Adaptive Monitoring in Support of Adaptive Management in Rangelands

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Forum

Adaptive monitoring in support of adaptive management in rangelands

By Sarah E. McCord and David S. Pilliod

On the Ground

- Monitoring supports iterative learning about the effectiveness of management actions, information that can help managers plan future actions, facilitate decision-making, and improve outcomes.
- Adaptive monitoring is the evolution of a monitoring program in response to new management questions; new or changing environmental or socioeconomic conditions, improved monitoring methods, models, and tools; and experience implementing the monitoring program.
- Adaptive monitoring is connected to research and management through the exchange of data; analytical, methodological, and technological developments; information; and understanding.
- We review recent advances in adaptive monitoring and discuss new opportunities for both the research and management communities to improve monitoring in the years ahead.

Keywords: adaptation, collaboration, co-production, innovation, partnership, rangeland science.

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Introduction

Monitoring has long been a mainstay of adaptive management. Adaptive management is the iterative process of learning from previous management actions and experiences, and using that information to plan future actions, facilitate decision-making, and improve outcomes. Rangeland monitoring has deep roots but the formal use of that information for adaptive management is relatively shallow and not consolidated. As rangeland management moves into the 21st century, managers are increasingly expected to evaluate which types of management approaches are most effective for a given problem and to use that information to justify decision-making. This in no way implies that old or traditional ways of doing things are wrong, but the profession is faced with limited resources to deal with increasingly larger and complex issues such as maintaining forage production and wildlife habitat in the face of invasive species, wildfires, and climate change.[1] Further, these issues now force us to think beyond the pasture and the immediate to consider problems and solutions at multiple temporal and spatial scales.

A brief history of where we have been as a profession can help us understand where we are headed. Early monitoring strategies in rangeland management focused on detecting seasonal rangeland responses to livestock grazing to identify the need for short-term management adjustment (e.g., pasture rotation).[2] As grazing pressure from livestock interacted with other natural and anthropogenic forces, such as drought, invasive grasses and forbs, shrubland and woodland encroachment, and wildfires, rangeland managers started developing long-term management strategies to maintain or improve rangeland productivity. In the 1970s, the US National Environmental Policy Act[3] and other land management policies[4] compelled public natural resource agencies to enact monitoring programs to evaluate individual and cumulative effects of the multiple uses of rangelands, such as grazing, energy development, and recreation.[2] More recent monitoring approaches now also include efforts to understand condition and change in the context of land potential and climate variability.[5,6] As land managers seek to balance short-term and long-term management priorities as well as local and landscape-level priorities, monitoring is critical to providing information across these scales to support the most appropriate land management strategies.

As uses of rangelands evolved, so too have monitoring approaches adopted by the rangeland community. Some of the longest running monitoring efforts include those conducted at the Jornada Experimental Range in New Mexico, Santa Rita Experimental Range in Arizona, Great Basin Experimental Range in Utah, and US Sheep Experiment Station in Idaho where over a century of plot-scale vegetation data have shaped understanding of range condition and trend in the United States.[7] These focal study areas led to the development of mainstay monitoring methods, such as quadrat sampling, line-intercept, line-point intercept, grid-point intercept, and Parker three-step.[8] Adaptations to these methods were used to monitor livestock utilization, including use-pattern mapping, which is a short-term vegetation mapping strategy to identify grazing use and intensity.[9] Some of these methods were standardized for national monitoring programs aimed at providing information about conditions and trends at landscape scales, such as the USDA Forest Service's Forest Inventory and Analysis, the Bureau of Land Management's (BLM) Soil Vegetation Inventory Method, Natural Resource Conservation Service's (NRCS) National Resources Inventory (NRI), and others. Although some of these long-term monitoring programs were defunded or reduced in scope, there has been renewed energy in the past two decades for standardized, multiagency, and partner rangeland monitoring efforts. Current monitoring programs, such as the BLM's Assessment, Inventory, and Monitoring (AIM) program (Kachergis et al. this issue), provide an example of the challenges of implementing and maintaining such programs but also the benefits of providing such information for natural resource managers. Image-based monitoring, through ground photographs, airborne imagery, and satellite sensors, was introduced in the 1990s and has only increased in application for rangeland monitoring.[10,11] Instead of replacing field-level monitoring, these new technologies are best integrated with field data and local ecological knowledge.[12]

