Roadmap To Rangeland Monitoring:
How Do We Produce Actionable Data on U.S. Public Lands?

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Meridian Institute's Western Rangelands Data Initiative

Prepared By:
Kristin B. Hulvey, Ph.D. | Working Lands Conservation
Megan K. Nasto, Ph.D. | Working Lands Conservation

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About Working Lands Conservation

Working Lands Conservation is a trusted science partner with over nine years of experience co-creating monitoring programs with landowners, agencies, and grassroots collaboratives across the West. We specialize in producing meaningful, actionable science that supports land stewardship and enhances ecosystem health. Our work is grounded in relationships and guided by the belief that good science grows from collaboration, local knowledge, and a shared commitment to working lands. Whether it's soil carbon, plant diversity, or rangeland resilience, we help communities turn data into decisions.

About Meridian Institute and the Western Rangelands Data Initiative

Meridian Institute is a nonprofit consultancy that facilitates collaboration and the development of actionable solutions to complicated, often controversial problems -- big and small, global and local. Through the Western Rangelands Data Initiative, Meridian facilitates collaborative, multistakeholder engagement to advance data-informed solutions to enhancing ranch and rangeland sustainability in the West. WRDI is funded by the Walton Family Foundation and Conscience Bay Research.

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Takeaways

- **Commonly employed quantitative protocols have significantly improved the consistency and quality of rangeland monitoring data collection across the western U.S.**

- Not all data collection is undertaken across public rangelands for the same reason. Monitoring strategies are tailored to reach desired outcomes. For example, **monitoring for regulatory compliance or permit renewal on public rangelands does not guarantee collected data can inform adaptive management.** This is because monitoring to understand if land health standards are met doesn't necessarily require an understanding of the drivers of landscape health (such as grazing disturbance) or the explicit inclusion of these drivers into monitoring strategy (such as by including gradients of grazing duration or timing in monitored plots).

- **Actionable data that can inform adaptive management is generated when monitoring designs link management practices to landscape health outcomes**. When a manager's interest is to alter grazing practices, using a design that compares conditions under different grazing practices or compares conditions before vs after implementation of a new grazing practice will highlight how grazing disturbance affects landscape conditions.

- **Including a broad group of partners in the creation of monitoring plans ensures that the problems addressed, and the solutions developed are agreed upon, obtainable, and sustainable.**

Introduction

Monitoring Western U.S. Rangelands

Rangelands in the western U.S. span hundreds of millions of acres, covering a diverse array of ecosystems including grasslands, shrublands, savannas, and woodlands[1,2]. These landscapes are vital for supporting wildlife and human livelihoods[3,4]. They provide habitat for wildlife, sequester carbon, support biodiversity, and offer forage for livestock, which is central to the region's agricultural economy. Given their vastness and variability, rangelands play an essential role in both environmental sustainability and rural economies across the western U.S.

Managing these lands – especially when publicly-owned – presents environmental, institutional, and socioeconomic challenges. First, variability in climate, especially recurring drought, coupled with invasive species, overgrazing, and the growing frequency of wildfires, can degrade rangeland health in increasingly unpredictable ways [5,6,7]. Second, managers must navigate complex regulatory frameworks and competing land uses such as livestock production, energy development, recreation, and conservation[6]. Third, the desired outcomes of management often differ among stakeholder groups using the land [8,9]. For example, ranchers and ranching communities are likely to value economically viable grazing most highly, while federal managers may focus on conservation of wildlife habitat, and the public care most about fishing, hunting, and other recreational activities [4]. This diverse set of pressures requires a delicate management balance to ensure that all values – or ecosystem services – remain sustainable and productive across the vast rangeland landscape.

Monitoring is perceived as a tool to ensure public rangelands meet stakeholder expectations, both by cataloguing the attributes of a landscape under current land-use, and potentially highlighting when management change is required to reach management goals. Despite this, there can be a gap between collecting information about rangelands in a systematic way (aka monitoring) and using this information to alter management to reach management objectives. This gap has been the topic of countless conversations among rangeland stakeholders. Inevitably such discussions include someone asking: "**Can the management community create a monitoring protocol that will tell us all the important things we want to know about our rangelands, and will result in information that points us to the management changes we should take to improve rangelands the way we desire**?"

Well, the management community ***has*** created monitoring protocols -- a wide variety of them, with many created specifically for use on public rangelands. This fact inspired the following report. In this report, we review existing protocols, highlight the types of information they are designed to collect, and ultimately ask whether they result in 'actionable data' – that is, information collected through monitoring that links management practices to the ecological, economic, and social outcomes that different stakeholders value on rangeland landscapes.

A Roadmap to Rangeland Monitoring

This report examines whether existing rangeland protocols are helping practitioners learn what they want to know about their rangelands and leading to management changes that improve rangelands in ways wanted by stakeholders. It is also intended to provide information, resources, and guidance for private landowners, public lands managers, and scientists alike to monitor rangeland health to the most meaningful degree. Finally, this report will offer ideas about how to close the gap between collecting monitoring data and altering management on rangelands so that the effort invested in monitoring results in beneficial outcomes for landscapes and people.

To achieve the above goals, we used a multi-pronged approach.

1. We explored the history of rangeland monitoring in the US to understand how management goals on public rangelands have changed over time, how these various goals may have influenced the protocols used today, and the types of information these protocols produce (Section 1, Table 1).
2. We reviewed the most-used rangeland health assessment and monitoring protocols, summarizing their purpose, key attributes, strengths, and limitations (Section 2, Table 2, Appendix 1).
3. We interviewed experts in rangeland monitoring, many who had created and/or used the reviewed protocols throughout their career (Section 3, Figure 1). The goal of these conversations was to learn:
    - Why currently used protocols were created,
    - The context in which they are used on public rangelands,
    - Whether experts felt that these protocols were effective for gathering data,
    - If these protocols were producing information that led to actionable data.
4. We present three case studies that encompass important concepts learned through this exploration (Section 4).

Section 1: A Brief History of US Rangeland Monitoring

Monitoring protocols are often viewed as detailed, bias-free instructions that outline how to learn deeply about a landscape. Like a recipe, one might consider these instructions to be time-tested and complete. Monitoring protocols, however, include the worldview of those who create them. For example, they often contain implicit assumptions of how ecosystem processes work, which in turn forms a lens through which monitoring goals are framed and decisions are made about what is the important information to collect. Because of this, understanding the history of rangeland monitoring on public lands in the US provides a framework for understanding why the protocols currently used to monitor these landscapes provide the information they do, and what they might be missing.

The history of assessing rangelands in the western U.S. dates to the late 19th and early 20th centuries, when concerns of overgrazing and land degradation began to surface following widespread livestock expansion[10]. Early efforts to evaluate rangeland conditions were largely observational and subjective, often focused on livestock productivity rather than ecosystem functioning, thus assessing only one ecosystem service generated within these systems. The 1930s Dust Bowl underscored the urgent need for better land stewardship and led to the establishment of federal agencies like the Soil Conservation Service (now the Natural Resources Conservation Service [NRCS]), which began to implement more structured approaches to land management. By the mid-20th century, range condition assessments based on vegetation composition and deviation from a perceived ‘climax’ plant community became a dominant framework, though it often failed to capture the full complexity of rangeland ecosystems[8,11] (Table 1).

In the 1990s, a paradigm shift occurred with the development of more 'ecosystem’ based frameworks for evaluating rangeland health[12,13,14] (Table 1). Recognizing the limitations of earlier models, agencies such as the Bureau of Land Management (BLM), U.S. Forest Service (USFS), and the NRCS adopted new approaches that focused on three key attributes: soil and site stability, hydrologic function, and biotic integrity[15,16]. These indicators emphasized ecosystem processes rather than just plant composition, allowing for a more holistic understanding of rangeland conditions. State-and-transition model emerged from this new paradigm, with ‘climax’ and ‘reference states’ of plant communities still anchoring these ideas, but with inclusion of variation derived from management legacies, place, and fluctuations in climate[8]. This shift laid the groundwork for today’s objective-based monitoring systems, which aim to integrate scientific rigor with management relevance to support sustainable use of rangelands across the West.

Over the past 20 years, the rangeland management paradigm has been shifting again (Table 1). Rangelands are increasingly being recognized as socio-ecological systems – that is complex, integrated systems where humans and the environment are interconnected and mutually exert strong influence on each other[17]. This is an important framework with which to consider management of rangelands because it highlights that people not only use or conserve the ecosystem, but that they also have agency to manage for suites of ecosystem services based on their values and relationship with the land. Additionally, while management goals within the Climax- and Ecosystem-based rangeland frameworks were largely determined by the regulatory agencies that control public rangelands, the Ecosystem-Service framework includes the idea that local communities and other stakeholders who serve as both consumers and stewards of the ecosystem services generated on these landscapes have a place in deciding management goals.

Table 1. Attributes of rangeland management models that influence monitoring protocols, their implementation, and the potential of each model to generate actionable data. Models include: climax, ecosystem, and ecosystem service-based (modified from Chapin et al. 2009[20]; Bestelmeyer and Briske 2012[8]).

