Rangeland Ecol Manage 67:68–77 | January 2014 | DOI: 10.2111/REM-D-12-00178.1

Monitoring of Livestock Grazing Effects on Bureau of Land Management Land

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Abstract

Public land management agencies, such as the Bureau of Land Management (BLM), are charged with managing rangelands throughout the western United States for multiple uses, such as livestock grazing and conservation of sensitive species and their habitats. Monitoring of condition and trends of these rangelands, particularly with respect to effects of livestock grazing, provides critical information for effective management of these multiuse landscapes. We therefore investigated the availability of livestock grazing-related quantitative monitoring data and qualitative region-specific Land Health Standards (LHS) data across BLM grazing allotments in the western United States. We then queried university and federal rangeland science experts about how best to prioritize rangeland monitoring activities. We found that the most commonly available monitoring data were permittee-reported livestock numbers and season-of-use data (71% of allotments) followed by repeat photo points (58%), estimates of forage utilization (52%), and, finally, quantitative vegetation measurements (37%). Of the 57% of allotments in which LHS had been evaluated as of 2007, the BLM indicated 15% had failed to meet LHS due to livestock grazing. A full complement of all types of monitoring data, however, existed for only 27% of those 15%. Our data inspections, as well as conversations with rangeland experts, indicated a need for greater emphasis on collection of grazing-related monitoring data, particularly ground cover. Prioritization of where monitoring activities should be focused, along with creation of regional monitoring teams, may help improve monitoring. Overall, increased emphasis on monitoring of BLM rangelands will require commitment at multiple institutional levels.

Key Words: land health status, land use impacts, public lands, rangeland health, sagebrush steppe

INTRODUCTION

Effective rangeland management requires regular monitoring and assessment of natural resource status and management effects (Williams et al. 2007). Monitoring provides documentation of changes in resource status, and the resultant information should be used to make management adjustments and improve progress toward meeting management objectives. Numerous handbooks, technical references, and websites provide guidance on rangeland monitoring and assessment (e.g., Elzinga et al. 2001a; Herrick et al. 2005, 2009; Pellant et al. 2005; Karl et al. 2012), and there exists a long history of laws and initiatives intended to improve monitoring and status of rangelands in the western United States (e.g., recent BLM initiatives, such as Rapid Ecoregional Assessments and Assessment, Inventory, and Monitoring Strategy; for history of rangeland monitoring, see West 2003). Yet despite its importance, regular monitoring often is lacking and remains a systemic problem due to other priorities or to lack of resources, such as time, money and personnel. This is true not only for rangelands (West 2003) but also for natural resource management in general (e.g., Bernhardt et al. 2007; Kiesecker et al. 2007; Kettenring and Reinhardt Adams 2011).

Rangeland monitoring is an especially important issue for the Bureau of Land Management (BLM), which manages almost 1 000 000 km^2 of public land, of which 635 000 km^2 are managed for livestock grazing (BLM 2012). Private livestock operators are issued either grazing permits or leases that specify when and how intensely they may graze their allotments of BLM land. Grazing and monitoring of BLM lands, however, has long been steeped in conflict. Monitoring data, including their quality and interpretation, lies at the heart of much of this conflict. Organizations of interested people focused on ameliorating perceived negative effects of livestock grazing on public lands have regularly engaged the BLM in litigation (Pool 2010). At question is the status or health of rangelands. Monitoring data, collected by or provided to the BLM, should be able to provide answers but in many cases may be difficult to interpret and/or may be incomplete. Similarly, livestock operators also litigate against the BLM over disputes about enforcement or interpretation of federal regulations on their grazing allotments (Pool 2010). Again, high-quality monitoring

Research was funded as a part of US Geological Survey Sagebrush Ecosystems Coordinated Research (SECR).

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Manuscript received 13 December 2012; manuscript accepted 18 September 2013.

data could be used to provide a clear indication of rangeland status and clarify whether livestock grazing management is resulting in achievement of resource management objectives.