When combined with other monitoring efforts that target local scales and management objectives, these monitoring data could (and need to) provide the requisite information for adaptive management (Fig. 1; note the adaptive management loop in orange). The challenge for the next generation of rangeland managers and scientists, however, is implementing monitoring programs that directly inform a diversity of adaptive management objectives and avoiding pitfalls that have plagued previous efforts. No longer can the collection of data be sufficient, for example, to simply "check the box" for monitoring and then file the data away. Monitoring data need to be managed appropriately and be accessible to be useful (note that data management is the central cog in Fig. 1; also see McCord et al., this issue). We now have the capacity to capture and store monitoring data electronically, whether from field plots or remote sensing, and importantly, use those data in models and tools to support decision-making. Further, the more readily available and useful monitoring data become for adaptive management, the more likely monitoring will be supported and done well. Effective adaptive management creates a positive feedback for effective monitoring. Effective monitoring is standardized and robust, but also adaptable.

Although the implementation and application of monitoring data in rangelands is as diverse as rangelands themselves, adaptive monitoring is a process that can unite the rangeland community, from public resource managers to ranchers and researchers. The term adaptive monitoring first began to be used in the mid-1990s as way of communicating the importance of refining monitoring plans used in ecosystem management.[13,14] Czaplewski[14] put it well, "Adaptive management acknowledges that decisions must be made in spite of imperfect understanding of their consequences; likewise, adaptive monitoring is designed to accommodate the unknown objectives and technologies of the future." Stakeholders of monitoring programs recognized the need for flexibility to accommodate changes in natural resources and management paradigms, in addition to changes in stakeholder and societal priorities. Lindenmeyer and Likens[15,16] further clarified the concept of adaptive monitoring as the intentional evolution of a monitoring program in response to new management questions, new or changing environmental or socioeconomic conditions, improved monitoring methods, models, and tools, and experience implementing the monitoring program (Fig. 1; note the adaptive monitoring loop in green).[15,16] Our paper and this special issue embrace the intent and spirit of that definition. Critical to implementing successful adaptive monitoring is a formal process of evaluating a monitoring program to ensure continued relevance to stated management and monitoring objectives, emerging scientific understanding, efficient use of resources, and data quality.[17,18] In this way, adaptive monitoring is connected to research and management through the exchange of data analytical, methodological, and technological developments; information; and understanding (Fig. 1; note the co-production loop in blue and the interconnectedness of all loops through data sharing). A good example is the need to track invasive annual grasses in the western United States, which not only influence wildfire risk, livestock forage, and wildlife habitat, but also fluctuate annually. Allred et al. (this issue) describe how the Western Governors' Association worked with local, state, and federal managers and scientists to combine field data (e.g., AIM, NRI) and the latest remote sensing products[19–21] to improve monitoring for better decision-making and strategic (and timely) management actions.[22]

The foundations of adaptive monitoring include defining clear management and monitoring objectives. These objectives then inform the selection of the sampling area extent, monitoring methods, and sample design, including defining requisite sample sizes, limits of inference, and monitoring intervals (see Stauffer et al., this issue). After careful design of the monitoring program, monitoring data are collected along with co-variates (e.g., soil, ecological site, weather), management records, and disturbance history. These data are then used to evaluate whether the monitoring objectives are achieved. For example, in a watershed risk assessment in rangelands of northern Queensland, Australia, Negus et al.[18] demonstrated a successful approach for adaptive monitoring where monitoring and assessment designs were steadily improved by using a feedback process of information gained from previously collected monitoring data.[18] These data were used to evaluate possible changes to management or the monitoring program. Hence, the key idea of adaptive management using adaptive monitoring is to not only iteratively improve rangeland management but also improve our strategies for gathering information about the condition and trend of rangelands. We also note that an equally important key to adaptive monitoring is to be cognizant of the continuity of information through time (as monitoring evolves) and document any changes to methodological variability or data uncertainty along the way. A review of 50 years of surface water monitoring in Sweden revealed that "using scientifically sound adaptive monitoring principles to balance continuity

Figure 1. Conceptual diagram of contemporary interactions of management, monitoring, and research in US rangelands today. The adaptive monitoring loop (green loop) connects monitoring with research through the development and advancements of models, analyses, methods, and technology. This process requires research-management co-production of relevant timely science and monitoring improvements (blue loop). These products, such as models and management scenarios, also can be useful for adaptive management (orange loop). Data created from monitoring, if managed properly, also can feed into research (e.g., models, forecasting) and ultimately feed back into either the monitoring or adaptive management cycles (e.g., alternatives, decision-making). Hence, data management and data sharing are the crucial cog for free exchange of information between research and management and the advancements and testing necessary for effective, robust adaptive monitoring. Collectively, these elements and connections create the machinery of successful adaptive management for the foreseeable future.