	Climax Model	Ecosystem Model	Ecosystem-Service Model
Model description	Rangelands are succession-based, with systems always moving towards a stable climax state	Several states are possible within rangelands based on historical management, site characteristics, climate, and threshold dynamics caused by human disturbances	Peoples' values and needs are a valid consideration when balancing the generation of rangeland ecosystem services and influence end-states in addition to site conditions and climate
Reference condition	Historic climax plant community	Historic climax plant community, including historical range of variation	Landscapes with optimized balance of desired ecosystem services
Role of people	To use rangeland resources	As protectors of historical baselines	As stewards, consumers, and managers of a balance of valued ecosystem services
Main ecosystem services managed for	Meat & fiber	Meat & fiber, existence value of species & habitats, recreation	Options vary by local community, and include elements that support the ecosystem, livelihoods, and communities
Science-management linkage	Top-down from management agencies	Top-down from management agencies	Top-down from management agencies, but with increasing input from local communities, through bridging institutions such as state government agencies, non-profit organizations, & extension programs
Respected knowledge system	Individual management experience & academic agricultural experiments	Agency career experience, academic multidisciplinary studies, ecological experiments (many reductionist)	Stakeholder experience (agency managers, ranchers, academic, nonprofit, Traditional Knowledge), collaborative group studies that co-produce knowledge, landscape scale tools (visual, statistical), cross-scale and non-reductionist studies
Monitoring goals	Monitoring is used to learn how far land has departed from climax state	Monitoring is used to assess characteristics and health of rangelands based on what is known about site characteristics and climate, and sometimes management and disturbances.	Monitoring is used to assess whether people are reaching their management objectives for rangelands that can include the generation of multiple ecosystem services

Ultimately, each rangeland management model generates a framework that guides monitoring (Table 1). For example, within the Climax Model, monitoring was used to determine how far rangelands had departed from climax states. Within the Ecosystem Model, monitoring focused on assessing rangeland characteristics and health, often over time (i.e. trend evaluation), and with consideration of how site characteristics and climate contributed to a range of possibilities of the current state.

The Ecosystem-Service Model has the potential to create actionable data in a way that previous frameworks did not. This is because this framework explicitly considers the value of ecosystem services to people in place, which shifts the goal of monitoring from simply assessing changes over time, to linking rangeland disturbances to ecosystem processes that generate valued suites of ecosystem services. Disturbances on rangelands can be human-caused such as via grazing or recreation, or alternatively can be driven by climate. Either way, linking disturbance to ecosystem service generation allows people to consider how management of disturbance can influence rangeland outcomes for ecosystems and people.

A Need for Actionable Data

"Management is the only thing that causes improvement, not monitoring."

- William Burnidge, The Nature Conservancy

While rangeland monitoring in the western U.S. has changed significantly over the past few decades, it doesn't always lead to actionable data. Actionable data is information that has been strategically collected, processed, analyzed, and contextualized so as to inform decisions, drive immediate action, or contribute to long-term management strategies.

Common reasons monitoring doesn't lead to actionable data are often covered in rangeland monitoring textbooks. First, rangeland ecosystems are ecologically and socially complex, making it difficult to identify straightforward and universal monitoring metrics. They include wide-ranging differences in climate, soil types, predominant vegetation, land use practices, historical development, and cultural influences [10,19]. All of these factors make universal conclusions about how to manage systems extremely difficult. Second, monitoring may be undertaken in ways that add error to collected information, resulting in data that cannot be used to understand the ecosystem, or understand it as precisely as required for one's purposes. For example, monitoring can be conducted inconsistently, at the wrong spatial and temporal scales, and lack clear objectives. Third, limited resources and staffing can hinder the ability of managers to collect, interpret, analyze, and communicate monitoring results. This can lead to an inability to use collected information for the implementation of necessary management changes.

Addressing these common monitoring weaknesses, however, does not guarantee that data gained through monitoring will be actionable. Rather, to gain actionable data, it is also vital to consider the factors that are leading to changes in rangeland health – that is the drivers of change. Some of these factors such as short-term weather, directional changes in climate, or loss of habitat due to development may be out of a manager's control. However, across rangelands, there are practices that a manager has the power to change through adaptive management. For example, when the driver of change is livestock grazing these practices might include: altering grazing timing or duration, or extending periods of rest from disturbance. By incorporating drivers of change into monitoring design managers can understand how they might change practices to achieve desired rangeland conditions.

A second, equally important factor to obtaining actionable data is recognition of the importance of social context when designing monitoring strategies and interpreting monitoring data. Including stakeholder values and desired management outcomes in monitoring discussions can lead to a restructuring of monitoring strategy so that the metrics measured, the allowed error, and the contributed resources all are geared toward collecting data with the precision and accuracy needed to link current management to current conditions. This will also ensure that any management solutions developed are supported and able to be implemented by all of those involved – from policy makers to on-the-ground managers. These solutions will be both possible and durable.

In short, actionable data is critical for adaptive management – and a key tool for sustaining the health, productivity, and resilience of rangelands in the West.

Section 2: Rangeland Monitoring Protocols & the Production of Actionable Data

Federal agencies responsible for managing public rangelands in the western U.S., such as the BLM and USFS, use a suite of protocols to assess and monitor rangeland conditions. These protocols are tailored to terrestrial, lentic (wetlands and springs), and lotic (wadable streams and rivers) systems, and are categorized by their function: qualitative assessments for rapid evaluations of condition; and quantitative monitoring for long-term data collection and trend analysis.

A primary use of these protocols on public rangelands is to evaluate whether landscapes meet land health standards. For instance, BLM staff may use AIM Strategy protocols to monitor sagebrush steppe habitat for sage-grouse, collecting data on vegetation composition, bare ground, and shrub cover to determine whether critical habitat is degrading. Similarly, the USFS might use MIM data to evaluate whether streams have stable banks, healthy stands of woody riparian vegetation, and assess in-stream pools and riffles for fish habitat. Qualitative protocols like IIRH and PFC are often used during rangeland health assessments or allotment reviews to rapidly identify areas not functioning properly or trending toward degradation, prompting more detailed, site-specific monitoring or changes in management. Ultimately, the data generated by these protocols are intended to inform regulatory compliance of land health standards created by agencies to guide the care of public lands. As such, these protocols play a critical role in supporting environmental analysis under the National Environmental Policy Act (NEPA), grazing permit renewals, and Endangered Species Act consultations by providing defensible, qualitative and quantitative evidence of land condition and trends.

Ultimately, these protocols also have the potential to generate actionable data that can inform adaptive management decisions. However, it is entirely possible that gathered data allows the determination of the attainment of land health standards, while at the same time, does not provide any guidance on how to change current management to improve ecological conditions. Rather, this requires monitoring that links drivers of ecological change to landscape conditions. This extra bit of information is only gained by explicitly including a gradient of different types of management in the monitoring design, or by performing before versus after studies of management change.

The following summary is meant to provide a very basic overview of public range and monitoring protocols. We have included a detailed list of protocols in Appendix 1 that includes: The system the protocol was created to be used within, the purpose the protocol as stated by the group that created it, the type of monitoring that occurs within the protocol, the scale of intended use, the ecosystem attributes measured, core methods employed by the protocol, and examples of use.

Qualitative Protocols

Qualitative protocols are primarily used for rapid, expert-driven assessments that are intended to help inform management objectives and prioritize areas for more detailed quantitative investigation. Such quickly executed protocols offer practical alternatives to resource-intensive quantitative monitoring, especially when working across large landscapes. This is especially true for the BLM given that they manage over 245 million acres across the western U.S.

These qualitative protocols are valuable because they can be implemented relatively quickly and without the need for specialized equipment or long-term datasets. They were developed to draw on the expertise and field experience of interdisciplinary teams, often including range specialists, hydrologists, soil scientists, and botanists, to holistically evaluate site conditions. The use of ecological site descriptions, which are expert-created descriptions of reference conditions for combinations of location, soil type, and vegetation composition, is meant to ensure that evaluations are grounded in an understanding of what constitutes proper functioning or healthy conditions for a specific landscape. While inherently more subjective than quantitative methods, these qualitative assessments were designed to be repeatable, systematic, and serve as an initial screening tool to identify management priorities, areas of degradation, or sites where monitoring efforts should be focused. These protocols are also meant to facilitate communication among land managers, stakeholders, and the public by providing a common framework and language for describing rangeland conditions.

Two examples of qualitative protocols are: Interpreting Indicators of Rangeland Health (IIRH) and Proper Functioning Condition (PFC).

- Interpreting Indicators of Rangeland Health (IIRH) – This protocol was co-developed by the Department of Interior's BLM and U.S. Geological Survey, and U.S. Department of Agriculture's USFS, NRCS, and Agricultural Research Service – is widely used for terrestrial systems and employs 17 indicators grouped under three attributes: soil and site stability, hydrologic function, and biotic integrity[14]. Examples of these indicators include plant community composition, presence of invasive species, litter distribution, and erosion patterns. Assessments are supposed to be conducted by an interdisciplinary team that compares current conditions against a defined reference state or ecological site description. While IIRH does not generate numerical scores, it is meant to guide management by identifying potential resource concerns and areas in need of further study or management action.
- Proper Functioning Condition (PFC) protocols are the counterparts to IIRH used in riparian environments, including both lentic (e.g., wetlands and seeps)[21]; and lotic (e.g., streams and rivers)[22] systems. Like IIRH, PFC assessments are team-based evaluations that focus on physical processes and ecological functions, such as bank stability, vegetation cover, hydrology, and sediment transport.

While qualitative protocols are valuable tools for assessing rangeland conditions, they have several limitations. Qualitative assessments rely heavily on expert judgement, which can introduce observer bias and inconsistency, particularly when training or experience levels vary. Because they are not quantitative, the protocols offer limited to no capacity for tracking changes over time or for supporting statistically robust analyses. Additionally, the protocols focus exclusively on ecological indicators of rangeland conditions, omitting socioeconomic, cultural, and land-use factors that are integral to a comprehensive understanding of health. The site-specific scale of the assessments also limits the protocols' ability to capture broader landscape or regional dynamics, and their reliance on static reference conditions may not adequately reflect evolving environmental realities such as climate change or novel ecosystems. Furthermore, the protocols do not directly evaluate the outcomes of management practices, reducing their usefulness for adaptive management or for tracking progress towards specific objectives and goals.

