Monitoring Grazing Use: Strategies for Leveraging Technology and Adapting to Variability

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Source: Rangelands, 44(1) : 64-77

Published By: Society for Range Management

URL: https://doi.org/10.1016/j.rala.2021.07.005

Monitoring grazing use: Strategies for leveraging technology and adapting to variability

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On the Ground

- Collection, interpretation, and application of use-based monitoring data across large landscapes is challenging given the inherent variability in growing conditions and field-based estimates.
- We present several approaches on leveraging geospatial data and technology to cope with this variability including weather and climate data, satellite remote-sensing data and associated tools, as well as livestock GPS collars.
- Field-based estimates also can be improved with more careful consideration of field methods and improved observer training and calibration.
- Planning and co-implementing of use-based and long-term landscape monitoring can inform causes of declining or improving rangeland health and better inform adaptive management.

Keywords: climate variability, Global Position Systems, grazing monitoring, rangelands, remote sensing, utilization.

Rangelands 44(1):64–77
doi 10.1016/j.rala.2021.07.005

Introduction

Grazing by livestock can have negative, neutral, or positive consequences to the ecological and economic functioning of rangelands.[1–3] These outcomes are largely dependent on matching management objectives (i.e., land health, water quality, habitat, and profit) with appropriate grazing management over time. One source of information to help guide and evaluate adaptive management decisions are annual and seasonal estimates of livestock use. Use-based monitoring methods estimate the percent of the current year's growth consumed or destroyed by livestock (i.e., utilization) or the amount of vegetation remaining (i.e., residual biomass) after livestock have left a grazing area.[4] Utilization and residual vegetation data, in conjunction with other monitoring information, can be used to understand spatial and temporal patterns of livestock use, effects of grazing, and causes of changes in rangeland attributes. This use-based data is important to guide adjustments to management strategies to help ensure objectives are met in a changing environment.[5] In some management scenarios, use indicators are considered when adjusting livestock management within a grazing season. While, in other management applications, these data are collected at the end of the grazing period or growing season and used retrospectively to inform grazing management in subsequent years, or to assist with assessing changes in resource condition over time. Thus, adopting practices that optimize the quality, accuracy, and extent of utilization and residual vegetation data, is an important component of developing a comprehensive monitoring plan that supports effective short and long-term management of rangeland resources (i.e., upland production, riparian vegetation, water quality, and fish and wildlife habitat). By not working to improve the accuracy and efficiency of use-based monitoring data and the integration of this data with long-term datasets we risk negative impacts to rangeland resources as well as reduced economic returns over the long run.

Although estimating utilization and residual vegetation may seem straight forward, in practice estimating how much forage has been removed or what remains across large spatial and temporal extents is challenging.[5,6] Commonly used in-field methods have been shown to be subjective,[7,8] costly to collect, [9] and inadequately repeatable between observers across large areas.[10] Additionally, accurate utilization estimates require field observers to understand and account for the current year's growing conditions.[6] Failure to correctly account for variability in growing conditions can introduce bias to measurements, adding complexity to data interpretation. Use-based data are also difficult to integrate with long-term monitoring datasets, which are essential to understanding the influence of livestock management on vegetation and ecosystem processes over time. These difficulties arise due to differences in sampling design (i.e., location and dates for where and when data are collected) and differences in data collection methods.

Here, we address the challenges of collecting and implementing use-based monitoring data for rangeland management. Specifically, we focus on 1) acknowledging and incorporating year-to-year variability in growing conditions (i.e., climate variability) with use-based monitoring data collection and interpretation, 2) improving accuracy and reducing bias of field-based observations, 3) using geospatial technology (i.e., remotely-sensed satellite data and GPS collar data) to collect and estimate use-based monitoring data across large extents, and 4) integrating use-based monitoring with long-term condition and trend monitoring. To illustrate our key ideas, we present examples from ongoing projects at the University of Idaho's Rinker Rock Creek Ranch (RRCR) in southern Idaho and The Nature Conservancy's Zumwalt Prairie Preserve in northeastern Oregon.

Our aim is not to provide an exhaustive list of challenges and solutions regarding use-based monitoring, nor to prescribe management recommendations, but rather to highlight current challenges and provide actions for practitioners and managers to consider when implementing use-based monitoring. The ideas offered here should be considered within the context of each unique ecosystem, management framework, and established long-term monitoring objectives. We conclude by offering some aspirational ideas to help guide current and future research and application of use-based monitoring.

The challenge of use-based monitoring in climatically variable rangelands

Use-based monitoring data and their interpretation are heavily influenced by current and past weather conditions due to the interactions between livestock grazing, available forage, and water resources. In rangelands, precipitation and temperature influence the start and end of the growing season, the spatial pattern of available forage, as well as the quantity and quality of forage (See Derner and Augustine[11] on managing drought adaptively).[1,12] Precipitation amount and timing also affect the availability of water sources (e.g., catchment ponds, streams) used by livestock, which impacts animal distribution and management options. Furthermore, the intensity and pattern of grazing is affected by weather, due to its relationship on plant growth and livestock behavior,[6] which in turn influences measures of utilization and residual biomass. Failure to account for the influence of climatic conditions when planning, collecting, and analyzing short-term monitoring data can lead to an incorrect or incomplete understanding of livestock use. For example, utilization estimates taken in areas which do not represent livestock distribution across a pasture due to variable year-to-year growing conditions, and management actions provide limited insights about grazing use patterns. Thus, sampling design and key areas should represent the grazing occurring across any given management unit during the year and time of interest (see RCRR flexibility example below).

Addressing the climate variability challenge

Variability in growing conditions (i.e., climate and weather) is a major driver of rangeland management outcomes and provides important context for interpreting monitoring data. Integrating growing-condition information into both the sampling and interpretation of use-based monitoring data provides a more detailed understanding of whether (and possibly why) an area is meeting or heading toward management objectives (informed by long-term monitoring). Climate and weather data must be incorporated into the interpretation and evaluation of use-based monitoring data to 1) help with adaptive management, and 2) help understand how management may be affecting trends of other indicators over time (see section: The challenge of integrating use-based monitoring with long-term condition and trend monitoring). Therefore, to address climate variability with use-based monitoring we recommend 1) building flexibility into use-based monitoring, and 2) reviewing and interpreting annual use-based data within the context of the weather conditions and any subsequent changes to management due to growing conditions.

Building flexibility into use-based monitoring strategies ensures that they are responsive to the variability inherent in rangeland systems and informative in the face of changing growing conditions. This flexibility is necessary because ranchers often adjust grazing plans from year to year based on growing conditions (see Box 1). If changes were made to the normal or past year's grazing rotation in response to growing conditions, modifications to key-area or targeted monitoring by adding or moving key areas within pastures may be appropriate.[13] For example, the rancher managing grazing at RRCR (see Box 1) altered cattle grazing from year to year to accommodate variation in livestock use patterns and seasonal precipitation. This resulted in cattle entering one of the pastures from a different direction, so an additional key area for utilization monitoring was established to account for the change in livestock movement. In a year that cattle were herded in this new direction, utilization at a previously established monitoring plot in the pasture indicated almost no use ($< 5\%$), and utilization at the new key area was $14\% \pm 2.1\%$. Considering the length of the grazing period and the previous years' monitoring data, the utilization captured at the new monitoring plot was more representative of actual livestock-forage use. While this example is related to key area monitoring, the idea of flexibility in locating monitoring plots can be extended to monitoring approaches that incorporate randomized plot selection by creating sampling designs annually or by developing sampling strategies that account for how livestock use land differently in wet, dry, and normal years. These approaches should be informed by experts on the ground, and/or other data sources such as remotely-sensed data or GPS collar data (see section: The challenge of understanding livestock use across large landscapes).