and change has ensured long-time series and the capability to address new questions over time."[23]

Although adaptive monitoring is central to rangeland monitoring, it is often implemented informally and thus challenges remain for formally implementing adaptive monitoring. These include balancing benefits of single scale, single purpose monitoring with efficiencies of multiscale, multipurpose monitoring. In this tension, rangeland managers also may struggle to adopt monitoring sample designs and methods that are representative of ecosystem responses to management.[24,25] Although adaptive monitoring implies flexibility, changes to long-term monitoring protocols also may need to go through a testing and calibration process so that crucial metrics are comparable through time. These crucial metrics are sometimes called core indicators, such as bare ground or vegetative cover.[6] Ensuring that monitoring programs are relevant to managers is particularly important as sustaining institutional and policy support for long-term monitoring efforts and data stewardship is a persistent challenge. Monitoring programs benefit when policy support is both broadly applicable to evolving management challenges yet specific enough to be implemented. For example, the US Federal Land Policy and Management Act of 1976, which directs BLM to manage for multiple use and sustained yield (and to adapt as necessary), suggests that monitoring conducted under the AIM program is central to BLM's mandate. However, widespread adoption of AIM only occurred after specific policy and funding was provided, which directed the need for the AIM program to monitor and manage Greater sage-grouse (*Centrocercus urophasianus*) habitat (Kachergis et al. this issue). Maintaining this policy support into the future will be critical to the long-term success of the AIM program. It is critical that this policy also enables evolution of monitoring when needed.

Adaptive monitoring is an inherently iterative process, so there is always more to learn. As technology and our understanding of rangelands evolve, so too will our conceptual understanding of monitoring. Through adaptive monitoring, we can learn from past mistakes, better understand the challenges of monitoring, and rise to meet those challenges in new and creative ways. The purpose of this special issue is to further explore applications of adaptive monitoring in rangelands and highlight key conceptual and technological advances that support adaptive monitoring. Here we briefly discuss the recent advances in monitoring, highlight new opportunities, and reflect upon future challenges for the rangeland monitoring and management communities.

Recent advances in monitoring

In the past decade, significant conceptual and technological advances have spawned a new era of rangeland monitoring. Here we discuss four of these key advances.

Broader adoption of standardized, yet flexible monitoring programs

A persistent challenge in rangeland monitoring is ensuring that monitoring data are relevant to local management objectives but also scalable to enable assessments at landscape and regional scales and for unanticipated management questions.[6] Standardized monitoring methods collected in a structured fashion as part of local, regional, and national monitoring programs allow rangeland managers to bridge these scale challenges. Kachergis et al. (this issue) describe how BLM has adopted this strategy for AIM, where a set of core monitoring principles, including standardized methods, guide a multitude of terrestrial, lotic, and wetland monitoring projects led by personnel at the field, state, and national level. As a result, field resource staff can use monitoring data collected by national monitoring efforts, and national monitoring efforts are able to leverage field monitoring programs to boost sample sizes in regional assessments. This monitoring program is standard, in that a common process is followed and core datasets are produced, but also flexible as the management objectives can set the sample design approach and identify supplemental indicators to better describe local ecosystem processes and management activities.

Standardized monitoring methods, such as the core terrestrial methods described in Herrick et al. (2018),[26] can also unite the broader rangeland community. For instance, many land management agencies,[6,27–29] conservation agencies and organizations,[30] research networks,[31] and local research studies also use the same standard methods described in Herrick et al. (2018).[26] Ranchers and producers have also adopted these methods or compatible versions of these methods (Derner et al., this issue).[32] Because of standardized methods, there is local flexibility in collecting data, but also opportunities for aggregating data to understand regional conditions across land ownerships in new ways. The rise of standardized monitoring also creates opportunities to increase standardization and create more broadly applicable training programs. In this issue, Newingham et al. describe the key elements of success in bringing the next generation of monitoring professionals into the community, both through university courses and professional training opportunities.