Rangeland monitoring and management on BLM land also has long been a subject of legislative actions. According to the Federal Land Policy and Management Act of 1976, the BLM must "manage the public lands under principles of multiple use and sustained yield" (Public Law 94–579, Sec. 302). The Public Rangelands Improvement Act of 1978 further commits federal land management agencies to providing regular updates on the condition and trend of rangelands. For the BLM, these legislative actions typically translate into management of livestock use in a way that sustains other land uses (e.g., wildlife conservation) and the monitoring of livestock grazing effects. Current grazing regulations require that monitoring data and/or field observations be used to support decisions about stocking rates on BLM allotments (43 CFR 4110.3). Thus, quantitative condition and trend data (commonly reported as ground cover and seral status) can directly influence management, and collection of these data constitutes a major priority for grazing management on BLM land.

In addition to collecting and reporting quantitative condition and trend data, the BLM also qualitatively evaluates land health across its allotments. Rangeland health indicators have long been used to determine rangeland status (West 2003) and, in combination with available quantitative data, are used to evaluate specific rangeland attributes or land health standards. In 1995, the BLM identified nationwide fundamentals of rangeland health that must address minimum standards for 1) watershed function; 2) nutrient cycling and energy flow; 3) water quality; 4) habitat for endangered, threatened, proposed, candidate, and other special status species; and 5) habitat quality for native plant and animal populations and communities (43 CFR 4180.2). The BLM also required individual regions to use these national standards to develop, in consultation with local Resource Advisory Councils, region-specific land health standards (LHS) and indicators. To evaluate land health, BLM field office personnel are required to perform individual on-the-ground evaluations of these standards in all grazing allotments. Evaluations are based on a suite of indicators associated with region-specific standards (see Table S1, available online at http://dx.doi.org/10.2111/REM-D-12-00178.s1).

Since 1997, livestock grazing practices on BLM land have been linked to the status of LHS; if an allotment fails LHS due to current livestock grazing management, appropriate corrective action must be taken, and the terms and conditions of the grazing permit may be adjusted (43 CFR 4180.2). If current grazing practices are identified as significant causal factors resulting in failure to meet LHS, management actions must be proposed to help achieve compliance (Fig. 1; 43 CFR 4180.2). In cases when allotments fail LHS, monitoring data can play a critical role in identification of causal factors (see Fig. 1). Yet BLM monitoring efforts have been criticized over the past several decades as being hampered by funding/personnel issues and confusion and inconsistencies associated with monitoring methods (West 2003). It is not clear at regional or rangewide scales which types of vegetation, soil, and livestock grazing–related monitoring data are being collected on BLM land, which methods are being used, or how consistently data are

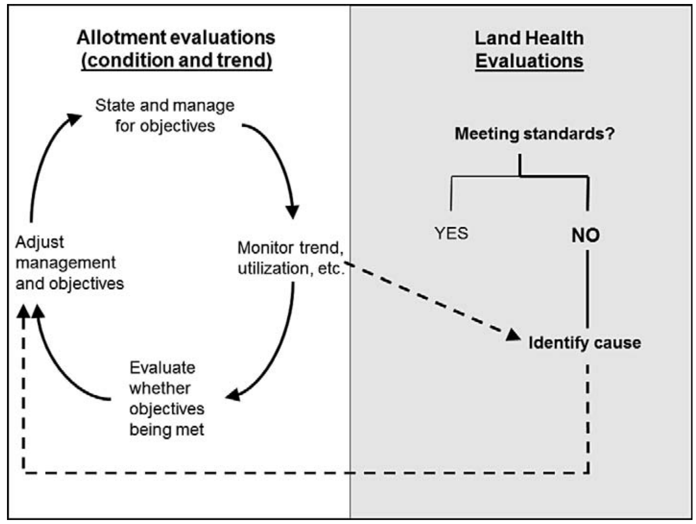

Figure 1. Schematic of (1) the BLM allotment evaluation process, which is based on monitoring data, and (2) the land health evaluation process, which is based on a combination of quantitative and qualitative rangeland health indicators. Dotted arrows indicate feedbacks between the two processes.

being collected, analyzed, and interpreted. Similarly, it is unclear whether these data sets are complete and sufficiently consistent across time and space to make regionwide assessments of livestock grazing effects on rangeland status.

