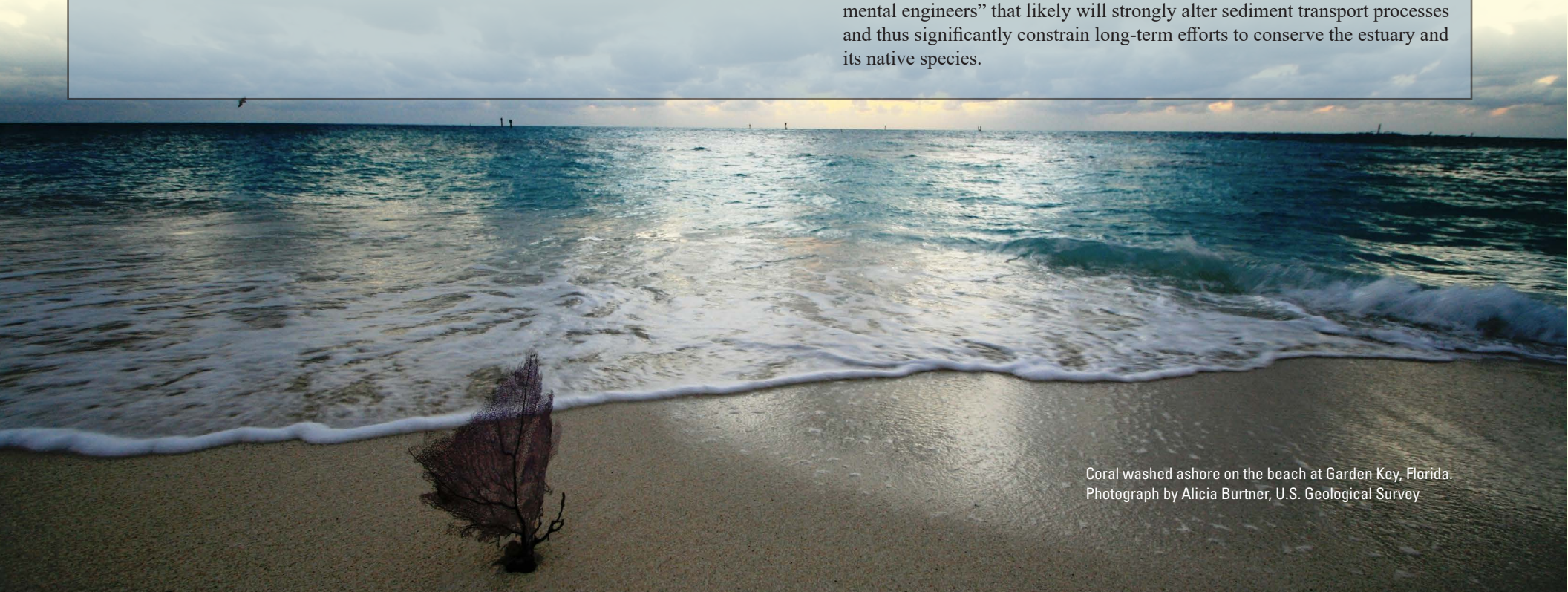


A working ranch in Montana during the spring round-up and branding, 2006. Photograph by Suzanna Soileau, U.S. Geological Survey

Informing Management and Restoration in Iconic American Landscapes

The USGS priority ecosystem science programs are making a major, sometimes game-changing, difference nationally. Priority ecosystem science programs help managers and policy makers address issues that range from declining fish and waterfowl populations, loss of natural habitat, invasive species and disease, poor water quality, and effects of energy extraction and land and climate change. Some examples of recent successes:

- In *America's Everglades*, the Greater Everglades Priority Ecosystem Science Program (U.S. Geological Survey, 2021j) quickly developed a web-based decision-support tool at the request of the U.S. Fish and Wildlife Service to aid them in assessing real-time hydrology effects on the endangered cape sable seaside sparrow (*Ammodramus maritimus mirabilis*).
- In the *Chesapeake Bay*, the Nation's largest estuary (U.S. Geological Survey, 2021a), USGS scientists worked with stakeholders to apply new findings to enhance management of recreational fish and waterbird species, their habitats, as well as the lands that are important for the 18 million people who live in the multistate watershed.
- In the *Northern Great Plains*, the Platte River Priority Ecosystem Science Program (U.S. Geological Survey, 2014) characterized preferred habitat of satellite-tracked whooping cranes (*Grus americana*) to better define targets for management actions intended to assure the long-term survival of this endangered species.
- In the *desert Southwest*, the Southwest Energy Development and Drought Priority Ecosystem Program (U.S. Geological Survey, 2021m) is creating site-specific reclamation knowledge and innovative decision support tools to help operators mitigate risks and ensure sustainable development of the Nation's oil and gas resources.
- In *Washington's Puget Sound*, the Puget Sound Priority Ecosystem Science Program (U.S. Geological Survey, 2021i) integrated field studies and cutting-edge modeling that together yielded innovative tools for designing successful nearshore restoration projects and understanding what drives successful long-term outcomes for endangered salmon in Puget Sound.
- In *California's Sacramento-San Joaquin Estuary*, the San Francisco Bay and Delta Priority Ecosystem Science Program (U.S. Geological Survey, 2021g) completed a major study of the effects of exotic aquatic plants as "environmental engineers" that likely will strongly alter sediment transport processes and thus significantly constrain long-term efforts to conserve the estuary and its native species.



Coral washed ashore on the beach at Garden Key, Florida.
Photograph by Alicia Burtner, U.S. Geological Survey

Strategic Action 3

Embrace the Human Dimensions of Landscape Management

American landscapes inspire passion in all of us. Changes in public land policies and practices that affect those landscapes are felt by nearby communities and those much farther away. Landscape management decisions can affect everything from the soil underfoot to the volume of water in rivers and the availability and cost of electricity. Economic factors, technological change, political and economic institutions, and human attitudes and beliefs all shape the activities that take place on, in, and near landscapes and their embedded ecosystems. These human dimensions also affect how people value air, water, and other resources within landscapes and how they manage them. Thus, the third strategic action for USGS landscape science is to emphasize integration of data on the human forces that drive and respond to landscape changes into our physical, biological, and ecological research programs.

Include stakeholders in development of landscape science. Landscape management decisions are made and influenced by a broad circle of diverse parties, including public land managers, Tribal and local communities and governments, nongovernmental organizations, private landowners, and other members of the interested public. Working to understand the interests, objectives, and perspectives of all stakeholders and the sources and types of scientific information that will be most useful to them will strengthen USGS landscape science. Moving beyond engagement to embrace a coproduction approach to landscape science, in which scientists and managers work together as partners to develop decision-relevant science, is our goal. Bringing land owners and managers to the table will require demonstrating how landscape science can inform and improve resource management decisions and outcomes. The USGS can draw from many of the projects mentioned in this report to make that case.

A man walks across the desert in the Uinta Basin of Utah, along the Green River, 2019. Photograph by Mitchell Eaton, U.S. Geological Survey

Include the social sciences as an integral part of landscape science. Understanding how various stakeholders, including owners of private lands and users of public lands, value natural resources and are affected by natural resource management decisions is critical to landscape science. Within specific landscape science projects, scientists working together with people who live and work on American landscapes, including Native peoples, farmers and ranchers, recreation guides, and energy developers, can offer novel opportunities for mutual learning through application. Considering the distinct perspectives of those who use, benefit from, and value ecosystems on how those ecosystems function as working landscapes can also help identify new and creative management options that may be more likely to be implemented successfully. Landscape science activities under this strategic action may also focus on understanding how political, institutional, and social arrangements contribute to or impede successful implementation of natural-resource management plans and policies.

Use social-science-informed approaches to develop integrated research designs. Multiple theoretical models can be used to frame relationships between human and natural systems and understand the processes through which each system may affect the other. A key in moving toward more transdisciplinary research is to intentionally and consistently create study designs that allow theories and methods to be combined across the physical, biological, and human components of landscapes. USGS landscape science will be richer and more relevant by using social science expertise to facilitate the multidisciplinary research process.