Rising recognition of the importance of multistakeholder collaborative monitoring approaches

An important but overlooked aspect of monitoring programs is the value of partnerships between managers, conservation planners, producers, and scientists who aim to bridge the research-management gap in the spirit of co-production.[33] Co-production can mean many things, but here we are referring to a situation where scientists and managers discuss relevant management problems, the research needed to resolve those problems, and how the community can work together to gather needed monitoring data and other information to address those problems (Fig. 1). In other words, both researchers and managers are "at the table" from the beginning, which enhances communication, builds trust, and often results in better, more useful outcomes or end products.[1,34] Historically, monitoring was not considered part of research and many agencies that conducted monitoring were not allowed to conduct research. Co-production breaks down these barriers and has the potential to greatly improve the rigor and inference of monitoring designs, quality of monitoring data, and proper use of those data for analysis and decision-making. An example of co-production using monitoring data is observable in the NRCS Conservation Effects Assessment Project Grazing Land Component (CEAP-GL), where NRCS staff work closely with scientists to use the NRI monitoring data to inform conservation outcomes and ecosystem services valuations.[35,36] Simultaneously, scientists work with CEAP-GL staff to improve conservation planning by improving models and decision support tools, such as the Rangeland Hydrology and Erosion Model,[37] the Aeolian Erosion model (AERO), and the Rangeland Analysis Platform.[11] Cross-scale, multidisciplinary, and collaborative partnerships will continue to be important as multijurisdiction threats to rangeland ecosystems persist (e.g., invasive species, wildfire, and climate change).

Software, cloud computing, and data are more accessible than ever

Recent advances in computing technology have fundamentally shifted how rangeland managers design, collect, and analyze monitoring data. The rise of open-source statistical software, available in languages such as R and Python, means that designing probabilistic sample designs and producing both design-based and model-based estimates of condition and trend on rangelands is more accessible to rangeland managers than ever. Stauffer et al. (this issue) provides an overview of the sampling resources available to the rangeland community and guidance for adopting those resources. Data collection technology also has improved, from electronic data capture systems (e.g., ESRI Survey123, LandPKS) to support observational monitoring to the reduced cost of sensor and remote sensing-based data collection. Cloud computing environments, such as Google Earth Engine, paired with the increased availability of remotely sensed imagery, and standardized monitoring data (as training datasets) provide new opportunities to monitor rangelands at continuous spatial scales, more frequent temporal intervals, and even back in time. Allred et al. (this issue) review considerations and opportunities for using remote sensing-based indicators that can be used alongside other monitoring data in assessments and management decisions. Jansen et al. (this issue) explore how remote-sensing technologies, including unmanned aerial vehicles, paired with improvements in GPS technology can improve use-based monitoring. Finally, the availability of monitoring data requires careful consideration of data stewardship habits within the rangeland community. It is important for all members of the rangeland community who interact with data to understand the data lifecycle and how best to leverage technology and cultural practices to prevent errors if possible and detect errors when they occur. In this issue, McCord et al. discuss ten practices for the rangeland community to adopt to improve data quality within rangeland monitoring. All these advances provide new opportunities to produce more relevant monitoring data and for the rangeland community to develop improved assessment and analysis approaches to understand rangelands across scales.

Improved assessment frameworks that help rangeland managers interpret monitoring information

With the new kinds and amounts of monitoring data available, new assessment frameworks are needed to help rangeland managers interpret these data and inform rangeland management decisions.[38,39] For instance, where rangeland managers may have previously relied upon site-based assessments (e.g., specific pastures or allotments) at a small number of locations with limited inference, now both quantitative and qualitative data from thousands of monitoring locations are randomly placed to provide much greater inference and power at multiple spatial scales. These monitoring plots combined with wall-to-wall remote sensing products have completely changed the amount and quality of information available and the types of questions that can be asked at both local and landscape levels. To be clear, in no way do we want to discourage or denigrate site-based assessments or assessments that use qualitative instead of quantitative methods. In fact, all information is valuable and can be combined in a "preponderance of evidence" approach. In this issue, Lepak et al. discuss the opportunities in combining quantitative data with qualitative rangeland health assessments to understand a broader range of ecosystem processes. One consideration when combining data is addressing uncertainty among datasets. Allred et al. (this issue) provide a framework for understanding uncertainty and error in remote sensing-based monitoring datasets. Jansen et al. (this issue) also discuss how to evaluate sources of uncertainty in data collectors to select the most appropriate utilization method.