Quantitative Protocols

Quantitative monitoring protocols are meant to be used to collect standardized, repeatable measurements over time, supporting data-driven evaluations of rangeland trends and the effectiveness of management actions. When implemented over multiple years these protocols can track progress toward management goals and regulatory standards, and they are frequently integrated with qualitative protocols when used by Federal rangeland managers, to form a more complete picture of rangeland health. The ability to quantify change and test hypotheses about management effectiveness makes quantitative monitoring essential for accountability, planning, and long-term stewardship of rangelands.

Two example quantitative protocols are Terrestrial Assessment, Inventory, and Monitoring (AIM) and Multiple Indicator Monitoring (MIM).

- Terrestrial Assessment, Inventory, and Monitoring (AIM): The Terrestrial Assessment, Inventory, and Monitoring (AIM) Strategy, created by the BLM but used by a number of federal agencies, was designed to provide a national consistent framework for collecting high-quality field data [23]. AIM focuses on core indicators such as vegetation canopy and ground cover, soil surface stability, plant species composition, and vegetation height, often paired with geospatial data like remotely sensed imagery. These indicators were selected to be sensitive to land management actions and ecosystem changes, allowing for statistically robust comparisons over time and across broad landscapes. The AIM Strategy emphasizes consistent methods, rigorous training, quality assurance / quality control to ensure data reliability, and the results are used in land health evaluations, adaptive management plans, and Environmental Impact Statements.
- Multiple Indicator Monitoring (MIM): For riparian systems, particularly lotic environments, the Multiple Indicator Monitoring (MIM) protocol provides a complementary quantitative approach[24]. The MIM protocol was designed to assess the effects of land uses such as livestock grazing on streambank stability, vegetation cover, woody species regeneration, and greenline composition over time. Unlike qualitative assessments, the MIM protocol is meant to use permanent transects and standardized measurements, such as stubble height, bank alteration, and woody species age-class structure, to detect ecological trends with statistical rigor. These data were chosen to support decision-making in grazing management, permitting, and habitat conservation.

These quantitative protocols, especially the AIM family of protocols, have significantly improved the consistency and quality of rangeland data collection across the western U.S.

At the same time, the large resource requirements for implementation can introduce obstacles in gathering wanted spatial and temporal coverage of data.

Using Protocols to Generate Actionable Data on Public Lands

Ultimately, it is possible for data collected using existing qualitative or quantitative protocols to be actionable. But, solely monitoring for land health compliance does not always lead to the production of actionable data that informs adaptive management. For monitoring to be successful for this purpose protocols will need to: (1) include metrics that can answer questions of interest for adaptive management goals, (2) are employed spatially and temporally at the scales needed to inform management concerns, and (3) include a measurement of the management practice being evaluated as affecting ecosystem health.

Employing protocols in this way will require involving more stakeholders in the process of setting goals, choosing metrics, and interpreting collected data. This idea has been recognized within both the federal agencies that monitor rangelands, as well as groups eager to partner with federal agencies to help create such actionable data. For example, in 2017 the BLM announced the Outcomes-based Grazing Authorizations Initiative, which was created 'to offer a more collaborative approach between the BLM and its partners within the livestock grazing community when issuing grazing authorizations.'[25] This led to 11 demonstration projects in six states established to link monitoring on rangelands to adaptive management. The Initiative's goals align with the Ecosystem Services Model of rangeland management, by emphasizing not only ecological but also economic and social outcomes of management and incorporating cooperative management of public lands. [26]

A second partnership between the BLM and the Intermountain West Joint Venture also focuses on collaboration among diverse partners (federal agencies, state fish and wildlife agencies, private landowners, Tribes, and the energy industry). Established in 2016, this partnership has evolved through successive intra-agency agreements (2016, 2019, 2023), with commitment to growing field-level support, increasing communications, and enhancing science delivery and technical transfer of science, actions that all increase the opportunity to produce actionable data for management [27,28]

A thorough review of these programs is beyond the scope of this white paper but would greatly enhance findings. For now, we provide a list of external resources for additional review (Table 2) and acknowledge the importance of adding information about lessons learned from these programs into future drafts.

Table 2. List programs and projects that are exploring the creation of actionable data on public rangelands

Program/Project	Description	Resources
Outcomes-based Grazing Authorizations Initiative	Internal BLM Program: Designed to offer a more collaborative approach between the BLM and its partners within the livestock grazing community when issuing grazing authorizations.	- https://www.blm.gov/press-release/blm-announces-outcome-based-grazing-projects-2018 - https://www.blm.gov/programs/natural-resources/rangelands-and-grazing/livestock-grazing
Partnering to Conserve Sagebrush Rangelands	Partnership with Intermountain Joint Venture: Executed through five-year Intra-Agency Agreements that focus on work to manage habitat for healthy wildlife population, reduce wildfire risk and hazardous fuels, and expand efforts within priority watersheds across the West.	- https://iwjv.org/habitat/sagebrush-rangelands/ - https://www.partnersinthesage.com/blog/2023/fueling-conservation
Winecup Gamble Complex Grazing Project	This is one of the projects within the BLM's Outcome-based Grazing Authorizations Initiative.	- https://www.partnersinthesage.com/blog/outcome-based-grazing-winecup-gamble

Section 3: Monitoring Management Outcomes: Expert Insights

If protocols can be likened to recipes, undertaking monitoring is akin to being a chef. It takes years of practice to learn the subtleties of how slight differences between metrics, methods, and in-field decisions contribute to a body of data that can tell a landscape's story. Because of this, we interviewed a group of highly skilled rangeland ecologists and managers to learn from their years of experience authoring, using, and altering rangeland protocols, including some of those listed in Section 2 and Appendix 1.

We began conversations by asking experts about their experience with monitoring, touching on the protocols they had used. We asked about their intentions for monitoring, including whether a goal was to produce actionable data and if the data produced was indeed actionable. We asked what prevented their data, or other data they've seen collected, from being actionable and how to solve this problem. Finally, we asked for a list of the most important steps when conducting rangeland monitoring for actionable data. Beyond gaining insight on the above ideas, these conversations were intended to capture the wide array of experiences across the careers of interviewed experts.

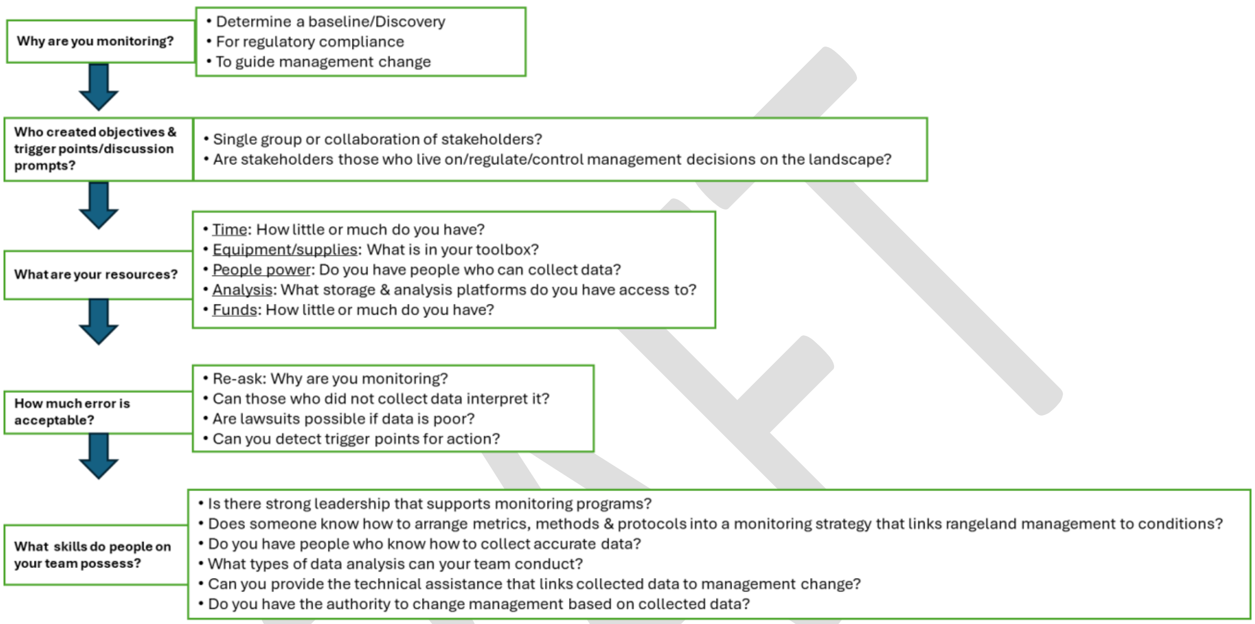
What is Necessary to Collect Actionable Data?

In each conversation, experts presented salient perspectives and experiences that have been gained across a career of monitoring western rangelands. They stem from times when interviewees ended up with data sets that were either fantastic or worthless (yet equally informative). They also highlight considerations and suggestions for the collection of actionable data. We summarize these ideas below in Figure 1, and accent them with quotes in the following sections.

A number of foundational concepts repeated in multiple conversations form a trove of advice for anyone developing a monitoring strategy or creating a monitoring protocol.

While they are often the same foundational ideas found in excellent monitoring texts[29, 30], having experts call them out drives these concepts home. We outline these concepts in Figure 1 and tie them to additional considerations when a goal of monitoring is to collect data that can inform management change.

Figure 1. Key considerations when designing a monitoring strategy for actionable data, created by Working Lands Conservation with insights gained from Expert Interviews.