Box 1. A rancher's perspective on adaptive management in response to variable growing conditions.

Leveraging technologies and approaches for improving rangeland monitoring requires building relationships between researchers and ranchers as well as consideration of the day-to-day management of livestock. Understanding the limitations faced by ranchers provides context for overcoming the challenges of climatic variability, dealing with nonsampling error, managing across landscapes, and integrating with long-term condition and trend monitoring. In an interview with Wyatt Prescott, livestock manager on RCRR, he describes some of his challenges with managing livestock on a public land allotment.

Wyatt Prescott, Prescott Cattle & Consulting, Fairfield, ID. Manager of University of Idaho cattle grazing on Rinker Rock Creek Ranch near Hailey, Idaho.

Question: How do you change your grazing management with year-to-year variability in growing conditions?

"We're changing things every year. We're changing things every month, really every week for that matter. We're trying to stay as adaptive as we can and listen to what the resource is telling us."

"We do two things, mainly, to control where cattle are at or how they're using a particular pasture. First, we use some mineral to try and draw cattle in a certain direction and then second, we ride … frequently … to keep as much pressure off certain riparian areas as we can. Every year's different."

"A perfect example in how we've adapted – is- we set out with a plan of what area of the pasture we're going to start cattle on and how we're going to use that pasture. We target areas and strategically move them. It takes us a couple of years for the cows to tell us how they're going to naturally drift … and where they're going to go. We try to take notes on how cattle respond … and what areas they naturally flow to and we adjust accordingly."

Question: What are some of the challenges of practicing adaptive grazing on a federal grazing permit with a prescribed number of livestock grazing a pasture for a specific time period?

"…That's my whole problem with it all, is the numbers. I think we need to throw the numbers away and let's just talk about utilization and trends. And, numbers would prove themselves out. But I mean, somebody could put 25 cows in here (the pasture) and somebody could put 200 cows in here and they could achieve the same utilization. "

"…The other thing about flexibility I want to state just real quickly is sometimes you are limited by flexibility within the public lands grazing permit regime. That's a real challenge to work around because then you have to be extra flexible on your private ground that you have more flexibility on. And so, one of the things that's key in that flexibility is to try to implement more flexibility in public lands permits and the way to do that is through the permitting process. "

Author's comment

It is apparent Wyatt is in favor of outcome-based or adaptive management that allows flexibility on the timing, intensity, duration, and frequency of grazing to meet management goals on the ground. He highlights the importance of utilization and trend monitoring to inform whether the management is achieving the desired outcome. Having flexibility to alter the number livestock and location of livestock to fit current conditions at different times could build resiliency for grazing systems and the ranching enterprise.

Monitoring data also should be reviewed in relation to utilization goals, and interpreted within the context of weather conditions that interact with vegetation response, management response (See Smith et al.[6] for more on utilization's role in Rangeland Management), and management outcomes at plot, pasture, and landscape scales. Local weather station data, and online resources such as the drought monitor (https://droughtmonitor.unl.edu/ [14]), drought index tools (e.g., DroughtView: https://droughtview.arizona.edu/,[15] Historical Water Watcher' web tool: https://climatetoolbox.org/tool/Historical-Water-Watcher,[16] and ClimateEngine: http://climateengine.org/[17]) and productivity forecast tools (e.g., GrassCast: http://grasscast.unl.edu[18,19]), can be used to understand the amounts, timing and magnitude of weather events in relation to grazing and use-based monitoring data. For example, in some areas desired residual biomass amounts have been established to meet management objectives such as fuel load reduction or wildlife habitat structure requirements. The effect of livestock grazing on achievement of these desired residual biomass amounts is influenced by yearly growing conditions, and grazing management (i.e., timing of grazing, stocking rates, and livestock distribution patterns).[20]

Currently on the Zumwalt Prairie Preserve grassland managers are using yearly estimates of residual biomass provided by satellite data to help with adaptive management.[21] For ex-