In these efforts, however, challenges remain to interpret monitoring data in the context of rangeland potential. Benchmarks are an emerging tool for using quantitative monitoring data in assessments. Benchmarks provide a quantitative mechanism for understanding if rangelands are in suitable, marginal, or unsuitable condition by setting desired thresholds, either based on ecological potential[40] or desired environmental conditions such as reference states tied to reference areas.[41,42] The advent of new assessment frameworks provides opportunities to build new standard analysis workflows that can speed the use of monitoring data in decision-making processes (Kachergis et al., this issue).

New opportunities in adaptive monitoring

The recent advances in rangeland monitoring that we describe are paving the way for new uses of monitoring data in adaptive rangeland management. For instance, Germino et al. (this issue) demonstrates the uses of quantitative monitoring to evaluate post-fire recovery and management strategies. Monitoring data collected to understand land health also can be adopted for use in wildlife habitat assessments. This topic is discussed in detail by Pilliod et al. (this issue), although they point to the need for better integration of wildlife habitat characteristics into rangeland monitoring programs. Other opportunities include expanding the use of remote-sensing data products to inform adaptive management (Allred et al., this issue) and strengthening the connections between short-term, use-based monitoring and long-term monitoring. New uses of rangeland monitoring data also extend to the development of new indicators that combine existing data. For instance, structural diversity (e.g., canopy gap and height) and spatial heterogeneity are useful indicators for assessing wildlife habitat suitability (Pilliod et al., this issue) and potential for soil erosion by wind.[43] Rangeland researchers also might consider integrating rangeland monitoring data with data from other large-scale research networks (e.g., the National Ecological Observatory Network, the Long-term Ecological Research Network, and the Long-term Agroecosystem Research Network).

Opportunities for collaborative rangeland management and monitoring rely on shared data resources. To date, these collaborative efforts have focused on adopting common standardized methods,[26] electronic data capture tools (e.g., LandPKS[32]; Database for Inventory, Monitoring, and Assessment (DIMA)[44]; Vegetation GIS Data System[45]), and a shared vision for the adaptive monitoring process.[8] However, as we move into a broader era of data-supported decision-making, there is critical need to continue existing investments in long-term monitoring by sharing data collected using these common frameworks to better understand both local and landscape rangeland ecosystem patterns and trends. Data repositories of standardized rangeland data, such as the Landscape Data Commons, provide opportunities for land managers to understand local monitoring data in the context of regional trends. There is also a broad need for the availability of management history data to pair with monitoring data. For example, legacy data on land treatments from BLM-administered lands are now available in the Land Treatment

Digital Library,[46] which can be useful for local, state, or regional assessments.[47] Having these data compiled in one location and available in a geodatabase helps managers understand the disturbance and restoration history of their lands while also enabling scientists to design experiments to understand factors affecting rehabilitation and restoration outcomes and rates of recovery. These data also can feed into decision support tools, like the Land Treatment Exploration Tool,[48] which facilitates the adaptive management process by providing that information to help managers learn from the past and improve land treatment outcomes. This information and process are still needed for oil and gas reclamation, grazing, fuel breaks, road effects, and sustainable recreation activities so that we can adequately represent the multiple, sustained uses of both private and public rangelands.

Our capacity to manage rangelands for diverse uses in the face of a changing climate will depend in part on our ability to use the information available to us to inform decisions and to seek out new information when needed. In highlighting the importance of and need for adaptive monitoring, we recognize that evolving technology and an increased understanding of ecosystem dynamics will require adjustments to how we collect and use rangeland monitoring data. However, the success of adaptive monitoring in adaptive management is also contingent upon policy foundations that acknowledge uncertainty and allow for rangeland managers to "make adjustments as necessary,"[4] as our understanding of rangeland responses to management evolves. Multistakeholder collaboration and co-production also will be critical to building a shared vision of rangeland management in response to emerging rangeland information. In this special issue, we examine the many aspects of contemporary monitoring to support adaptive management. We bring together scientists and managers to continue an ongoing dialogue about the value of current monitoring approaches and to contemplate the future of rangeland monitoring. Our goal is to prepare the next cohort of rangeland scientists and natural resource specialists for the future of adaptive management in our nation's rangelands through the collection, stewardship, and use of monitoring data.

Declaration of Competing Interest

Sarah McCord and David Pilliod are the Guest Editors for this special issue, but were not involved in the handling, review, or decision for this manuscript. The content of sponsored issues of Rangelands is handled with the same editorial independence and single-blind peer review as that of regular issues.

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