The first major objective of our study was to address the availability and status of existing livestock grazing–related BLM monitoring and rangeland health data. Specifically, we 1) examined types, availability, and consistency of rangeland monitoring data from a sample of BLM offices and 2) evaluated the degree to which these data could be used to infer livestock grazing effects. Our second major objective was to use expert opinion to identify potential strategies for improving monitoring of rangeland status and livestock grazing impacts on BLM land. Our study focused on livestock grazing because it has been identified as a potential threat to Sage-Grouse habitat, yet there is no consistent means of evaluating its impact (Connelly et al. 2011).

METHODS

Field Office Sampling

We visited BLM field offices to evaluate availability of rangeland monitoring information. We first inspected individual grazing allotment files for the presence of grazing plans and/or allotment management plans (AMPs). Although not required, these plans outline specific resource management objectives relating to livestock grazing (e.g., forage allocations for wildlife or range improvements) and, in the case of AMPs, wildlife. We next inspected allotment files for availability of four types of monitoring data: 1) *Actual Use*—livestock numbers and grazing dates (self-reported by grazing allotment permittees or lessees), 2) *Utilization*—percent of current year's vegetation production consumed by animals, 3) *Vegetation Trend*—quantitative measures of plant community changes over time, and 4) *Photo Points*—repeated photos at fixed locations within the allotment. We did not inspect supporting riparian, wildlife, or wild horse data.

We inspected these data for a total of 310 randomly selected allotment files in 13 BLM offices (covering 15 BLM resource areas and six states) that fell within sagebrush (*Artemisia tridentata*) steppe and potential Greater Sage-Grouse (*Centrocercus urophasianus*) range. Seven of the 13 field offices we selected were among those already participating in a complementary BLM study exploring spatially explicit approaches to land health evaluations. The remaining six offices were selected semirandomly with preference given to offices with a history of cooperation or collaboration on previous or related projects. Thus, our BLM office selection is biased toward those with a greater willingness to participate and share monitoring data.

For each allotment, we recorded presence or absence of each data type (grazing/allotment management plans, Actual Use, Utilization, Vegetation Trend, and Photo Points) for every year between 1997 and 2007. We did not include earlier dates because data prior to 1997 were typically archived off location. We were unable to account for incomplete spatial coverage of data within a given allotment because sample locations changed over time and were inconsistently named (i.e., data were counted as present even if they existed for only a subset of pastures or key areas within that allotment). We then identified which of these 310 allotments were deemed by BLM to have not met LHS (see below). By examining data presence in the resulting subset of data, we were able to assess which monitoring information was available to support determinations of livestock-caused LHS failures.

The 310 allotments were stratified to be one-third "Maintain" ($n=109$) and two-thirds "Improve" ($n=201$). Since 1982, the BLM has been classifying allotments as Maintain or Improve, with the intention of concentrating monitoring efforts on Improve allotments (BLM WO IM 82–292). Allotments classified as Maintain are characterized by resource conditions that do not require management changes, while resource conditions in Improve allotments suggest a need for management changes. We excluded allotments classified as "Custodial" because management changes are considered unfeasible in those allotments. Custodial allotments are typically small, isolated pieces of federal land located within nonfederal land areas. "Uncategorized" allotments were also excluded.

LHS Data

To determine LHS status across all BLM land, we used a data set compiled by the national BLM office in 2008. Individual states/regions were responsible for translating the five nationwide fundamentals of rangeland health into their own state/region-specific standards. As a result, the specific content, wording, and number of standards varies across states/regions (Table S1, available online at http://dx.doi.org/10.2111/REM-D-12-00178.s1). Our examination of broad-scale patterns required us to standardize data by placing state or region-specific LHS into three universal categories relevant to livestock grazing: Upland, Riparian, and Biodiversity (Table S1, available online at http://dx.doi.org/10.2111/REM-D-12-00178.s1). We omitted standards that fell outside the scope of this study (e.g., air quality or water quality). For allotments where LHS evaluations were completed between 1997 and 2007, we determined if standards in our universal Upland, Riparian, and Biodiversity categories were "met" or "not met." If a standard was not met, we identified whether BLM attributed failure to meet the standard to livestock.