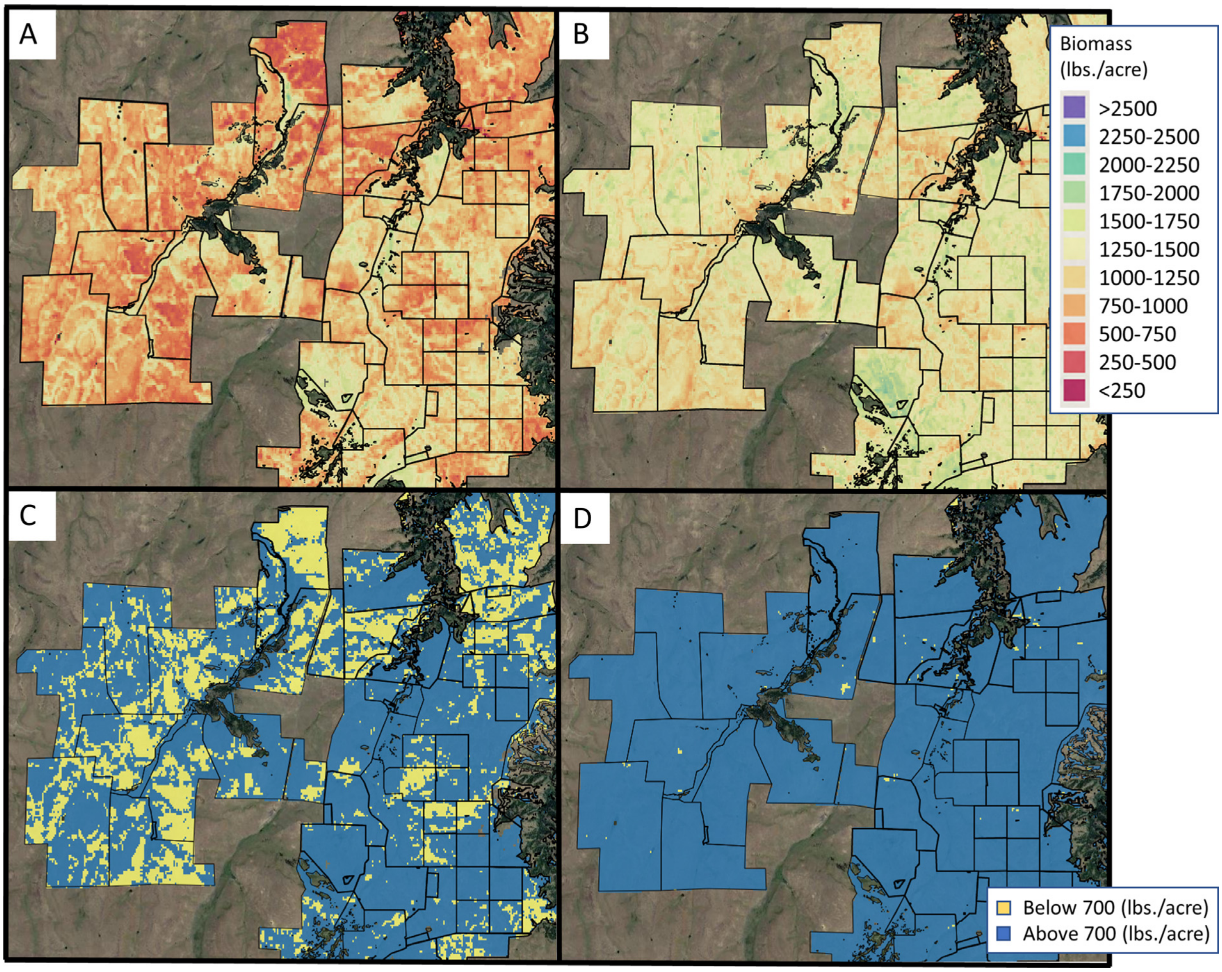

Figure 1. Fall residual biomass in mid-October from 2015 (A) and 2019 (B) as estimated by biomass models from Jansen et al.[21] Classified residual biomass on the same dates in mid-October from 2015 (C) and 2019 (D) using a 784.6 kg/ha (700 lb/acre) threshold. In 2015, the Zumwalt Prairie Preserve experienced below average rainfall, and in 2019, there was above average rainfall. Fall residual biomass highlights the variation in residual vegetation between wet and dry years despite similar livestock management on the Zumwalt Prairie Preserve, Oregon. The threshold value 784.6 kg/ha (700 lb/acre) was guided by findings from Jansen et al.[22] These maps were created using mapping tools at RangeSAT.org.

ample, when relating field plots within the 40% to 60% utilization class (estimated by the landscape appearance method) to satellite-based estimates of residual biomass across wet and dry years, we observed that biomass varied by nearly 532.4 kg/ha (475 lb/acre) (dry year-2015: 782.35 kg/ha [698 lb/acre], wet years-2016/2017: 1313.64 kg/ha [1,172 lb/acre], see Jansen et al.,[22] for more details). Mapping residual biomass amounts as well as classifying these images using the dry year threshold guided by the above relationship, illustrates the yearly variation in amount and pattern of residual biomass (Fig. 1). By comparing utilization or residual biomass estimates with climate data, land managers and ranchers get a more complete and accurate understanding of what they can expect in coming years and whether management decisions are aligning with management goals. This also allows for better predictions of weather, forage, and livestock interactions to improve annual management planning and within-season adjustments in subsequent years.

Another example of how growing conditions impact vegetation growth and subsequent monitoring is provided from RRCR. At the plot scale, a wet or dry year can bias initial ocular estimates of forage utilization at key areas due to fluctuations in annual grass cover (Fig. 2). Across the ranch, 2020 was a dry year and forage utilization on the Middle Pasture key area was 37 ± 3.9% (using the height-weight method). Conversely, 2017 had 24 ± 3.7% utilization for the same stocking rate, and abundant moisture resulted in higher-than-average production of annual grasses (Fig. 2). At first glance, comparing the two years data without the context of growing conditions, there a is potential to incorrectly estimate heavy grazing on perennial grasses in 2020 and underestimate utilization in 2017 due to the visual obstruction of perennial grasses. Under these extremely variable growing conditions it is possible that visual methods of estimating utilization, such as landscape appearance, may be more susceptible to bias compared to measurement-based techniques, such as height-

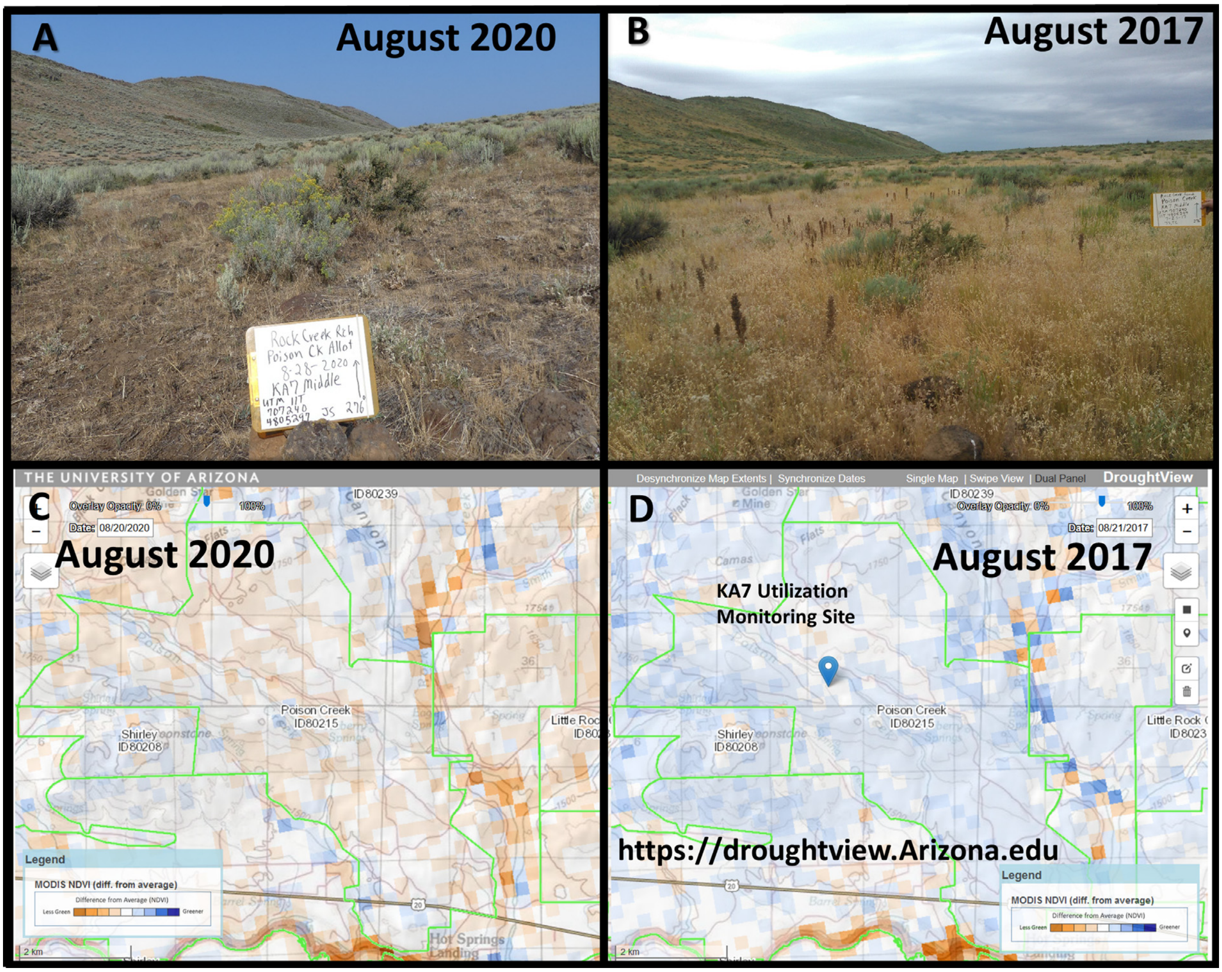

Figure 2. The University of Idaho's Rinker Rock Creek Ranch's Middle Pasture Key Area 7 after a severe drought in 2020 (A) and wetter year in 2017 (B). The Normalized Difference Vegetation Index satellite imagery (C: 2020, D: 2017) provided by droughtview[15] compares greenness for the 2-week period of interest to the average greenness since 2000. More blue indicates wetter than average and orange indicates drier than average. Utilization, as measured using the height weight method in 2020, was 37 ± 3.9% compared with 24 ± 3.7% in 2017. Visual inspection of the photo in 2017 would indicate almost no utilization due to abundant annual grasses being present.

weight (see section: Addressing nonsampling error in field estimates).