Get Clear About the Goal of Data Collection

A fundamental starting point in any successful rangeland monitoring program is being clear about the purpose of data collection (Figure 1: Box 1). Not all data collection is undertaken across public rangelands for the same reason. Three common goals when monitoring include:

- **Determining baseline condition and/or Discovery** - At times the main goal of data collection is to learn about a place and landscape. This may include collecting information on any number of metrics, including species composition, ecosystem health, ecosystem functioning, diversity, soil type, to name a few.
- **Regulatory compliance –** Land management agencies, like the Bureau of Land Management (BLM) and the U.S. Forest Service, have a responsibility to monitor public lands for regulatory compliance. This includes ensuring that land use authorizations and permits adhere to relevant laws and regulations, including those related to environmental protection, public health and safety, and resource

management. Many of the protocols reviewed for this report are used to meet this requirement.

- **To inform management change** – Monitoring to inform management change requires the ability to link management practices to rangeland conditions. It thus includes thinking about the effects practices have on rangeland attributes and processes of interest and then identifying metrics that capture these effects.

Once the overall goal of the study is clear, a second decision is whether to collect data once or to collect information repeatedly over time.

- **Assessment** refers to gathering information to understand the current condition of a site at a single point in time, e.g. plant species composition, amount of bare ground, or streambank stability. It offers a snapshot that helps land managers evaluate current status but does not reveal how conditions are changing.
- **Monitoring**, on the other hand, involves repeated measurements over time, enabling the detection of trends such as vegetation recovery, invasive species expansion, or habitat degradation.

While assessments are valuable for determining baselines, for discovery, and potentially for compliance, only monitoring can demonstrate whether management actions are achieving desired outcomes or if conditions are improving or worsening. Because of this, informing management change usually requires monitoring rather than assessment.

An additional nuance lies in whether collected data is being used to detect trends or to compare conditions to a defined reference – such as an ecological site description or a historic benchmark.

- **Monitoring for trends** focuses on directional change over time, regardless of where a site sits in relation to an ideal or reference state.
- **Reference-based comparisons**, in contrast, assess how closely a site matches what is expected for a healthy or functional system, without necessarily revealing whether the site is improving or declining.

"To do an assessment to say something is healthy (e.g., Rangeland Health Assessment), you need a standard of comparison to do this. Whatever vegetation metric you use had better match up to what your standard of comparison is going to be. In rangelands, a really common standard to use is an Ecological Site Description."

- Shane Green, Retired NRCS, National Grazing Lands Team

Establish Objectives & Trigger Points -- Preferably with those in charge of management

All rangeland monitoring efforts must be guided by clear, well-defined objectives (Figure 1: Box 2). Collecting data for its own sake is not only inefficient, but it can also lead to large datasets that provide little insight into actual management needs. Without specific questions to answer—such as whether grazing practices are sustaining perennial cover or whether streambank vegetation is recovering post-restoration—monitoring efforts risk becoming an unfocused drain on agency and stakeholder resources. Even worse, implementing large-scale protocols simply because they are institutionalized or widely used, without adapting them to local questions and conditions, can result in data that fail to address the most pressing questions on the ground.

- **Monitoring objectives** clearly state what is being measured (e.g., a priority species, population, process, ecosystem characteristic), a selected scale (location), a sensitive attribute and direction of change (e.g. bare ground is increasing), a value of change that indicates when a trigger point is crossed (e.g., by 10%, doubled) and time frame of change (e.g., annually, every three months, every 5 years)[29]. Effective objectives thus help define not only *what* data to collect, but also *why* and *how often*. They prioritize limited resources, focus fieldwork, and guide decisions on sampling design, frequency, and indicators.

For monitoring efforts to additionally produce actionable data, objectives need to include guidance on when a change in management needs to occur. This is done by identifying thresholds in monitored conditions that trigger management changes (Figure 1: Box 2).

- **Trigger points** are agreed upon thresholds that when crossed, spur rangeland managers to adjust management. Their existence ensures that managers shift from data collection to action. Without these, groups have noted that they have gotten stuck in an endless cycle of data collection. Knowing when to act can save limited resources and prevent conditions from degrading.

Example of a management objective, trigger point, and management response:

- <u>Management Objective</u> - Maintain <20% cheatgrass cover in pasture each year.
- <u>Trigger</u> – Cheatgrass cover increases to 20% this year.
- <u>Management Response</u> - Initiate chemical weed control the following field season.

Multiple interviewees highlighted that collecting actionable data is more effective when Objectives and Trigger Points are developed collaboratively with input from managers, specialists, and stakeholders. One expert called Trigger Points: '*Discussion Prompts*', which creates an expectation that in collaborative groups these points are moments of discussion among teams about the need for adaptive management. Co-development of these aspects of monitoring ensures efforts produce actionable information tailored to these groups' values, resources, and ultimate management goals.

"I noticed at one wet meadow site that tamarisk was increasing. This is a flag to start treatment. Once that is done then we are hoping to see willow spread. This [the increase in tamarisk] is the discussion prompt and will instigate a conversation about management and monitoring."

-- Jan Reinhart, Utah Department of Agriculture & Food's Grazing Improvement Program

Allocate Monitoring Resources Wisely

Many people we spoke with highlighted that some monitoring is better than no monitoring, but that bad monitoring is a waste of time. This is especially true for data intended to inform changes in management. Many of the protocols we reviewed in Section 2 and Appendix 1 are comprehensive and complex. We spoke to agency managers who noted that implementation of these took lots of people power to collect, curate, and analyze. This is by no means a problem only faced when using these Federal Protocols. Three of the managers we talked to from non-federal organizations called out these same resource limitations (Figure 1: Box 3). Some of these managers noted that, at least within some of their projects, they had not yet been able to collect second rounds of data (and thus cannot yet examine trend). While this isn't bad monitoring, it does prevent the ability to find trigger points and make decisions that can lead to adaptive management.

One way interviewees suggested bringing data collection more in line with action was to decide how much error is acceptable before the information can no longer be used for its intended purpose (Figure 1: Box 4). There is no doubt that public land monitoring protocols are created to surpass the very high bar of standing up in court if litigated. In these cases, resources need to be dedicated to collecting data that tells a detailed story about the monitored landscape. However, when the standard is not to withstand litigation, there may be many opportunities to use simpler methodologies. For example, what if the goal of monitoring is to learn whether bare ground is increasing in a pasture, and use that information to decide if a grazing practice should be changed? As one interviewee noted, it is likely that walking with the rancher across the pasture each year and counting how many steps end on bare ground will suffice. "Collecting this amount of data each year is better than having the rancher collect data once and never do it again…' due to a complex protocol[18].

Know the Power of the People on your Team

The success of any monitoring program depends on having people on your team that can get the job done (Figure 1: Box 5). This includes people with the scientific skills to design a monitoring plan, collect data, and curate and analyze it. However, there are also a number of roles that become important if we want monitoring to lead to actionable data. These include those with skills to facilitate conversations among diverse stakeholders who value different uses of public rangelands, to lead collaborative monitoring efforts including creating common objectives and trigger points, and to ensure monitoring consistency – whether that is as a strong leader in a government office or a rancher who is leading stewardship on their landscape.

When leadership treats monitoring as an afterthought or burdensome obligation, it often results in patchy implementation and limited use of the data. Conversely, when leadership supports monitoring as a critical tool for adaptive management and accountability, it fosters a culture of continuous learning and stewardship. Agencies that succeed in using monitoring effectively are almost always those where leadership has invested in it as a strategic foundation for land management.

-- Summarized from interview with Pat Fosse, Retired BLM Assistant Field Manager, Dillon MT & UT Fillmore Field Offices

Two additional skill sets that are not always included on monitoring teams include folks with technical knowledge that know how to implement management changes and people with the authority to make management decisions. For the most part, the Ecological Model of range management has led to monitoring to understand rangeland environmental characteristics. However, if the interest is to create actionable data, we will need people at the table that know not just how new management might improve ecological conditions, but also those who know which management options are feasible for ranchers/managers to implement, and then can help design those systems.

"I guarantee if you took the average rancher out and drove around on an allotment, and asked ... 'If you owned this, how would you manage this differently.' They would have specific ideas – for example, changes to permit limitation, changes to water systems, or changes to seasonal cattle movement."

- William Burnidge, TNC

Finally, because changing management on public lands is constrained by policy hurdles, such as NEPA, threat of litigation, and institutional inertia stemming from historical ways of managing and conflicting values and interests for land use within agencies, monitoring data is most likely to be actionable when decision makers in regional public rangeland management offices want this as an outcome.

Create Data that is Trustworthy

Trustworthy data is often defined as data collected consistently, reliably, and without bias. The agencies who have created protocols used for public rangeland monitoring have worked hard to ensure data meets this definition (See case study #1). The reviewed protocols have clear methods, detailed standard operating procedures, and robust training programs. A side effect of creating protocols able to collect this kind of trustworthy data is that they are comprehensive, and thus also complex. This in itself can lead to inconsistently collected data due to lack of knowledge of how to use protocols correctly. To counter this, agencies invest in preparing technicians, seasonal crews, and contractors to use protocols correctly and interpret indicators accurately.

In our conversations with rangeland experts, many pointed out that data also needs to be trustworthy in a different way. That is, it needs to be trustworthy to the people being asked to make management changes. Changing grazing operations requires a burden of proof that can convince a rancher/manager that the effort to change management and the funds it will likely require (e.g. added fencing, water troughs, range riders, virtual collars) will produce a result better than the status quo.

"[Monitoring] methods should be very targeted to the social aspects of monitoring. Monitoring has to change management action. It is a cascading connecting of dots for me, for you, and for all of us. Protocols that help people learn and meet people where they are, are important, as are protocols that include the people who will make management decisions and aren't too complex for people to participate in."