Expert Opinions

We assembled, through informal conversations, opinions of 20 federal rangeland scientists (representing the US Department of Agriculture [USDA]–Agricultural Research Service in six states, the USDA–Natural Resources Conservation Service [NRCS] in four states, and the USDA–Forest Service in one state) and 22 university rangeland scientists (representing 13 universities) on how best to monitor rangeland condition and livestock grazing effects. We selected rangeland experts based on their membership in the Society for Range Management, professional reputation, and record of peer-reviewed publications in rangeland science literature. We selected individuals who would not have a potential vested interest in the current monitoring system or any potential financial benefit or loss associated with current monitoring information. Conversations took place at the 2009 Society for Range Management annual meeting in Albuquerque, New Mexico, or over the telephone. We presented scientists with the following hypothetical monitoring scenario asking them to prioritize activities for monitoring of livestock grazing effects on rangeland resources: "Assuming a new piece of land has been acquired by the BLM or some other land management agency, how would you set up a monitoring program to (1) monitor rangeland condition, and (2) determine livestock impacts (that is, make explicit connection between livestock grazing and land condition)? First, what would be the single most important field measurement, and how would you interpret that data with respect to (1) and (2)? Second, if you could instate a full monitoring program for that piece of land, what would you do? Assume that one person can spend ½ day per year collecting this monitoring information. Also, assume that the number of livestock, dates of livestock grazing, and climate/rainfall information will be collected (outside of your ½ day monitoring program) and made available to you."

Statistical Analyses

For field office data, we used Pearson's chi-square contingency tests to compare presence of all four data types (Actual Use, Utilization, Trend, Photo Points) between all Maintain and Improve allotments sampled ($n=310$). Then, for each data type (Actual Use, Utilization, Trend, and Photo Point), we used contingency tests to compare data presence between the full data set and the subset of data that had failed LHS due to livestock. Specifically, we tested data presence for Maintain vs. Improve allotments for those two data sets. Next, we used analysis of variance (ANOVA) to test for differences in percent data presence among those four data types. Our model included a main effect of data type ($n=4$), a block effect of field office ($n=13$), and their interaction. The response variable was the arcsin-transformed percent presence of each data type.

For LHS data, we used a split-block ANOVA design to test for differences between allotment categories (Maintain/Improve) and among data types (Upland, Riparian, and Biodiversity). The model included BLM state offices as block, allotment category (Maintain/Improve) as subblock, data type as main treatment (Upland, Riparian, and Biodiversity), and all 2-way interactions. The model was run twice, first with arcsin square-root transformed "% of allotments meeting LHS" as the response variable and second with arcsin square-root transformed "% of allotments with unmet LHS attributed to livestock" as the response variable. In all cases, we used Tukey post hoc tests to compare among data types.

RESULTS

Field Office Sampling

Overall, more data were present for the 201 Improve than the 109 Maintain allotments we sampled, although differences were not significant (Table 1; $\chi^2=2.0$, $P=0.57$). We found that, between 1997 and 2007, allotment files contained significantly more Actual Use data (Maintain/Improve=59%/77%) and repeat Photo Point data (Maintain/Improve=53%/61%) than quantitative Vegetation Trend data (Maintain/Improve=34%/38%), with forage utilization present an intermediate amount (Maintain/Improve=51%/52%) (Table 1; $F_{3,36}=7.56$, $P=0.005$; Tukey $P<0.05$). We also found significant variation among field offices with respect to data availability ($F_{12,36}=3.69$, $P=0.001$).

Actual Use was reported in an average of 6.3 (of Maintain) and 6.8 (of Improve) of the 11 yr sampled (Table 1). Actual Use data were present for at least one of the 11 yr in 59% of the 109 Maintain and 77% of the 201 Improve allotments (Table 1). When Actual Use data were present for an allotment in a given year, data were not necessarily complete. This was especially the case on large multipermittee (e.g., 8–10 different livestock operators) allotments, where only a subset (e.g., one or two) of permittees may have reported numbers.