The challenge of variability in use-based field estimates

The first step for improving the accuracy and repeatability of utilization measurements is understanding the sources of bias and nonsampling (e.g., measurement) error so that quality assurance processes can be put in place to prevent or mitigate biases and errors before they occur.[5,23] This practice of investigating sources of error and bias is commonplace in bird surveys,[24] plant community estimates[10] and lotic monitoring,[25] however recent studies that consider sources of variability among techniques and observers in rangeland management are lacking. The studies which have tested the accuracy and repeatability of estimating utilization across observers and grazing rates concluded that estimates were affected by many factors unrelated to grazing intensity, including the method used, training, professional experience and the location and intensity of measurements (Fig. 3A).[7,26–28]

Nonsampling errors can introduce bias and increase variability (i.e., noise) in monitoring data that can lead to misinformed management decisions. Error based on the location and intensity of measurements (i.e., sampling error) can also influence utilization estimates, however this error can be quantified using confidence intervals and the uncertainty considered when using the data.[6] Because nonsampling error is not captured in calculation of confidence intervals or statistical tests, their effects are difficult to determine but can be significant. Here we focus on nonsampling errors and associated bias of three commonly used utilization methods: landscape appearance, height-weight, and paired plots (Table 1).[29]

Addressing nonsampling error in field estimates

Many nonsampling errors can be prevented through: 1) the selection of appropriate monitoring methods, 2) using multiple field methods in tangent,[28] 3) improved training and study

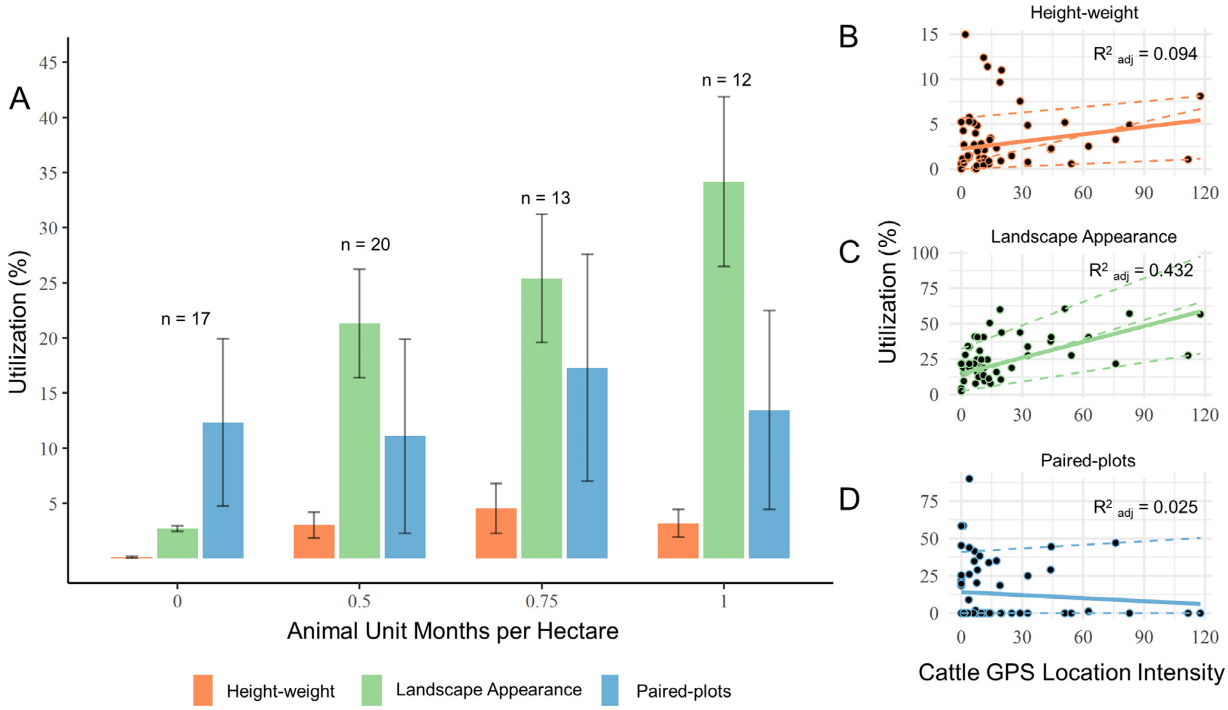

Figure 3. Field-based grazing intensity estimates from the Zumwalt Prairie Preserve Experimental study in Wallowa County, Oregon. A, Mean utilization estimates and 90% confidence intervals from three field-based methods across four stocking rates (n = 4 pastures at each stocking rate). Methods were conducted in the same locations and at the same time as each other using protocols outlined in the Interagency Utilization Studies technical reference (See McCord et al. [23]). It is important to note that the different methods use slightly different subplot designs based on the time available, what was most appropriate for the method, and how the methods are described in the Utilization Studies technical reference (See McCord et al. [23]). See Laurence-Traynor[28] for details. Paired-plots were the only method unable to detect a difference between the no grazing and grazed treatment plots. B-D, Linear regression (with 10th, 50th and 90th percentiles) of utilization estimates from individual sampling plots (n = 66) against the count of cattle GPS locations at each sampling plot over the duration of the grazing period including a no grazing treatment, low, moderate, and high stocking rates. C, Landscape appearance estimates showed the closest relationship to cattle locations across all levels of grazing intensity ($R^2_{adj} = 0.432$).

Table 1
Descriptions of three commonly used utilization methods as defined in the Interagency Utilization Studies technical reference[29] and described by Lommasson and Jensen[64] and Heady[65]

Field Method	Type	Description
Landscape appearance	Ocular estimate	Ocular estimate of forage utilization based on the general appearance of the rangeland. Utilization levels are determined by comparing observations with written descriptions of each utilization class.[65]
Height-weight	Measurement	Heights of ungrazed and grazed grass or grass-like plants are measured to determine average utilization. Measurements of plant heights recorded along transects are converted to percent of weight utilized by means of a utilization gauge[64] developed from height-weight relationship curves for each forage species.
Paired plot	Measurement	Forage from protected and unprotected plots is clipped and weighed at the end of the use period. The difference between these two weights represents the amount of forage consumed or otherwise destroyed during that period.