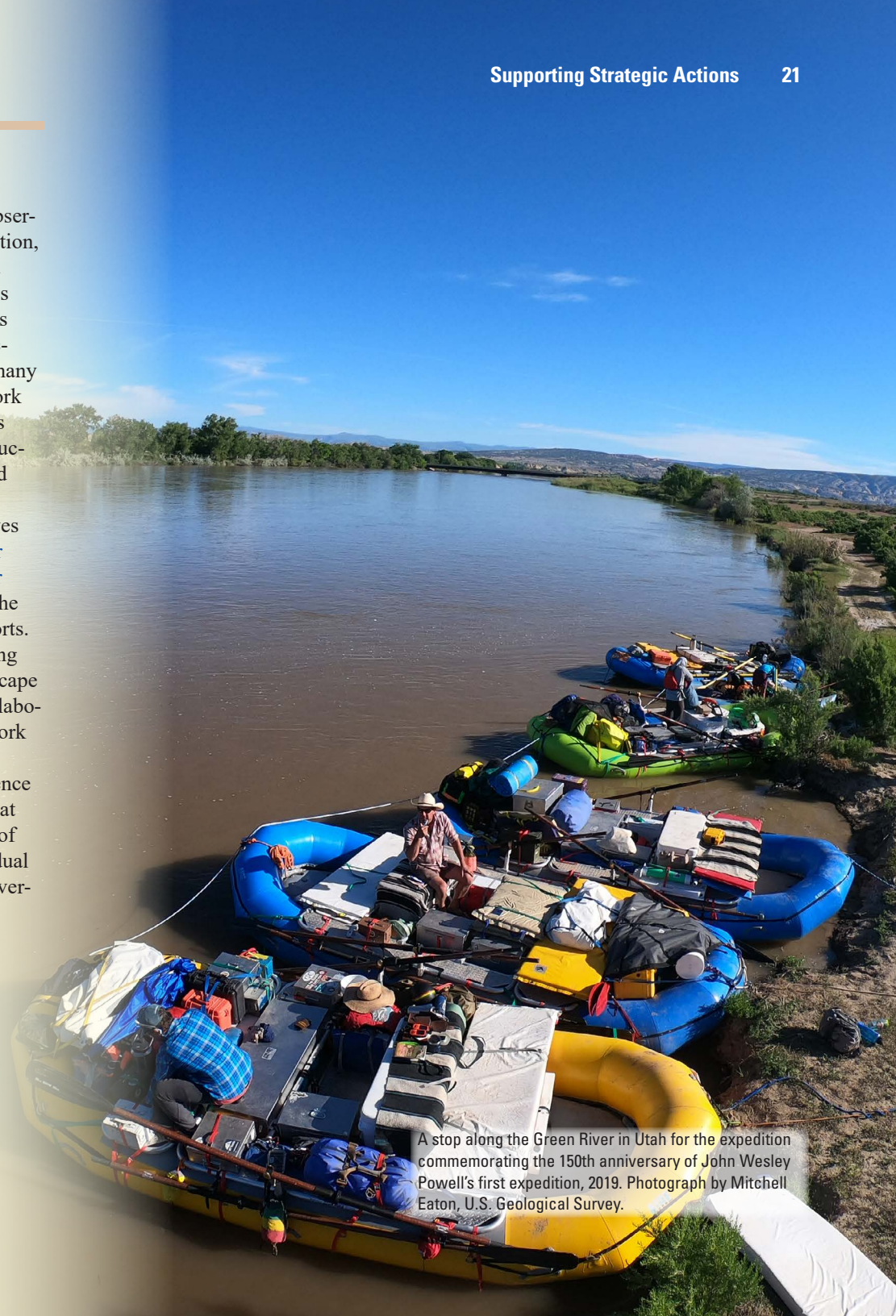
U.S. Geological Survey, National Park Service, and landowner partners collaborate in the desert southwest on vegetation studies. Photograph by Erika Geiger, U.S. Geological Survey.

Strategic Action 4

Promote Science Collaboration

Landscape science aims to create frameworks within which research and observations from a range of disciplines and from past, present, and future data collection, analysis, and synthesis efforts can be combined to describe, predict, and respond to changes in socioecological systems. Successfully creating this science requires many types of collaboration. In addition to working closely with decision makers (strategic action 1) and with broader sets of stakeholders (strategic action 3), successful landscape science should involve collaboration among specialists from many disciplines. This fourth supporting strategic action for landscape science is to work intentionally and creatively to strengthen science collaboration within and across USGS mission areas and science disciplines as well as collaboration and coproduction with external science and management agencies, conservation networks, and landowner organizations.