-- James Rogers, Northway Ranch Services

Two interviewees highlighted that including ranchers/managers in the process of developing monitoring plans and protocols can help to make data trustworthy. Some suggestions to do this included: incorporate these groups' ideas about what needs to be learned from monitoring into monitoring plans, work together to decide upon trigger points, and work together to outline potential management action that would result from reaching a trigger point (See case study #2). They additionally noted that working together to share knowledge of patterns on the range, to link them to past management, and using the process of deciding what to monitor together was a way for all members to ‘connect the dots’ between management and land condition. For example, one respondent noted:

“I always ask folks I’m working with: ‘What do you think here? Why did we come to this site? What’s your objective?’ Then we will monitor it. When ranchers participate in the monitoring, they are intuitively thinking about the monitoring, because they were there. Through this process they get excited about ongoing conditions.”

-- James Rogers, Northway Ranch Services

It is worth noting that there are not many examples of collaborations between federal agency staff and ranchers working together to develop monitoring plans on rangelands, but see discussion of the BLM’s Outcomes Based Grazing Authorization Initiative and the BLM’s partnership with IWJV on pg 15 and Case study #3. From our conversations with experts, this appears to be due to the need of Federal Agencies to monitor for compliance rather than explicitly for management changes that could lead to improved compliance. In a sense, Agency Staff are working to take snapshots of current conditions on rangelands to make decisions on grazing plans and permit renewals. This type of activity may be a one-time assessment, or if a study has been set up in a field office, there may be repeated measurements over time. At times, however, the monitoring protocols used do not incorporate any gradient of grazing practices, or comparison among sites with different grazing practices that would truly allow managers to link current state to grazing practices.

What Hinders the Production of Actionable Data?

While our interviews highlighted key aspects of monitoring that can lead to actionable data, they also revealed a series of factors that prevented its creation. We briefly list these insights below.

Fear of Unfavorable Outcomes

A subtle but significant barrier to effective monitoring is the fear of what the data might show[18]. In some cases, managers or stakeholders may worry that monitoring results will reveal trends inconsistent with desired outcomes or policy goals, for example, evidence of habitat degradation or grazing-related impacts. This nervousness can lead to reluctance to collect or share data, particularly if there is concern that negative results could trigger regulatory consequences, public scrutiny, or restrictions on land use. In some instances, this can discourage participation from permittees or lead to avoidance of monitoring altogether, undermining transparency and the potential for science-based adaptive management (See case studies #2 and #3).

Misalignment Between Protocols and Management Objectives

Effective monitoring depends on alignment between the protocol being used and the specific management objectives it is meant to inform. However, this alignment can be lacking. Managers may be required to use protocols designed for broad-scale inventory when what they really need is fine-scale data for site-specific decisions. Questions to help guide protocol selection include: Who is the intended audience for the data? Are the protocols designed to be actionable at the field office level, or are they primarily for regional or national reporting? And, what level of error or uncertainty is acceptable for the decisions at hand? When these factors are not explicitly addressed, monitoring efforts risk becoming exercises in data collection without clear purpose or utility, wasting valuable time and resources.

Institutional Constraints and Protocol Rollout

Monitoring protocols like the BLM's AIM Strategy were developed to bring consistency and scientific rigor to rangeland monitoring across large administrative areas. While these institutional protocols are valuable for ensuring standardized data collection, they also come with rules and constraints that can limit their flexibility. For instance, national protocols may specify fixed indicators, methods, or plot layouts that are not well aligned with local management questions. As a result, the data collected under such protocols may not always be usable or interpretable at the scales most relevant to field offices or on-the-ground managers. This top-down approach, while well-intentioned, can reduce the utility of the data for site-specific decision-making and slow adoption if local managers do not see how it informs their work (See case study 1).

Protocol Drift and Change Over Time

Another challenge is that protocols themselves often change over time as science evolves, technology improves, or agency priorities shift. While such updates are necessary to reflect the best available science, they can lead to discontinuities in datasets and complicate long-term trend analysis. Subtle changes in sampling methods, indicator definitions, or data handling procedures can make it difficult to compare new data with older records, reducing the ability to track ecological change across years or decades. Agencies must carefully manage these transitions, providing documentation, training, and data translation tools to ensure that trend detection remains robust and defensible.

Lack of Knowledge of Local Ecosystems and Communities

Finally, effective interpretation of monitoring data requires ecological understanding—of the local system and of the relationship between indicators and management outcomes. A number of factors can hinder this knowledge retention. First, many federal land managers and biologists rotate through positions or locations every few years, which makes it difficult to develop long-term ecological insight. It takes time to understand how a particular ecosystem responds to grazing, weather patterns, fire, or restoration, and how these drivers interact to affect plant communities, soils, and hydrology. It also takes time to build trust with local ranchers and other public land users who may have been working on management projects with previous federal land managers. When land managers rotate, this social trust and local knowledge is lost. Second, identifying a well-balanced suite of indicators that can reliably track trends over time is a skill developed through experience, iteration, and deep engagement with the land. Without this continuity, even well-executed monitoring may fall short of its full potential to guide sustainable management.

Section 4: Case Studies

The goal of the following case studies is twofold.

Case Study #1 is an examination of one of the most well-known groups of Federal monitoring protocols used on public rangelands – The Assessment, Inventory, and Monitoring (AIM) Protocols. These protocols are widely used, and to some extent have replaced others as Agencies have moved from qualitative protocols to more quantitative protocols. As such we were interested in understanding whether these protocols are being used within the Agencies to produce data that can inform management, and if not, how they might be used to do so.

Case Studies #2 and #3 highlight key concepts introduced in Sections 1-3 of this report. Each shares the story of a collaborative group monitoring public rangelands to inform adaptive management. They highlight key, and sometimes subtle, decisions that helped to create a monitoring strategy able to produce actionable data that can inform adaptive management.

(1) **Can the AIM family of protocols result in actionable data?**

Concepts: *Monitoring goals, Resources, Error*

To be added upon further expert review

(2) **La Sal Sustainability Collaboration**: Co-creation of monitoring plans

Concepts: *Monitoring goals, Objectives & Trigger points*

The La Sal Sustainability Collaboration (LSSC) provides an example of a stakeholder group collecting actionable data across a large public-private landscape (115,300 ha) in the southern Utah La Sal Mountains and adjoining lands. Established in 2014, the purpose of the Collaboration was to co-create an approach to management where federal, state, and private lands are operated as an integrated, sustainable system. The landscape of interest included private and public lands managed by the BLM, USFS, and the Utah School and Institutional Trust Land Administration (SITLA). The group was co-convened by the Utah Grazing Improvement Program (UGIP) and the Grand Canyon Trust (GCT). Other consensus-seeking members of the LSSC included San Juan County, the Sierra Club (SC), Trout Unlimited (TU), the UT Division of Wildlife Resources (DWR), and livestock operators.

By aligning stakeholder goals, the LSSC created a partnership able to adapt to challenges on the landscape. By co-developing key aspects of their monitoring protocol, they have been able to use collected data to inform management changes.

Monitoring Goals: The monitoring plan intentionally included not only ecological goals, but also social, economic, and administrative goals. The group's recognition that these four aspects of rangeland management all need to be addressed to reach desired landscape outcomes was key to the group's success.

Objectives & Trigger Points: For each ecological, social, economic, and administrative goal, the LSSC team co-identified: ***Issues, desired conditions, indicators, and discussion prompts***, that is, they together determined:

- What are the objectives and issues associated with each goal?
- What are the desired conditions?
- What are the indicators we can use to assess conditions?
- What are the prompts we will use to make us step back and discuss what we are seeing?

The group took this approach for a number of reasons. First, the team leaders realized that monitoring can be abstract, that is, it is not always clear how metrics used for monitoring are linked to desired management outcomes. Within the LSSC, there was a need for everyone to know what each party within the collaboration wanted to accomplish (i.e., Outcomes) before they could think about how to measure them. Critically, during this process, it was recognized that ecological goals were expressly tied to social and economic goals – that is the landscape health hinged on the values of ranchers and managers, needs from landscape use, resources each group could bring to the table, and the ability of the team to carry out management and monitoring. As such, co-creation of metrics and outcomes extended to social needs, economic goals, and administrative requirements.

The group also tackled the co-creation of prompts that would initiate group discussion and action. The identification of landscape characteristics that were negative or positive (triggers), and the moment when action was required was a process of learning how others interpreted landscape changes, and their thoughts on how management actions could affect such changes. This co-creation resulted in a shared understanding of management practices and landscape condition that reached beyond any single stakeholder groups' personal experience. To reach agreement, the group spent time in person and on conference calls nailing down goals, objectives, desired conditions, and barriers to reaching these.

Importantly, this co-creation process addressed risks perceived by different people on the team. For example, the ranchers expressed nervousness about the monitoring results highlighting current management practices leading to poor landscape conditions, particularly on Federal lands where such a finding could lead to regulatory action. By including everyone in the process of determining *Objectives* and *Trigger Points*, the team built trust, and established the belief that the monitoring would be used to create a record of what landscape health was, and point the team toward changes as needed to fix problems that were identified by everyone as important.

Ultimately, the LSSC, used the ***Issues, desired conditions, indicators, and discussion prompts*** framework to build a monitoring plan. Below we give an example for one aspect of the plan focused on desired ecological outcomes:

- What are our objectives and issues? - Objective = create ***ecological resilience*** across the landscape; issue = ***watershed health*** needs to be maintained
- What are desired conditions? - Stable soils
- What are indicators of stable soil? - Percent bare ground
- What are prompts for discussion? - Is bare ground increasing with subsequent data collection? If yes, discuss what the cause is and figure out what we can do to mitigate this increase.