area-specific observer calibration (McCord et al.[23] this issue, Newingham et al.[30] this issue), and 4) improved sample design (Stauffer et al.[31] this issue). To reduce nonsampling error use-monitoring method(s) should be selected based on careful consideration of the experience level of observers, resources available, the level and range of grazing intensity, as well as the amount and type of vegetation. Several studies have documented that the speed and utility of visual estimates (e.g., landscape appearance) come at the cost of increased observer bias particularly with less experience observers, while measurement-based techniques (e.g., paired-plots and height-weight) have reduced potential for bias, but may take more time to implement.[5–7,28] As well as observer experience and efficiency, it is also important to consider the intensity and distribution of expected grazing and the distribution of forage plants as these factors will affect how well a particular method and associated sampling locations represent the grazed area. For example, species cover and distribution data from long-term condition and trend datasets can help determine if a key species-based method would be representative of the grazed area and which key species may be most appropriate (see The Challenge of Integrating Use-based Monitoring with Long-term Condition and Trend Monitoring section below). While more research is needed on the specific advantages and disadvantages of different utilization methods in certain grazing systems, Fig. 4 demonstrates

Landscape Appearance

+ Low time/funding commitment
- High level of observer experience needed (Jasmer & Holechek [27], Smith et al.)
+ Accurate across a broad range of grazing intensity
+ Considers spatial distribution of forage plants and grazing (Jasmer & Holechek [27])

Height Weight

+ Moderate time/funding commitment
+ Low level of observer experience needed (Laycock [7])
- Less accurate at lower grazing intensity (Halstead et al. [8], Laurence-Traynor [28])

Paired-plots

- High time/funding commitment
+ Moderate level of observer experience needed
- More accurate when forage plants are homogenously distributed (Coulloudon et al. [29])
- Less accurate at lower grazing intensity (Laurence-Traynor [28])

Scenario	What time/funding is available?	What is the experience level of observers?	What is the spatial distribution of forage plants?	What is the expected level of grazing intensity?	Suggested utilization protocol
Scenario 1 (Zumwalt Prairie Preserve)	Low/moderate	High (e.g., >5 years)	Heterogenous	Variable (e.g., between 0-2 AUM/ha)	Landscape appearance
Scenario 2	High	Low/moderate	Homogenous	High (e.g., >2 AUM/ha)	Paired-plots
Scenario 3	Low/Moderate	Low/moderate	Heterogenous	High (e.g., >2 AUM/ha)	Height-Weight

Figure 4. Three examples of matching utilization monitoring protocol strengths and weaknesses with the time/funding available, level of observer experience, spatial distribution of forage plants, and expected level of grazing intensity. Paired plots were not a good fit for the Zumwalt prairie due to large time commitment required to collect sufficient samples to represent the highly heterogeneous plant community. This issue may have been less significant at higher levels of grazing intensity, as higher grazing pressure would likely even out the intensity spatially.

the decision-making process of selecting a method in three different grazing systems. Not only is it important to consider the questions in Fig. 4 but also to specify what the priority objectives are for your monitoring program – these should be the guiding principles on the kind, timing and amount of use-based monitoring that are most appropriate.

To inform method selection it may be helpful to collect pilot data from a range of different methods and sampling locations to evaluate their efficiency and accuracy. For example, at the Zumwalt Prairie Preserve, ocular estimation methods were better able to detect use patterns at lower stocking rates than measurement-based methods when field data were compared to actual cattle distribution measured from GPS collars (Fig. 3B-D). The paired-plot method was unable to capture spatial patterns of livestock intensity, and estimates made using this method did not detect differences among stocking rates. This was likely due to the relatively small sampling area represented by the paired plots compared to the other methods. This study area-specific information on the advantages and disadvantages of different monitoring methods can be used to improve future monitoring plans to improve measurement accuracy better reflect actual livestock use.

There is no perfect field-based method for every management area, however, accuracy of utilization methods can be improved through intra-method calibration, which requires using two or more methods in tandem.[28] Intra-method calibration uses utilization estimates from a measurement-based method (e.g., height-weight) from a small number of subplots to calibrate observers in implementing a larger number of less intensive ocular estimates such as landscape appearance. This approach is similar in concept to double sampling as used in annual production measurement[32] but does not seek to establish a statistical relationship between the techniques, just to improve consistency in the application of the estimation technique. As with observer calibration, these exercises should be conducted regularly, by all observers, and whenever moving between different plant communities or levels of grazing intensity. The time required for intra-method calibration technique can be reduced by using electronic data capture devices that automate utilization calculations (either from clipped paired-plots or using height-weight curves). In the Zumwalt Prairie Preserve study, the landscape appearance method, when using intra-method calibration with height-weight measurements, showed a higher degree of sensitivity to different levels of grazing and the tightest relationship to actual cattle use patterns compared to the other methods implemented singly (Fig. 3). Intra-method calibration exercises may be particularly helpful when only a single observer is conducting all utilization observations.

Nuances in livestock behavior and forage preference related to varying forage distribution and composition between different pastures can have large impacts on utilization and residual biomass estimates.[33] There is opportunity to improve field method training at the beginning of each field season; however it may also be beneficial to conduct training exercises frequently throughout the data collection period.[30] An effective training approach to reduce measurement error is for all observers to estimate and then compare utilization using the chosen method in the same plots or transects, akin to observer calibration exercises in McCord et al.[23] When using this approach, we recommend: 1) establishing an acceptable threshold of variance between observers prior to training (e.g., ±5%), 2) repeating training and calibration exercises across a range of utilization levels, 3) discussing differences in utilization estimates between observers, 4) repeating each exercise if any observer(s) estimates vary from the group average by more than the established threshold value and finally, repeating the exercise regularly (e.g., every two weeks) or each time the observers move to a different plant community. This approach aims to improve consistency and accuracy of observations at the pasture level by training observers to consistently estimate utilization of forage species, within the context of ecological potential, grazing intensity, timing, and duration. In the Zumwalt Prairie Preserve study, utilization estimates made by observers who had participated in the crew training exercises following these recommendations were more consistent as compared to estimates made by observers who had not taken part in the training exercises.[28]

The challenge of understanding livestock use across large landscapes

Many rangelands grazed by livestock are extensive land areas with large pasture sizes that exhibit varying degrees of use depending on the biotic and abiotic factors as well as management actions and infrastructure. While accurate field data on resource availability and resource use can be useful for identifying appropriate adaptive management, a noted weakness is that the area a single plot represents is often small (< 0.4 ha [1 acre]) or unknown.[34] Additionally, it can be cost-prohibitive to collect sufficient field data with probabilistic sampling designs to understand the amount and pattern of available forage and cattle distribution at the pasture, ranch or landscape scale.[9]

Knowing the amount and distribution of available forage, or residual biomass across large landscapes is difficult using data from traditional point-based field estimates, especially in the face of greater year to year climate variability. Without an understanding of how livestock carrying capacity changes across landscapes (over short and the long term), managers have the potential to overstock and harm the resource. Even if the amount of forage within a pasture is known with certainty, an added challenge is the undesirable distribution of the livestock across the landscape putting valued locations within pasture at risk of being overused. Our understanding of how livestock use rangeland resources is a product of decades of observational and behavioral studies which have been distilled into general guidelines for the expected distribution of livestock within pastures in relation to landscape features.[35,36] However, achieving accurate information on use patterns is difficult within large pastures typical of many rangeland grazing regimes because of the difficulties in locating and tracking livestock at sufficient temporal and spatial resolution.[37] This includes understanding when and where animals are grazing within pastures,[38] obtaining information on movement patterns in relation to temperature or water availability,[39] exploring interactions of livestock with wildlife populations,[40–42] and validating field-based measures of use.[28] Therefore, to better understand the interactions between livestock use and resource amount as well as wildlife, emerging technologies offer unique data sets to help improve use-based monitoring and inform adaptive management. We acknowledge that some of these technologies and suggestions may not be universally available or applicable currently, but are still worth presenting due to continued innovation, cost reduction and increasing availability overtime.