Learn from existing interdisciplinary teams. The USGS has several initiatives that support interdisciplinary work, including the John Wesley Powell Center for Analysis and Synthesis (U.S. Geological Survey, 2021k) and the Community for Data Integration (U.S. Geological Survey, 2021d). It may be useful to examine the history of these initiatives to identify the key features of the most successful efforts. Connecting those lessons with the theory and practice of creating high-performing teams (for example, Cheruvelil and others, 2014) can inform the design of landscape science activities to leverage and extend successful work to improve science collaboration and integrated science practices across the USGS and with our large network of science partners and collaborators. Transdisciplinary teams do not preclude focused studies best conducted within a discipline. Indeed, transdisciplinary science may consist of multiple projects addressing specific components of a problem that are then synthesized to yield answers to the overarching management questions of interest. A key is that this synthesis is planned from the beginning so that individual studies are designed to support the synthesis and transdisciplinary goals of the overarching challenge.



A stop along the Green River in Utah for the expedition commemorating the 150th anniversary of John Wesley Powell's first expedition, 2019. Photograph by Mitchell Eaton, U.S. Geological Survey.

Link research with tools to deliver on-demand actionable information. Connecting landscape science research with programs that describe and forecast environmental, social, and economic outcomes will help deliver actionable science products at the scales at which planning, management, and policy decisions are made. Connecting the science continuum, from research to highly applied operations support, is a necessity for successful landscape science. To date, the USGS has excelled at the research end of this continuum. A strategic focus on strengthening the operations end of the continuum, including supporting the production, delivery, maintenance, and improvement of high-order data and information products, can improve our ability to sustainably produce and deliver timely, useful science products.

Provide training and opportunities to practice interdisciplinary and transdisciplinary science. For USGS scientists to fully carry out the disciplinary, interdisciplinary, and coproduction work needed to produce actionable landscape science products, they may need additional skills beyond those provided by traditional scientific training. These skills range from gaining knowledge and experience in transforming qualitative information into quantitative inputs for predictive and decision-support models, to supporting efforts to communicate and work effectively with decision makers. Project management skills can help scientists synthesize project, mapping, and modeling outcomes to achieve overarching science goals and inform management decisions. Training to enhance facilitation and science communication skills can help landscape scientists work and communicate effectively with diverse stakeholders. Training in resource management decision-making processes, such as the National Environmental Policy Act (Public Law 91–190, 83 Stat. 852), and a working knowledge of the foundational environmental laws and policies that affect and guide the actions of our partners can vastly improve the ability of scientists to work as partners with decision makers. Finally, insight into the framework and context of current regulatory and governance environments can create a shared understanding among scientists, resource managers, and other stakeholders about the potential roles that landscape science can play in identifying practical solutions to the complex task of managing our American landscapes.

U.S. Geological Survey scientists and Tribal partners receive hands-on field training on wildland fire management in Montana; photograph by the U.S. Geological Survey.

Planning Implementation of the Science Strategy

Landscape science provides a framework within which research and observations from a range of disciplines and from past, present, and future data collection and analysis efforts can be combined to describe, predict, and respond to complex changes in American landscapes. Importantly, landscape science activities are not defined and carried out by the USGS alone: collaboration and coproduction with landowners and natural resource managers are key aspects of landscape science. In that spirit, we will work closely with our partners to develop a plan for implementing USGS landscape science. Some key principles that will form the basis for implementing this strategy include the following:

- *Support and learn from existing landscape science.* Continue and expand ongoing USGS efforts to work closely with partner agencies to identify priority science and data needs for resource managers and coproduce actionable landscape science products with partner agencies. Consider if elements of this strategy are missing from those projects and might usefully be added. Learn from and translate successful projects into guidance for future landscape science efforts.

- *Begin new partnership projects.* Identify a small number of potential new opportunities for working with our partners to conduct landscape science that meets known, near-term needs for science and data to inform priority landscape planning and management. Enact the strategic actions described above—including working closely with resource managers to plan for coproduction efforts across disciplines and scales with a strong decision-support focus—to plan landscape science activities that can address key management questions.

- *Develop best practices for coproduction.* Develop and share best practices for coproducing integrated, actionable landscape science products by learning from previous successes (and failures) within the USGS and with our partner agencies. This should include looking for keys to designing successful landscape science coproduction projects, promoting and institutionalizing integrated whole-system science practices, creating high-performing teams of scientists and managers, and designing useful decision-support practices and tools.