How has the '*Issues, Desired Conditions, Indicators, and Discussion Prompts'* framework led to collection of actionable data within the LSSC?: Use of the framework resulted in a high level of communication among stakeholders, facilitated knowledge sharing and co-definition of landscape health, and led to co-recognition of trigger points that indicate when conditions are degrading. The agreement to discuss needed changes in management when triggers were encountered also directly ties monitoring to ongoing co-development of management practices (i.e., adaptive management).

Co-production of LSSC objectives additionally led to the group's adoption of management tools that facilitate wanted outcomes. For example, in 2022, the group began to explore how virtual collars might help with cattle movement, a factor identified as affecting many desired landscape outcomes. The implementation of this technology required an agreement among LSSC members of its utility, a gathering of resources, and a dedication of time by multiple partners to deploy and monitor its use.

Finally, it is also important to note that while there is no doubt that the co-production monitoring framework is a foundation of the LSSC's success, LSSC members also identified other elements of their partnership as vitally important for project success. These include:

- Ongoing resources for sampling and data analysis– UGIP provides ongoing funding and person power to complete ongoing monitoring,
- Participation by a facilitator early in the process to help bridge gaps among the members of the LSSC,
- Active participation of the operations who move cattle across the landscape, and
- Engagement by organizations who have the power to make decisions about management changes.

(3) **The Three Creeks Grazing Project:** A new model for public lands monitoring

Concepts: *Monitoring goal, Resources, Skills*

The Three Creeks Grazing Projects provides a second example of a stakeholder group collecting actionable data across a large public-private landscape (56,000 ha) in northern Utah. The Three Creeks Grazing Project is a result of litigation over livestock grazing on BLM lands that threatened economic stability for producers due to potential restriction of grazing. In response, starting in 2011, permittees sought management options to ward off further litigation. They collaborated with state and federal agencies (BLM, US Forest Service, UDAF, UGIP, and SITLA) through an 11-year process to develop a management system on public-land allotments that balances livestock grazing with other rangeland ecosystem services. Producers patterned the grazing system after that used by a local private ranch, which grazes herds in pastures for shorter durations than employed on public lands. This shorter-duration grazing allows for rest, regrowth, and recovery of the rangelands. The resulting Three Creeks Grazing Allotment Consolidation Plan required grazing authorizations to be renewed under NEPA. The Plan involves consolidating 10 public-land allotments plus some of permittees' private lands. It combines permittees' livestock into two herds, which will be rotated across the consolidated-allotment landscape using shorter grazing durations and shifting the timing of grazing in pastures each year. Working Lands Conservation (WLC) has worked with Three Creeks Grazing, LLC, and UGIP over the past seven years to study how this innovative grazing system might improve water quality, forage, and sage-grouse habitat.

Monitoring Goals: Because the Three Creeks Grazing Project is situated on Federal lands, Federal agencies conduct regular monitoring. The BLM employes AIM protocols, while the Forest Service uses XXX. Beyond this Federally led monitoring, which occurs on all Federal Allotments, and is led by the Ecological Assessment that was part of the NEPA, there is no other written strategic plan for monitoring.

A strong group of partners, however, has worked together over the past eight years to conduct additional monitoring. This includes the permittee ranchers via a rangeland consultant for rangeland use, by UGIP who does herbaceous vegetation surveys every five years, and by Working Lands Conservation (WLC), who is a local research nonprofit. WLC has worked in partnership with all stakeholders to monitor water quality (E. coli, dissolved oxygen, temperature, pH), riparian health (Multi indicator Monitoring [MIM]), vegetation recovery in riparian corridors, Greater sage-grouse habitat within riparian corridors, biomass production within riparian corridors, soil health, and soil carbon sequestration. Additionally, WLC in worked with the local community to gauge the social effects and economic consequences of the project through a series of surveys, interviews, and budget analyses.

The extent of monitoring and the monitoring goals across the Three Creeks landscape have evolved over time. Before the grazing switch the local BLM office collected information across the site using a variety of protocols including AIM and MIM. UGIP began to collect data extending back to 2015 and has been a firm partner with the ranchers throughout the NEPA process upon creation of Three Creeks. Working Lands Conservation joined the partnership in 2016, first collaborating with BLM managers to help collect data using pre-established monitoring, and later adding additional methodologies and sites to align data with grazing practices across the landscape. After several years of working in the area, WLC scientists and the local ranchers built a trusting relationship (facilitated by UGIP), and as a result, WLC expanded monitoring to meet the expressed needs of the ranchers -- including learning more about soil health and soil carbon sequestration. All data work together to examine whether the new Three Creeks Grazing Plan is improving conditions on the BLM landscape.

The partners monitoring Three Creeks rangelands have a variety of goals, some overlapping, some unique. For example, the BLM and FS need to ensure that land is meeting land health standards within the new grazing system. This is no different to what they are required to do with all of the lands they manage. The ranchers are interested in making sure the new grazing system is producing forage for their livestock. WLC's monitoring goals are guided by relationship with all partners. They aim to help the BLM understand if the landscape is meeting land health standards for compliance obligations, and also if the new grazing system is resulting in landscape conditions that can benefit ranchers' operations. Because WLC is a research nonprofit, they also are examining the systemic outcomes of implementation of this innovative grazing system across a large landscape. If these grazing practices are successful in balancing cattle production with generation of diverse ecosystem services across a large, public rangeland, it could serve as a model for other public land managers hoping to implement innovative grazing practices on public rangelands. This final goal is consistently grounded in the values of the local community so that the information gained through this type of work is valuable for adaptive management.

Resources: Once the NEPA was approved for the Three Creeks Grazing Project, it cost about $5M to add infrastructure to change the grazing across the landscape. We do not have a tally of how much the BLM, FS, or ranchers has spent monitoring. WLC has spent about $3M over the past 10 years (inclusive of all salaries, supplies, travel, analyses) gained through a mix of USDA research grants and BLM cooperative grant funding. The WLC budget includes time to attend group and one-on-one meetings with all partners, share research results, and have discussions about what else people want to learn across the landscape. This is a total of about $60/acre over the 10-year project.

Skills: This large amount of funding for research, paired with lots of communication of goals, results, and ideas of what to study next undoubtedly is more than many projects have at their disposal. It, along with the unique group of people within the partnership including the ranchers (cattle mangers), BLM & FS (land regulators), UGIP staff (project champion with access to funding and political capital) resulted in a group that had the ability to: Ask questions about the role of innovative management (whole team), answer them through on the ground data collection (WLC), put ideas from adaptive management in front of those that had the power to make management changes (federal agencies, ranchers), and find funding to make ongoing management changes (UGIP, BLM). As such a key element that has led to the success of the Three Creeks Project producing actionable data is the alignment of partners with the power to take action.

How has monitoring within the Three Creeks Project led to actionable data?: Ongoing monitoring across Three Creeks has led to actionable data due to the shared goals, stable resources, and key skills of the partners discussed above. We want to highlight one additional key reason this monitoring has led to actionable data and resulting adaptive management: Upon designing the monitoring for Three Creeks partners needed to expressly understand how the change in grazing practices were linked to land health outcomes. Three Creeks monitoring thus aimed to link grazing disturbance to the generation of the land health outcomes desired.

The goal of the Three Creeks Grazing Project was to employ grazing rotation and addition of rest from grazing to improve landscape condition. Rotational grazing allows managers to control livestock disturbance by controlling the length of time cattle spend on rangeland (i.e., duration), and the period within a season when grazing occurs (i.e., timing). Rangeland managers debate, however, whether rotation provides measurable benefits for livestock and conservation outcomes. Because of this, managers often focus on livestock number (e.g., densities or stocking rates) as the main driver of rangeland health. As a result, reducing livestock numbers or fencing off areas are two common actions taken to improve range condition. One reason for this ongoing debate is that grazing studies rarely include gradients of grazing duration (e.g., short, medium, long grazing periods) or timing (early season, late season) that would allow researchers to link livestock disturbance to changes in ecosystem processes.

This limitation of grazing studies is illustrated by the simplistic comparison of rotational grazing to other grazing systems in the grazing literature [31,32] . Many such studies use a single category of 'rotational grazing' that lumps multiple durations and timings together into a single grazing treatment [31] . This is important because there is no reason to expect the disturbance resulting from grazing at various durations (2 weeks, 1 month, 2 months) or various times (spring, summer, fall) would result in similar changes to ecosystem processes. Studies comparing rotational grazing to commonly used continuous grazing mostly have found no difference in plant production/standing crop between the systems, and have produced mixed results about whether rotation affects animal production per head [31] . The few studies that examine how duration and timing contribute to landscape health [8,33,34] have found rotation can positively affect water quality [30] , positively affect species diversity [35,36,37] , but have mixed results on soil hydrologic function [38] .

The monitoring strategy for the Three Creeks Grazing project addressed this gap by examining how grazing management across gradients of duration and timing affect ecosystem processes and landscape health characteristics valued by producers and society. By including gradients of management action, we avoided pitfalls of lumped-rotational grazing system frameworks, and allow partners to examine how changes in management balance landscape health and livestock grazing.

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Appendix 1. General summaries of rangeland monitoring protocols targeting terrestrial, lentic, and lotic systems.