Addressing the challenge of estimating the resource and resource use across large landscapes with satellite remote sensing

Researchers have long sought to map vegetation attributes directly relevant to livestock grazing such as biomass or vegetation cover with remotely-sensed satellite data (e.g., Todd et al.[43]), but local management application of the developed products has been limited due to accuracy and scale issues, as well as timeliness and effectiveness of delivery to end users. By combining computer science, satellite data, and rangeland ecology, recent work has focused on the creation of online tools that display and visualize rangeland indicators derived from satellite data for adaptive management and decision making. Online tools provide access to biomass forecasts (e.g., Grass-Cast, https://grasscast.unl.edu/[18,19]), and monitor vegetation indicators such as cover or biomass production across years (e.g., The Rangeland Analysis Platform, https://rangelands.app/rap[44,45]) and in select locations standing herbaceous biomass across the grazing season (e.g., RangeSAT, https://www.rangesat.org/). These online tools and the underlying satellite derived vegetation datasets are created with the intention to empower ranchers and other land managers to use remotely-sensed satellite data to improve vegetation monitoring and help with decision making (See Allred et al.[46] this issue for more guidance on using satellite-derived maps for management).

Ongoing work on the Zumwalt Prairie Preserve highlights how remotely-sensed satellite data can be incorporated into use-based monitoring. For example, transforming Landsat satellite data to estimates of above ground herbaceous biomass as described by Jansen et al.[21] can provide maps of post grazing vegetation amounts (Fig. 5A), vegetation change maps using pre- and post-grazing images within a single grazing season (Fig. 5B), and maps or graphs of vegetation change over time at pixel (30 m × 30 m [98.4 feet × 98.4 feet]) and pasture scales (Fig. 5C). The Nature Conservancy on the Zumwalt Prairie Preserve is currently using pasture and ranch level statistics from this satellite-derived biomass data to assess grazing management yearly. Vegetation information provided by satellites with long data acquisition histories (e.g., the Landsat collection) also can be used to understand the variability of vegetation amount over time, which can provide

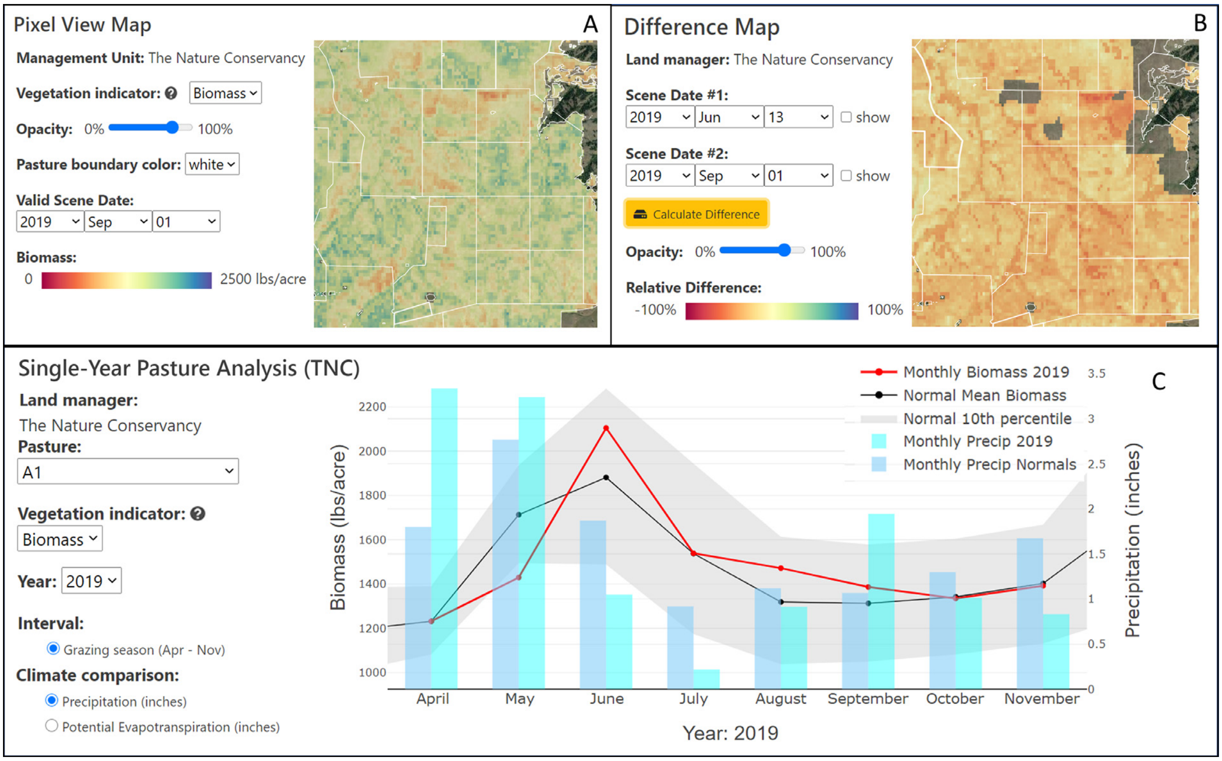

Figure 5. Select examples of RangeSAT (rangesat.org) tools that inform use-based monitoring and adaptive management. A, The Pixel View map displays 30 m (98.4 feet) resolution biomass data, here showing biomass for 1 September 2019, across a section of the Zumwalt Prairie Preserve, Oregon. B, The difference map allows users to display 30 m (98.4 feet) resolution relative difference maps for selected dates. Here the relative difference in biomass between 13 June and 1 September 2019 is displayed. C, The Single-Year Pasture Analysis tool provides a graph of average biomass within a select pasture over the growing season and includes climate data such as precipitation and temperature for the same location as the vegetation data for interpretation.

a clearer picture of carrying capacity and appropriate stocking rates. Also, many online tools either integrate or display climate data along with vegetation data (Fig. 5C), providing important context for interpreting the vegetation information and use-based monitoring data for the season or year(s) in question.

Linking satellite information to use-based monitoring can take many forms. Maps that display the change in biomass using pre- and post-grazing satellite images (i.e., relative difference maps) can inform managers and ranchers of where cattle are using a pasture or allotment more intensively compared with other areas (Fig. 6B), effectively providing a course-scale screening mechanism to monitor the landscape. These relative difference maps or residual biomass maps also can be used to optimize field data collection efforts by helping to locate and identify appropriate use-based sampling locations in more repeatable and objective ways either for targeted monitoring locations (i.e., key areas[29], Designated Monitoring Areas[47]) or to stratify an area for sampling design (e.g., Laurence-Traynor[28]).