Although all field offices surveyed had some photo monitoring data, only 58% of all allotments were monitored with photo points. Those allotments were monitored an average of

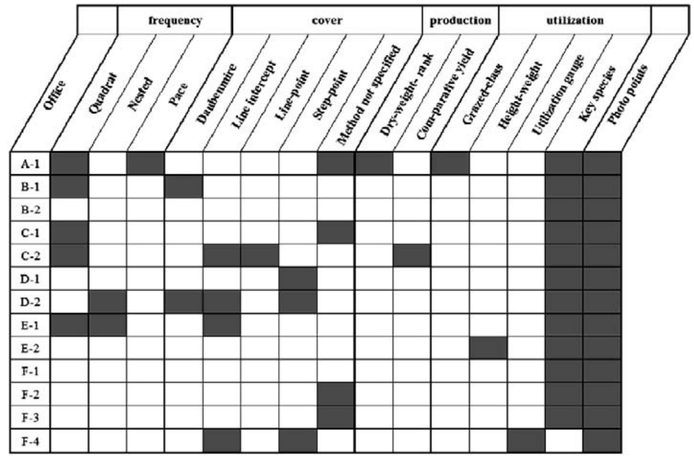

Figure 2. Shading indicates types of data (collected between 1997 and 2007) contained in a sample of 310 allotment files from 13 Bureau of Land Management (BLM) offices across six states (labeled A–F). All frequency, cover, and production techniques are described in the 1996 Interagency Technical Reference 1734-4, except Line-point, which is a variation of the point-intercept method. All Utilization techniques are described in the 1996 Interagency Technical Reference 1734-3(BLM 1996), except the Utilization Gauge method, which is a US Forest Service stubble height method. Both "State D" offices also collected Observed Apparent Trend data, a subjective numerical rating that considers vigor, seedlings, surface litter, pedestals, and gullies. Offices A-1, C-1, D-1, and D-2 also used 3×3 ft or 5×5 ft Range Trend Plots for visual estimates of key species attributes, such as cover, frequency, density, and vigor. Specific methodology varied across BLM offices.

1.3 (Maintain) and 1.7 (Improve) times between 1997 and 2007 (Table 1; Fig. 2). Additionally, we observed that even those allotments with little or no photo point data acquired during study years typically had earlier photo points from the 1960s through the 1980s. Utilization data had been collected at least once in the last 11 yr in 52% of allotments. All but one

Table 1. Top table summarizes office file results from 310 allotments selected at random across 13 Bureau of Land Management (BLM) field offices. Bottom table summarizes results from 62 of 310 allotments that cited livestock grazing as reason for not meeting at least one Land Health Standard. In both tables, allotments are divided into those being managed to "Maintain" vs. "Improve" rangeland condition. For each data type, "Freq." indicates the percentage of allotments across the region with at least 1 yr of data between 1997 and 2007 (although completeness of data within a given allotment is variable; e.g., some allotments may have data for only a subset of key areas or pastures). The "mean # yr" column indicates the average number of years for which data exist ± 1 SE (excluding allotments that had no data). AMP indicates allotment management plan.

	All sampled allotments				Allotments citing livestock issues			
	Maintain ($n=109$)		Improve ($n=201$)		Maintain ($n=17$)		Improve ($n=45$)	
Data type	Freq.	mean # yr	Freq.	mean # yr	Freq.	mean # yr	Freq.	mean # yr
1) Actual Use	59%	6.3 ± 0.5	77%	6.8 ± 0.3	47%	5 ± 1.2	84%	3.7 ± 0.6
2) Utilization	51%	4.4 ± 0.5	52%	4.7 ± 0.3	53%	2.6 ± 1.1	51%	4.4 ± 0.7
3) Vegetation Trend	34%	1.0 ± 0.0	38%	1.0 ± 0.0	35%	1.0 ± 0.0	36%	1.0 ± 0.0
4) Photo Points	53%	1.3 ± 0.1	61%	1.7 ± 0.1	65%	1.6 ± 0.2	71%	2.0 ± 0.2
AMP or grazing plan	17%	—	26%	—				
All four data types					35%	—	24%	—
Data types 1, 2, and 3					35%	—	27%	—
Data types 1 and 2					42%	—	49%	—
No data					29%	—	9%	—