Field Protocol	Institution / Agency	Applicable System	Purpose	Monitoring Type	Scale of Intended Use	Ecosystem Attributes	Core Methods	Examples of Use
Aquatic and Riparian Effectiveness Monitoring Program	USFS	Lotic (creeks; streams; rivers; ponds; reservoirs; lakes)	To determine the current condition of watersheds and track changes in watershed condition over time	Quantitative	Watershed	Soil and site stability; Hydrologic function; Biotic integrity	Substrate – pebbles; Surface fines on pool tails; Large wood; Benthic macroinvertebrates; Invasive plants and animals; Terrestrial plants; Terrestrial animals; PH; Specific conductance; Temperature; Total nitrogen and phosphorus	
Assessment, Inventory, and Monitoring (AIM) Strategy – Lentic Riparian and Wetlands Systems	BLM	Lentic areas (wet meadows; marshes; seeps; springs; peatlands; vegetated drainageways; swales; vegetated playas; kettle ponds; prairie potholes; vernal pools; riparian shrublands; riparian forests; oxbows; beaver complexes; floodplains;	To provide a standardized approach for measuring natural resource condition and trend on BLM public lands; The AIM Strategy provides quantitative data and tools to guide and justify policy actions, land uses, and adaptive management	Quantitative	Site; Pasture; Allotment; Ecoregion; State; National	Soil and site stability; Hydrologic function; Biotic integrity	Plot classification and description (Cowardin, hydrogeomorphic, general wetland types, elevation, slope, aspect); Photo points (transects, over, and features of interest); Hydrology and surface water characteristics (water sources, aerial extent of standing water, depth of standing water, characteristics of surface water body, characteristics of channels); Soil profile description (soil color and texture, hydric soil indicators, depth of organic layer, depth to water table, depth to permafrost); Natural and human disturbances (disturbances and degree of impacts);	Land health standard evaluations to inform authorizations of permitted uses; Invasive species tracking and management; Restoration, reclamation, and mitigation treatment effectiveness; Habitat condition assessment and monitoring for species of management concern; Land use planning and evaluation; Affected environment and alternatives analyses for proposed actions (e.g., the NEPA process); Performance measures reporting for the DOI Strategic Plan

		pond margins; reservoir margins; lake margins)					Plant species inventory and identification (species richness); Line-point intercept (vegetation cover and composition, ground surface attributes); Vegetation height and litter and water depths (vegetation height, litter / thatch depth, water depth) Woody structure (woody population structure, woody canopy structure); Hummocks (percent cover of hummocks, hummock height, angle of side slopes, vegetation cover of side slopes); Water quality (pH, specific conductance, temperature, nitrogen, phosphorus) Annual use (stubble height, soil alteration, riparian woody species use)	
Assessment, Inventory, and Monitoring (AIM) Strategy – Terrestrial	BLM	Terrestrial (grasslands, shrublands, savannas)	To provide a standardized approach for measuring natural resource condition and trend on BLM public lands; The AIM Strategy provides quantitative data and tools to guide and justify policy actions, land uses, and adaptive management decisions	Quantitative	Site; Pasture; Allotment; Ecoregion; State; National	Soil and site stability; Hydrologic function; Biotic integrity	Plot characterization (general plot information, location, topographic position, landscape position, soil profile); Plot observation (weather, signs of erosion, historical land use, current land use, off-site land use); Photo points (for visual record of data); Line-point intercept (for vegetation cover and composition); Vegetation height (for vertical structure); Gap intercept (for size and distribution of exposed ground); Soil stability test (for soil susceptibility to water erosion); Vegetation species inventory (for biodiversity)	Land health standard evaluations to inform authorizations of permitted uses; Invasive species tracking and management; Restoration, reclamation, and mitigation treatment effectiveness; Habitat condition assessment and monitoring for species of management concern; Land use planning and evaluation; Affected environment and alternatives analyses for proposed actions (e.g., the NEPA process); Performance measures reporting for the DOI Strategic Plan

Assessment, Inventory, and Monitoring (AIM) Strategy – Wadeable Lotic Systems	BLM	Lotic (creeks, streams, rivers, ponds, reservoirs, lakes)	To provide a standardized approach for measuring natural resource condition and trend on BLM public lands; The AIM Strategy provides quantitative data and tools to guide and justify policy actions, land uses, and adaptative management	Quantitative	Site; Pasture; Allotment; Ecoregion; State; National	Hydrologic function; Biotic integrity	Natural and human disturbances (disturbances and degrees of impact); Photo points (for visual record of data); Water quality (pH, specific conductance, temperature, total nitrogen and phosphorus, turbidity); Watershed function and instream habitat quality (pool dimensions, streambed particle sizes, bank stability and cover, floodplain connectivity, large wood, bank angle, Thalweg depth profile, pool tail fines, bankfull width, wetted width, slope, flood-prone width); Biodiversity and riparian habitat quality (benthic macroinvertebrates, priority noxious vegetation, priority native woody riparian vegetation, canopy cover, greenline vegetation composition)	Land health standard evaluations to inform authorizations of permitted uses; Invasive species tracking and management; Restoration, reclamation, and mitigation treatment effectiveness; Habitat condition assessment and monitoring for species of management concern; Land use planning and evaluation; Affected environment and alternatives analyses for proposed actions (e.g., the NEPA process); Performance measures reporting for the DOI Strategic Plan
Interpreting Indicators of Rangeland Health	BLM	Terrestrial (grasslands, shrublands, savannas, woodlands)	To provide a qualitative assessment protocol for rangeland health, allow for early detection of ecological problems, better communication about rangeland conditions, and informed decision-making for monitoring and restoration	Qualitative	Ecological site scale or equivalent landscape unit	Soil and site stability; Hydrologic function; Biotic integrity	Rills; Water flow patterns; Pedestals and / or terracettes; Bare ground; Gullies; Wind-scoured and / or depositional areas; Litter movement; Soil surface resistance to erosion; Soil surface loss and degradation; Effects of plant community composition and distribution on infiltration; Compaction layer;	BLM rangeland health assessments; Assessment of road impacts on rangeland health; Integrated grazing land assessment Ecologically based invasive plant management; NRCS plant planning; Ecological health index

							Functional / Structural groups; Dead or dying plants or plant parts; Litter cover and depth; Annual production; Invasive plants; Vigor with an emphasis on reproductive capability of perennial plants	
Multiple Indicator Monitoring (MIM) of Steam Channels and Streamside Vegetation	BLM	Lotic (Low-gradient [< 4%] perennial snowmelt-dominated and spring-fed streams; Small , mostly wadeable stream systems [active channel width < 10 – 15 m])	To provide information necessary for managers, landowners, and others to adaptively manage riparian resources	Quantitative	Site; Pasture; Allotment; Ecoregion; State; National	Hydrologic function; Biotic integrity	Stubble height; Streambank alteration; Woody riparian species use; Greenline composition; Woody species height class; Streambank stability and cover; Woody riparian species age class; Greenline-to-greenline width; Substrate; Residual pool depth and pool frequency	Monitor changes to streambanks and channels that resulted from management activities such as grazing, and impacts from wild ungulates, wild horses and burros, road placement / construction, recreation, mining, water diversion, and / or timber harvest); Monitor the effectiveness of restoration actions or post-fire recovery
The National Riparian Core Protocol: A Riparian Vegetation Monitoring Protocols for Wadeable Streams of the Conterminous United States	USFS	Lotic (streams; rivers)	To provide guidance on sampling riparian vegetation and physical characteristics along wadeable stream channels and their associated floodplains and valley bottoms	Quantitative	Site; Pasture; Allotment; Ecoregion	Substrate; Biotic; Hydrologic	Woody and herbaceous vegetation; Tree stem density, basal area, and condition; Geomorphic classification of fluvial surfaces; Active channel width; Channel cross-sections; Reach longitudinal profile	To effectively assess riparian vegetation responses to multiple disturbances

National Rivers and Streams Assessment – Non-Wadeable	EPA	Lotic (streams; rivers)	To generate statistically valid reports on the condition of our Nation's water resources and identify key stressors to these systems	Quantitative	Site	Water quality	*In situ* measurements (pH, dissolved oxygen, temperature, specific conductivity); Water chemistry (total phosphorus, total nitrogen, ammonia, nitrite, nitrate, basic anions and cations, silica, alkalinity, dissolved organic carbon, total organic carbon, specific conductivity, pH, turbidity, true color); Chlorophyll-*a*; Microcystin and Cylindrospermopsin; Periphyton composite and periphyton metagenomic; Benthic macroinvertebrate assemblage; Fish assemblage; Physical habitat assessment (thalweg profile, channel margin depth and substrate, large woody debris, bank angle and channel cross-section morphology, riparian vegetation structure, human influences, channel constraint, debris torrents, recent floods); Fecal indicator (*Enterococci*); Antimicrobial resistance (genes and bacteria); Fish tissue plug	
National Rivers and Streams Assessment – Wadeable	EPA	Lotic (streams; rivers)	To generate statistically valid reports on the condition of our Nation's water resources and identify key stressors to these systems	Quantitative	Site	Water quality	*In situ* measurements (pH, dissolved oxygen, temperature, specific conductivity); Water chemistry (total phosphorus, total nitrogen, ammonia, nitrite, nitrate, basic anions and cations, silica, alkalinity, dissolved organic carbon, total organic	

							carbon, specific conductivity, pH, turbidity, true color); Chlorophyll-*a*; Microcystin and Cylindrospermopsin; Periphyton composite and periphyton metagenomic; Benthic macroinvertebrate assemblage; Fish assemblage; Physical habitat assessment (channel / riparian cross-sections, thalweg profile, large woody debris, channel constraint, debris torrents, slope, bearing, recent floods); Fecal indicator (*Enterococci*); Antimicrobial resistance (genes and bacteria); Fish tissue plug	
National Wetland Condition Assessment	EPA	Lentic (tidal and nontidal wetlands)	To quantitatively describe the ecological condition of the Nation's wetlands, and measure progress toward attainment of the national goal to increase the quantity and quality of the Nation's wetlands	Quantitative	Site	Biotic integrity; Water quality; Soil / geomorphic stability	Vegetation (species composition and abundance, native species, alien species, floristic quality, guild composition, community composition, vegetation structure); Buffer (present and amount of cover of natural vegetation, residential and urban indicators, hydrology stressors, agricultural and rural stressors, industrial development stressors, habitat / vegetation stressors, targeted alien vegetation species); Soils (soil morphological and physical characteristics, soil chemistry, hydric soil field indicators, depth to water table);	