To illustrate this idea, we mapped field-based utilization data following a modified Landscape Appearance method (Fig. 6A), GPS collar data (Fig. 6B), and the change in biomass, displayed as the relative difference in biomass from pre- (26 July 2020) and post-grazing (11 August 2020) Landsat satellite images (Fig. 6C) across the Main Gate Pasture on the Zumwalt Prairie Preserve (biomass data was created following Jansen et al.[21]). This pasture was grazed from 27 July to 4 Aug 2020, with a stocking rate of 0.89 animal unit months per hectare (0.36 animal unit months per acre). Comparing these datasets to each other at a 30 m × 30 m (98.4 feet × 98.4 feet) spatial resolution using Spearman rank correlations (ρ = correlation coefficient) revealed moderate to weak relationships: GPS collar data versus the field data ($\rho = 0.60$, $P < 0.001$, $n = 94$), GPS versus Landsat satellite data ($\rho = -0.44$, $P < 0.001$, $n = 97$), and field data to Landsat satellite data ($\rho = -0.28$, $P = < 0.01$, $n = 94$). The strength of the relationship between data is likely dependent on the spatial scale of the datasets (e.g., Laurence-Traynor[28]) and will be explored more in future work across more pastures and spatial scales. While the statistical relationships at the 30-m scales are moderate to weak, visual comparison of the field, satellite data, and GPS data showed that all three methods captured similar broad patterns within the pasture. The satellite-derived relative difference data (i.e., biomass change) had larger negative change (darker pixels) in higher use areas around the water sources, as indicated by the GPS data, but this data also mapped higher amounts of vegetation change in areas not associated with higher livestock use such as in the southern leg of the pasture. In general, the field data, specifically utiliza-

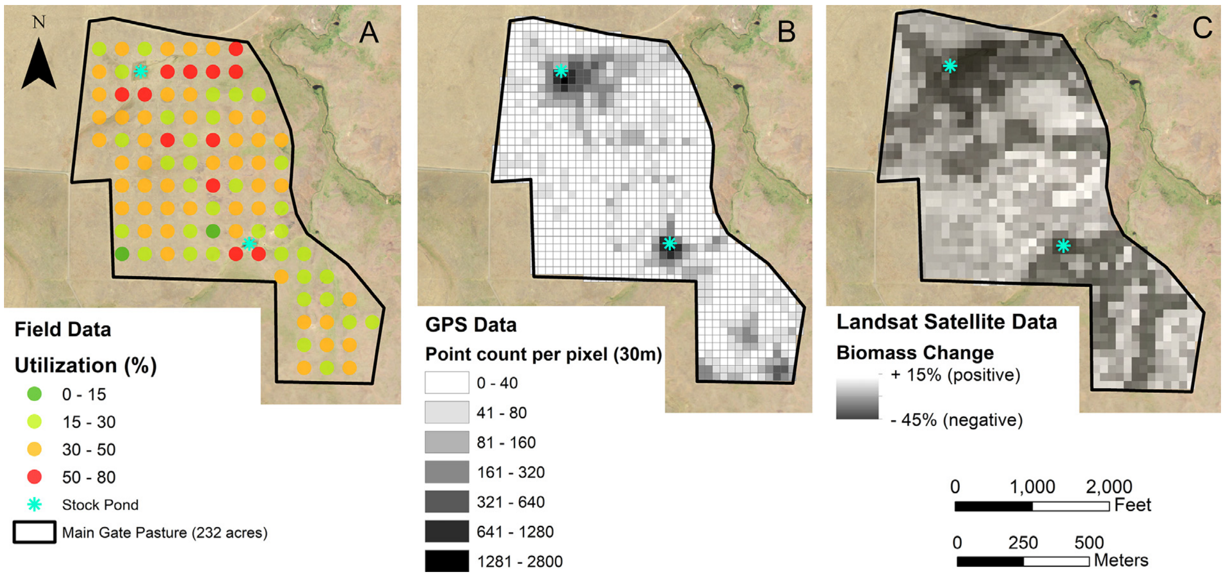

Figure 6. Data from 113 GPS collars (68% of the herd) tracking livestock use in the Main Gate pasture, which was grazed from 27 July to 4 August 2020 with a stocking rate of 0.89 animal unit months per hectare (0.36 animal unit months per acre) on the Zumwalt Prairie Preserve, Oregon for comparison with field-based estimates of utilization and satellite-derived predictions of biomass change. A, Map of field-based utilization data using a modified Landscape Appearance method (collected 5-6 August 2020). B, Map of GPS point data per 30 meters (98.4 feet) pixel, displayed as the number of points per pixel. C, Map of the relative difference in biomass computed using pre-grazing (26 July 2020) and post-grazing (11 August 2020) Landsat 8 satellite data and the biomass algorithm detailed in Jansen et al.[215]

tion measures >50%, also captured the heavier use around the stock ponds as well as in some other patches in the middle of the pasture (Fig. 6).

Although remotely-sensed data has the potential to complement and maximize the utility of in-field, use-based monitoring, adoption of these technologies is an ongoing process.[46] The usefulness and accuracy of the information provided by remotely-sensed data should be assessed in relation to specific monitoring and management questions. It is also important for end users to understand the differences and similarities between the field and remotely-sensed data in relation to the absolute accuracy (i.e., how well the data matches the phenomenon it represents), relative accuracy (i.e., how accurate is the data at detecting the correct fluctuations over time or space), as well as how data accuracy changes at different spatial scales (i.e., 1 pixel versus the average of all pixels across an area) and across the landscape. Integrating remotely-sensed vegetation information with other monitoring data is an ongoing area of research. Effective application of information provided by remote sensing to adaptive rangeland management will rely heavily on collaboration and feedback between tool creators and users. This will ensure that scientists and developers create user-friendly remote sensing-based tools, and that users have access to training as well as understand the intended applications of the data. It is also crucial that these tools are stable, maintained, and updated over long periods of time.

Addressing the challenge of estimating resource use across large landscapes with GPS data

Advances in GPS technology and reduced equipment costs now make it feasible to research livestock movements by tracking large proportions of livestock herds.[37,48,49] GPS data from collared livestock have improved researchers' and ranchers' understanding of relationships between cattle behavior and movement, forage utilization, and ultimately, rangeland health. Livestock GPS-collar data can augment utilization estimates by providing spatially and temporally explicit livestock distribution data that can be used to:

- Maintain accurate management records. The days and times cattle move into and out of each pasture can be used to calculate animal unit months by management unit, track how management plans were followed or altered, and maintain an accurate record of livestock movements between pastures or management units
- Understand the relationship between livestock movement and foraging behavior[38]
- Understand how livestock use pastures and how animal class, breed, and environmental factors interact to influence use patterns[37,39]
- Develop estimates of relative grazing intensity across the pasture (Fig. 6B)[50]
- Improve the placement of key-area or targeted monitoring plots
- Help train and or evaluate remotely-sensed vegetation models and provide more context to field estimates

The costs associated with purchasing and using livestock GPS collars are decreasing,[48,49] but the benefits of the data provided by these collars must still be weighed against the full costs of their use. Effective livestock GPS collars can be built relatively inexpensively, whereas commercial, ready-to-use units are more costly. Attaching and removing collars takes time, and processing and analyzing the GPS data requires additional time and technical skills. Current efforts to further reduce the cost and size of the collars through integration into existing cattle tagging procedures or emerging virtual fencing technologies may help overcome some of these barriers.[34,35]

GPS collars are a research tool more than a practical tool for ranchers and rangeland managers. Even with low-cost GPS collars, the cost to deploy collars on a large proportion of a herd is high. Data from most GPS collars are typically not returned in real time but collected after the grazing season, which requires additional handling of animals to remove the collars. Processing of the GPS data is also laborious (but improving, see Brennan et al.[51]), and analytical techniques are still in development (e.g., Augustine and Derner[38]). Thus, it is likely impractical for most ranchers and rangeland managers to deploy GPS collars in a way that would directly benefit their operations or be cost effective. Accordingly, the value of GPS collar technology at this time is in helping to understand livestock use of large landscapes (either through behavioral studies or direct mapping of grazing intensity), and the value of this technology to most ranchers and rangeland managers is in the learning achieved through research applications. Efforts to develop virtual fencing technologies[52,53] may ultimately provide easy-to-use tools for ranchers and rangeland managers to explore livestock location data to improve management, but such technologies are still in development and cost prohibitive for broad application.