Table 2. Results of Land Health Standards (LHS) evaluations conducted by Bureau of Land Management (BLM) allotments between 1997 and 2007. Allotments are divided into those managed to "Maintain" vs. "Improve" rangeland condition. For allotments that had "Not met" a standard, the "Livestock caused" column indicates the percentage of "Not met" due to livestock. Table summarizes whether allotments met all of their state Upland, Riparian, and Biodiversity Land Health Standards (three to five, depending on state; see Table S1). ANOVA indicates significant differences in meeting of "all standards" between Maintain and Improve allotments ($F_{1,18}$=7.74, P=0.02) and across states ($F_{9,18}$=31.27, P=< 0.0001). Standards that were "Not met" due to livestock differed significantly across states ($F_{9,18}$=3.14, P=0.02). Raw LHS data supplied by the BLM.

	"Maintain" allotments				"Improve" allotments					
State	Sample size	All standards met	≥ 1 standard not met	Livestock caused	Sample size	All standards met	≥ 1 standard not met	Livestock caused	No data	
A	n = 67	73%	27%	11%	n = 83	66%	34%	14%	n = 189	56%
B	n = 182	71%	29%	42%	n = 461	64%	36%	47%	n = 292	31%
C	n = 62	35%	65%	55%	n = 57	25%	75%	72%	n = 409	77%
D	n = 204	61%	39%	56%	n = 262	52%	48%	46%	n = 353	43%
E	n = 140	79%	21%	52%	n = 246	82%	18%	43%	n = 565	59%
F	n = 385	70%	30%	23%	n = 352	47%	53%	30%	n = 862	54%
G	n = 100	63%	37%	14%	n = 107	34%	66%	34%	n = 71	26%
H	n = 371	63%	37%	45%	n = 469	39%	61%	60%	n = 583	41%
I	n = 1463	87%	13%	47%	n = 670	68%	32%	56%	n = 124	5%
J	n = 130	89%	11%	14%	n = 180	85%	15%	41%	n = 1093	78%
Total	n = 3104	77%	23%	41%	n = 2887	59%	41%	48%	n = 4541	43%

office used the Key Species method (BLM 1996) of making ocular utilization estimates (Fig. 2). Quantitative vegetation trend data had been collected at least once in 11 yr in 34% of Maintain and 38% of Improve allotments and by 10 of 13 offices. Approaches to vegetation data collection, however, varied among offices (Table 1; Fig. 2). In particular, cover data were collected by 10 of 13 offices, with five different methods, and frequency data were collected by six offices, using three different methods (Fig. 2).

We found that 17% of Maintain and 26% of Improve allotments contained grazing or allotment management plans that had been updated since 1997. An additional 35% and 29%, respectively, contained plans that had last been updated prior to 1997 (Table 1).

LHS Data

Across all BLM allotments in the United States, the percentage of allotments with LHS evaluations completed between 1997 and 2007 ranged from 22% to 95% across surveyed states, with an overall average of 57% (Table 2). Of the 5991 allotments with completed LHS evaluations, the BLM found 67% to be meeting all LHS (77% of Maintain and 59% of Improve; Table 2) and 15% to have failed at least one standard due to livestock. Failures of Riparian standards were attributed to current livestock grazing management significantly more (63% of cases) than were Upland or Biodiversity standard failures (52% and 46%, respectively; Table S2, available online at http://dx.doi.org/10.2111/REM-D-12-00178.s2, Tukey $P < 0.05$). This effect appears to have been driven largely by the failure of Riparian Improve allotments (significant standards * allotment status interaction; Table S2, available online at http://dx.doi.org/10.2111/REM-D-12-00178.s2). We found that three offices did not use systematic indicator ratings for assessing uplands (e.g., Pellant et al. 2005), while nine did, and one was unknown.