							Hydrology (evidence of saturation and inundation, types of hydrologic alteration); Water chemistry (total phosphorus, total nitrogen, ammonia, nitrite, nitrate, basic anions and cations, silica, alkalinity, dissolved organic carbon, total organic carbon, specific conductivity, pH, turbidity, true color); Chlorophyll-*a*; microcystin	
PacFish InFish Biological Opinion Monitoring Program – Effectiveness Monitoring Sampling Methods for Stream Channel Attributes	USFS	Lotic (streams; rivers)	To determine whether priority biological and physical attributes, processes, and functions of riparian and aquatic systems are being degraded, maintained, or restored	Quantitative	Site; Pasture; Allotment; Ecoregion;	Hyrdologic function; Water quality	Bankfull width; Channel width; Side channels; Disturbance; Stream flow; Macroinvertebrates; Water chemistry; Photograph points; Large woody debris; Habitat units; Pool tail fines; Cross-sections; Pebble counts; Bank angle, stability, and type; Elevation gradient	
Proper Functioning Condition	BLM	Lentic (wet and mesic meadows,	To qualitatively assess the function of perennial and	Qualitative	Site	Hydrologic function;	Evidence of inundation or saturation (standing water, accumulating water in a shallow pit, hydric soil indicators,	Site priority determination for management, restoration, and / or monitoring actions;

Assessment for Lentic Areas		marshes, seeps and springs, peatlands, vegetated drainageways, swales, vegetated playas, kettle ponds, priarie potholes, vernal pools, riparian shrublands and forests, oxbows, beaver complexes, floodplains, and the margins of lakes, ponds, and reservoirs)	intermittent lentic riparian-wetland areas			Biotic integrity; Soil and geomorphic stability	sediment deposits, mud cracks, organic deposits / drift lines, algal flakes or crusts, macroinvertebrates, watermarks, drainage patterns, vegetation, oxidized rhizosphere, water-stained leaves); Evidence of sustaining water level fluctuation (hydric vegetation, no bare ground, no oxidation of peat); Evidence of enlarging riparian-wetland area (hydric vegetation, plant community shifts, rising water table / water surface, aerial imagery of stable or expanding extent, maximum topographic extent, no soil compaction, no gully incision, no channelization, no headcut migration); Evidence of riparian-wetland impairment (excess sediment, excess runoff, altered water quality, depleted surface runoff, altered subsurface discharge); Evidence of sufficient water quality (vigorous hydric vegetation, pH and alkalinity adapted assemblage of hydric vegetation, odor related to natural anaerobic conditions, presence of salt-tolerant species in sites that are natural brackish, no algal blooms, no direct discharge of brackish and saline produced water, no acid-mine drainage, no runoff from cultivated fields, no foul odors or discolored water, no high turbidity); Evidence of disturbances that impair surface- or subsurface-flow patterns (hoof prints, footprints, vehicle wheel tracks, roads, dikes, levees, livestock and wildlife trails, upstream dams or irrigation diversion, drop in water table, mortality of hydriv vegetation); Evidence of safe passage of flows with impoundment structures (properly	Determination of appropriate timing and focus for site restoration; Attainment of land health standards

							engineered spillway, non-eroding dam, no large tree roots or animal burrows compromising the integrity of the dam, properly installed drainpipes, regularly removed drainpipes, fully functional headgate, no cracks, slumps, and shifting pieces of ground, no headcut erosion or gullying in the spillway, no sediment-filled reservoirs); Evidence of adequate diversity of stabilizing riparian-wetland vegetation for recovery / maintenance (presence herbaceous and woody plants); Evidence of adequate age classes of stabilizing riparian-wetland vegetation for recovery / maintenance (presence of recruitment and replacement woody plants, continuous cover of rhizomatous plants); Evidence of riparian-wetland vegetation soil-moisture characteristics (hydric vegetation on appropriate geomorphic positions of a perennial stream); Evidence of stabilizing plant communities that are capable of withstanding overland flows, wind and wave actions, and can resist physical alteration (distinct and recognizable communities of stabilizing plants, well-developed patches of deep-rooted plant communities); Evidence of vigorous riparian-wetland plants; Evidence of an adequate amount of riparian-wetland vegetation to protect soil surfaces and shorelines, dissipate energy from overland flows and wind and wave actions, and resist physical alteration (no rills, concentrated flow patterns, or headcuts, no shoreline failures or slump	

							blocks, no bare-vertical banks on shorelines); No evidence of abnormal frost or hydraulic heaving (dense vegetation cover, no bare ground, no soil compaction); Evidence of favorable microsite conditions; No evidence of chemical accumulation affecting plant productivity / composition (no visible accumulation of chemicals, no pH alteration, no stunted plant vigor); Evidence of sufficient soil saturation to compose and maintain hydric soil (production of hydrogen sulfide gas, reduction, translocation, and accumulation of iron and manganese, accumulation of organic matter); Evidence of a riparian-wetland area in balance with water and sediment being supplies by the watershed (maintained water depth, vegetation buffers are effective at controlling runoff and trapping sediment, constant aerial extent of area, no rapid growth of a delta, no unstable shorelines); Evidence of adequate islands and shorelines to dissipate wind- and wave-event energies (rock and large coarse woody debris are in abundance, no shoreline erosion);	
Proper Functioning Condition Assessment for Lotic Areas	BLM	Lotic (streams; rivers)	To qualitatively assess the function of perennial and intermittent lotic riparian riparian systems	Qualitative	Site	Hydrologic function; Biotic integrity; Geomorphic stability	Evidence of inundated floodplain (fresh deposits of fine sediment, matted down floodplain vegetation, debris on upstream side of tree trunks, high water marks on rocks, trees, or other stationary objects, no incised channels, no vertical streambanks, no levees);	Site priority determination for management, restoration, and / or monitoring actions; Determination of appropriate timing and focus for site restoration; Attainment of land health standards

							Evidence of stable beaver dams (fresh wood cuttings, actively constructed dam ends, established riparian vegetation to support the dam, abandoned beaver dams vegetated with stabilizing riparian species); Evidence of a balanced sinuosity, gradient, and width / depth ratio with the landscape setting (no channel incision); Evidence of expanding riparian area or riparian area is at potential extent (increase in riparian plant cover, establishment of riparian vegetation in recent deposits, replacement of upland species by riparian vegetation); No evidence of riparian impairment from the upstream or upland watershed; Evidence of adequate stabilizing riparian vegetation diversity; Evidence of adequate age classes of stabilizing riparian vegetation; Evidence of riparian vegetation soil-moisture characteristics; Evidence of stabilizing plant communities capable of withstanding moderately high streamflow events; Evidence of vigorous riparian plants; Evidence of adequate amount of stabilizing riparian vegetation to protect banks and dissipate energy during moderately high flows; Evidence of an adequate source of woody material (mature trees large enough to serve hydrologic modifiers);	

							Evidence of adequate floodplain and channel characteristics to dissipate energy (rocks, woody material, vegetation, adequate floodplain size, overflow channels); Evidence of revegetating point bars with stabilizing riparian plants (gently to moderately convex profile, topographic continuity, fining-upward sequence of sediment, establishment of stabilizing riparian vegetation); Evidence of laterally stable steambanks (maintenance of a single-thread channel, formation and retention of bankfull indicators, development of nearly continuous stabilizing vegetation, smooth channel margins, natural rates of deposition); Evidence of vertically stable streambanks (no knickpoints, no loss of hydrologic connection to the floodplain); Evidence of a balance between the water and sediment that being supplied by the drainage basin (no formation of mid-channel bars, no braided channel bed, no rapid floodplain aggradation, no erosion, no development of knickpoints)	
The Rangeland Monitoring Network: Handbook of Field Methods	Point Blue	Terrestrial (grasslands, shrublands, savannas, woodlands)	To provide a standardized yet flexible methodology that captures key components of ecological function and offers landowners data for use in management decision making	Quantitative	Site; Pasture; Allotment; Ranch	Soil; Vegetation; Birds	Plot characterization (general plot information, catenal position, land use); Plot observation (weather) Bare ground cover; Litter depth; Soil water infiltration; Soil bulk density; Soil organic carbon;	Measure the spatial variation in ecological function; Identify relationships between management practices and ecological function; Establish a baseline that can be used to understand how ecological function changes over time

							Line-point intercept (for vegetation cover and composition) Point count (for bird surveys)	
Spring Ecosystem Inventory Protocol	Springs Stewardship Institute	Springs (cave, exposure, fountain, gushet, geyser, hanging garden, helocrene, hillslope-rheocrene, hillslope-upland, hypocrene, limnocrene, mound-form, rheocrene)	To assess the ecological integrity of spring systems	Qualitative; Quantitative	Site; Pasture; Allotment; Ecoregion;		Level 1 inventory (site description, human alteration, infrastructure condition, photographs, spring type, flow estimate); Level 2 inventory (site description, site condition, microhabitat description, surface type and subtype, slope variability, aspect, slope degrees, soil moisture, water max depth, open water, substrate, precipitate, litter, wood, photographs, vertebrates, invertebrates, vegetation cover, source geomorphology, flow force mechanism, channel dynamic, solar radiation, flow); Level 3 inventory (temporal – site description, site condition, microhabitat description, surface type and subtype, slope variability, aspect, slope degrees, soil moisture, water max depth, open water, substrate, precipitate, litter, wood, photographs, vertebrates, invertebrates, vegetation cover, source geomorphology, flow force mechanism, channel dynamic, solar radiation, flow)	