The challenge of using use-based data to inform long-term management decisions

Use-based monitoring data provides vital information for describing the amount, distribution, and type of forage use by livestock and ultimately for making short-term management decisions about when and where to move livestock. However, the usefulness of short-term monitoring data to inform broad-scale management actions depends, in part, on how well they can be used in conjunction with long-term condition and trend monitoring datasets. Conversely, while long-term condition and trend monitoring provides important contextual information to support grazing management decisions, it cannot (and is not intended to) replace use-based monitoring. These short- and long-term approaches to monitoring have often been viewed as competing or mutually exclusive activities directed toward different management goals. However, successful integration of use-based and long-term monitoring can facilitate interpretations of how land uses affect land conditions, enabling land managers to effectively evaluate management and adjust to meet management objectives. This integration is often challenging because much of range management and use-based monitoring over the past 40 years has been tied to key areas whereas many long-term sampling locations are randomly located and may not all be suitable for comparison with use-based monitoring plots. We present several ideas for leveraging the wealth of long-term data to improve the design, implementation, and analysis of used-based monitoring.

Addressing the challenge by integrating use-based monitoring with long-term condition and trend data

Examining measures of utilization alongside long-term condition and trend data can help isolate the effects of grazing from changes caused by other land use activities, natural disturbances regimes, and changing climatic conditions. Consistent monitoring datasets like those built through the Bureau of Land Management's Assessment Inventory and Monitoring (AIM) collect data across much of the western United States and represent a wealth of information on the condition of soil and vegetation resources and are one source of consistent condition and trend data on US rangelands.[54,55] Approaches to tease out causal relationships using these datasets have been explored in relation to fire and vegetation treatment evaluations[56–58] and wind erosion,[59] but less so with grazing management. Such analyses could be facilitated by integrating use-based monitoring with long-term trend monitoring plans to make more direct conclusions on causal relationships and provide land managers the information required to close the loop of adaptive management. When using long-term condition and trend plots, such as the ones from AIM, alongside use-monitoring data it may be necessary to use selection criteria to filter to the most appropriate plots that could inform management. For example, excluding recently disturbed plots or plots located in proximity to water tanks, and including plots which are of similar ecological potential to the grazed area.

Effectively planning, designing, and implementing an integrated monitoring plan requires collaboration between land managers and ranchers incorporating the following strategies: 1) co-location of long-term trend plots with use-monitoring plots where possible; 2) collection of long-term trend data using standard protocols appropriate for assessing the identified long-term management objectives using standard methods (e.g., the core indicators collected as part of the AIM strategy)[60]; and 3) consideration of how the timing and location of long-term data collection relates to use-monitoring schedules to ensure the data are relatable.

Better understanding of resource condition and trend using quantitative benchmarks and monitoring objectives such as using the procedures outlined by Webb et al.[59] and Bureau of Land Management[61] also can provide valuable context for defining short-term use objectives and can encourage flexibility in grazing management when appropriate. For example, long-term condition and trend monitoring could be used to help define current conditions and expectations for forage species cover and biomass in wet vs. dry years, which could inform short-term management strategies such as annual stocking rates, utilization targets, and pasture use decisions. Together these quantitative datasets also could be used to produce quantitative and conceptual models of ecosystem change to better inform management decisions.[62]

Lastly, long-term condition and trend data on the amount and distribution of forage species as well as information on plant community shifts can help to guide selection of key species for measuring utilization. When selecting key species land managers should consider which species are present across all grazed areas throughout the grazing period and which species may be of particular resource value or are indicators of resource change.[29] Long-term condition and trend data can provide information about both the abundance of species and how they change over time, which can be used to inform key species selection for a particular grazing system. Ecological-site-specific state and transition models may be used to understand how an area may respond to grazing management, and to identify changes in species composition associated with undesirable changes in the plant community.[62,63] If long-term condition and trend data show large changes in the plant community occurring over time, it may be necessary to review and adjust identified key species and measurement-based methods so utilization estimates continue to provide useful information for managers.

Conclusions

A variety of strategies have been presented to improve the quality and usefulness of use-based monitoring. It is our goal that the value, interpretation, and applicability of these data increases as a result of selecting the best methods and approaches for collecting use-based field data, leveraging remote-sensing tools, integrating with trend monitoring, and adjusting sampling approaches in the face of changing conditions. While there are undoubtedly many ways to improve use-based data, we have suggested that key considerations include:

1) Leveraging remotely-sensed and climate data for improved efficiency and interpretation of field data;
2) Consideration of the experience and training of observers, the level of grazing intensity, the type, amount, and distribution of forage plants, and the resources and time available when selecting utilization methods;
3) Implementing study area-specific crew training exercises and intra-method calibration to reduce observer bias and improve utilization estimate accuracy and precision;
4) Encouraging the use of and learning from GPS technology to improve understanding of linkages between use-based monitoring and cattle behavior and distribution across pastures;
5) Planning and implementing use-based and long-term monitoring in tandem to inform causes of declining rangeland health; and
6) Using long-term monitoring to inform priority areas for prescribed grazing and provide plant community data for key species selection.

We recognize fully supporting these approaches will require additional research into the suitability of specific use-based field methods across a broad range of grazing systems, continuous work to integrate emerging remote-sensing science and monitoring technologies with socioeconomic and ecological objectives of rangeland management, and continued development and availability of web-based tools and mobile applications that help rangeland managers make informed decisions.[62,63] Undoubtedly, application of these approaches will be varied depending on land ownership, as well as management objectives with successful implementation dependent on a collaborative social-ecosystem perspective that includes ranchers, agency employees, consultants, and scientists.

Declaration of Competing Interest

The authors whose names are listed above certify that they have no financial interest in the subject matter discussed in the manuscript. J.W.K. is the current Editor in Chief of Rangelands but was not involved in the review or decision process 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.

Acknowledgments

The authors would like to thank The Nature Conservancy of Oregon, specifically Jeff Fields, Heidi Schmalz, and Mike Hale. We would also like to thank Wyatt Prescott for his time and thoughts on grazing management. This article was supported in part by funding from the Bureau of Land Management and a Conservation Innovation Grants from the USDA Natural Resources Conservation Service (NR193A750008G005). JWK received support from USDA National Institute of Food and Agriculture McIntire Stennis project 1014627.

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