Land Health Standards and Monitoring Data

We examined which types of data were being collected to support determinations that current livestock grazing management contributed to failures in meeting LHS. In our sample of 310 allotment files, we found that when current livestock grazing management was identified as the reason for not meeting LHS (n=62), Actual Use data were present for 47% of Maintain and 84% of Improve allotments (Table 1), and forage utilization measurements had been made in 52% of these allotments (Table 1). Quantitative vegetation data were present for 35% of allotments failing due to current livestock grazing management, though additional vegetation data could potentially be gleaned from permanent photo points, which were present for 69% of allotments (Table 1). A full complement of monitoring data (four data types) was present for 27% of allotments, while 15% lacked data entirely (Table 1). Overall, the amount of data associated with the 62 Maintain and Improve allotments failing standards due to current livestock grazing management did not differ significantly from the full data of 310 allotments (Actual Use χ^2=2.3, P=0.13; Utilization χ^2=0.53, P=0.47, Trend χ^2=0.28, P=0.60; Photo Points χ^2=0.68, P=0.41).

Expert Opinions

Overall, federal and university rangeland scientists expressed relatively similar opinions on our discussion topics (Table 3). For data presentation, we separate our results for these two groups, but given our small sample sizes, we did not attempt to analyze group differences statistically.

Ground cover (including vegetation, litter, rocks, biotic crusts, and bare soil) was the quantitative variable most consistently identified by federal and university rangeland scientists (55% and 70%, respectively) as a top-priority field measure for monitoring rangeland condition and livestock effects (Table 3). Although measures of bare ground are

Table 3. Results of informal conversations with federal and university rangeland science experts on how best to prioritize monitoring of rangeland condition and livestock impacts. Experts were presented with a hypothetical monitoring scenario. Of the 22 university scientists, three participated in a group conversation and expressed consensus opinions; they are therefore counted as a single expert.

Monitoring priority	Federal (n=20)	University (n=20)
Cover	55%	70%
Bare ground	25%	15%
Gap	5%	5%
Production	10%	10%
Frequency	5%	0%
Density	10%	10%
Utilization	35%	25%
Cattle and/or wildlife condition	5%	10%
Soils	25%	10%
Reference areas or ecological sites	30%	40%
Photos	30%	15%
Remote sensing	30%	35%
Identification of at-risk areas	25%	15%

implicit in some approaches to cover measurement, 45% of federal and 21% of university scientists who mentioned cover also specifically mentioned bare-ground measurements, as did one other federal scientist (who had not specifically mentioned cover). Additionally, 5% of federal and university scientists mentioned gap measurements (which quantify the proportion of ground occupied by interplant gaps and provide information about potential for erosion). In addition to bare ground, 25% of federal and 10% of university scientists specifically mentioned soil measurements, such as aggregate stability and compaction.

Utilization measures were suggested by 35% of federal and 25% of university scientists as a highest monitoring priority (with an additional 15% of university scientists mentioning it as a secondary measure). Methodological approaches varied among individuals and included utilization cages (three federal and two university scientists), stubble height or residual biomass (four federal/five university), use pattern mapping (two university), and height/weight calculations (one university).

Thirty percent of federal and 40% of university scientists stressed the importance of having a reference for comparison when monitoring (Table 3). These bases for comparison included ungrazed reference areas (four federal and three university scientists), moderately grazed reference areas (three university), and NRCS ecological site descriptions (three federal and four university).

Thirty percent of federal and 15% of university scientists recommended using repeat photo points as a primary approach to vegetation and soil monitoring (with an additional 15% of university mentioning it secondarily; Table 3). Approaches included traditional methods of returning regularly to fixed locations to take landscape and ground plot photos as well as more intensive photo sampling along transects.

The use of remote sensing was suggested by 30% of federal and 35% of university scientists (Table 3). Approaches included high-resolution aerial photography (from airplane or lower-flying remotely controlled devices) and satellite imagery. In many of these cases, remote sensing was suggested as a tool for identifying risk and/or prioritizing monitoring activities. Overall, 25% of federal and 20% of university scientists mentioned the importance of using some type of tool or indicator (e.g., remote sensing or other ground-based assessment) to prioritize monitoring. One expert suggested that monitoring programs could be improved by forming specialized regional monitoring teams.