- *Adapt.* Actively communicate about and reflect on USGS landscape science activities with scientists, partners, and other stakeholders and be open to modifying and adapting the USGS landscape science strategy and implementation plan as we evaluate and learn from our initial implementation efforts

A moose lying in the snow amongst the trees in Wyoming, 2002. Photograph by John J. Mosesso, U.S. Geological Survey.

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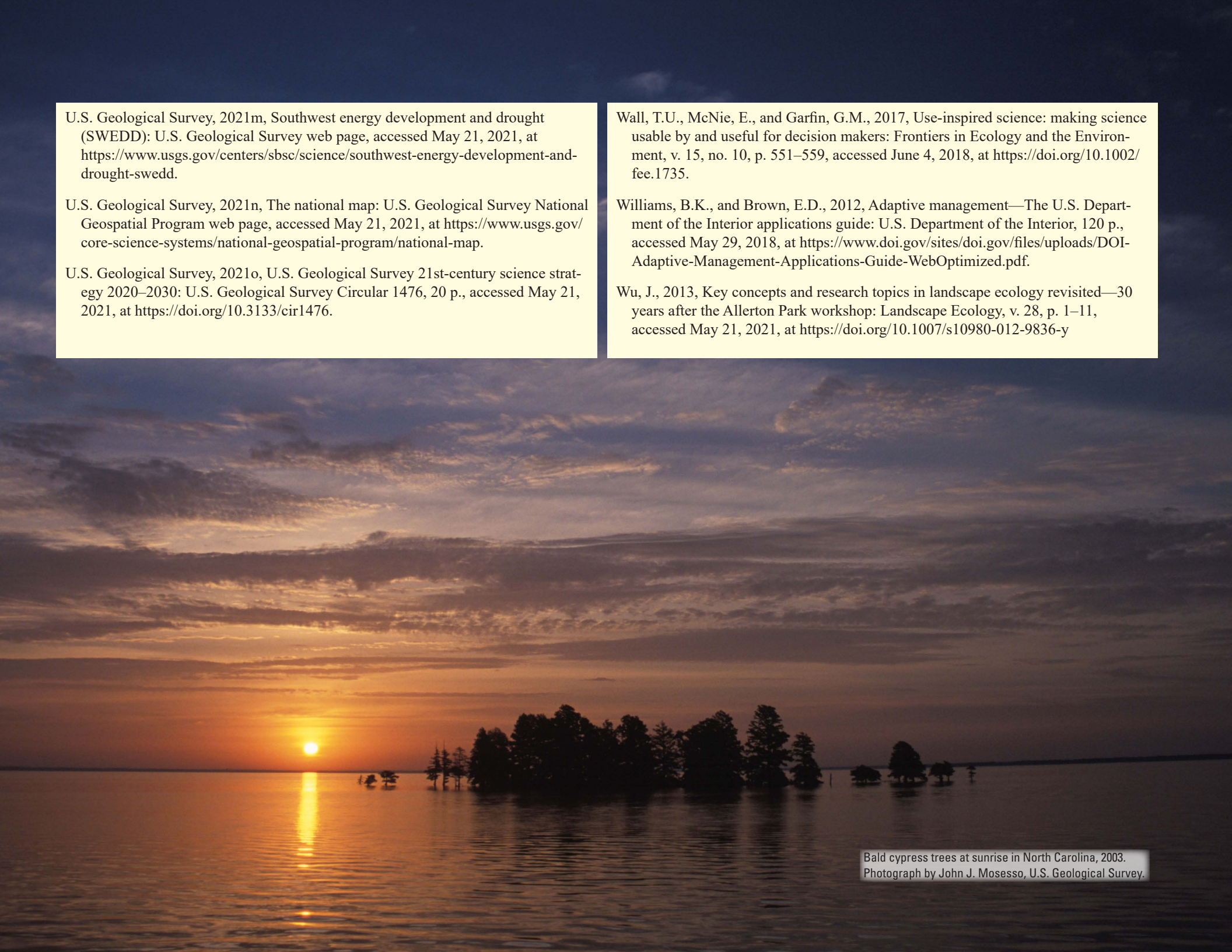

Bald cypress trees at sunrise in North Carolina, 2003. Photograph by John J. Mosesso, U.S. Geological Survey.

Back cover. Double rainbow over sagebrush country in the western United States. Photograph by Steve Hanser, U.S. Geological Survey.

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