DISCUSSION

Increased emphasis on collection of monitoring information, especially if data were collected with more consistent methodology, could facilitate reporting of condition and trend of BLM rangelands and enhance data-supported justification for management decisions. Such a shift in emphasis would likely not rely solely on action taken at the level of individual BLM field offices but rather would require increased commitment of resources at the institutional level. Standardization of techniques is a balancing act that requires cost–benefit analyses of various science-based approaches with input from the institution, science community, and interested stakeholders. The current BLM Assessment, Inventory, and Monitoring Strategy has attempted to move the agency in this direction (Herrick et al. 2010b; Toevs et al. 2011).

We found that when current livestock grazing management was identified as the reason an allotment failed to meet LHS, 27% of allotments possessed a full complement of data to support that determination, while 15% lacked data entirely. Monitoring data are needed for these determinations for two major reasons. First, although use of key indicators provides information on whether LHS are being met at the time of assessment, the process does not provide information about causality (e.g., Pellant et al. 2005). Instead, causality can be gleaned from regularly collected monitoring data (e.g., livestock numbers, utilization, and vegetation trend; Fig. 1). Second, BLM grazing regulations require that if an allotment fails LHS due to current livestock grazing management, appropriate corrective action must be taken, and the terms and conditions of the grazing permit may be adjusted (43 CFR 4180.2). Although expert opinion of BLM personnel may provide accurate assessments of livestock grazing effects, grazing management and permit adjustment decisions are difficult to defend in the absence of long-term monitoring data and may lead to legal challenges of such decisions.

Vegetation Cover and Frequency

Rangeland experts identified ground cover as one of the most important field measures for monitoring rangeland condition and livestock impacts (when combined with livestock actual use, season of use, and climate data). Methods for measuring cover are included in BLM technical manuals, and most BLM offices we surveyed conducted cover measurements. Cover measurements made by species, life form, or functional group can provide key information about health and functioning of plant communities and ecosystem properties (Herrick et al. 2005). Furthermore, cover measurements often include measurements of bare ground, with higher-than-normal bare ground typically reflecting increased potential for soil degradation (Pellant et al. 2005). Cover measurements are best made at phenologically consistent times within and across management units (to account for changes over a growing season, such as presence/absence of short-lived annual plants or leafing out of perennial plants) and, where possible, before major precipitation events occur that may contribute to soil erosion. Other potential approaches include focusing on perennial vegetation cover, which is the least sensitive to time of year, and acquisition of remotely sensed cover data that can be timed to control for time of year. Measures of interplant distances (i.e., basal gap or canopy intercept) also are less sensitive to timing and serve as useful supplemental indicators of longer-term change and potential for erosion (Herrick et al. 2005).

A supplementary approach to on-the-ground cover measurements is use of photo points. Overhead views of small (e.g., 1×1 m) permanent plots and landscape views can be repeated over time to track bare ground and cover by species or functional groups and detect significant landscape-scale changes in vegetation (Elzinga et al. 2001b; Herrick et al. 2005; Webb et al. 2010). Intensive sampling of multiple points along transects and use of high-resolution panoramic images are potentially useful modifications to standard photo point methodology (e.g., Nichols et al. 2009). Photo sampling is quick and inexpensive and requires little training. Moreover, qualitative or quantitative assessments of photos can be performed in the office, freeing up field time for other monitoring activities. In the case of the BLM, despite representing the most complete historic vegetation information, photo points were not used extensively or consistently over time; only 58% of allotments in our sample had been surveyed with photo points, on average less than twice in 11 yr. Increased emphasis on photo point data may provide opportunities for improvements in both quantitative and qualitative assessments, and photographic evidence also may provide the most compelling evidence when grazing decisions are contested and people are unfamiliar with data interpretation.

Alternative vegetation measures such as frequency (i.e., presence/absence data) may be easier and faster to collect and allow greater flexibility in timing of data collection. However, frequency may serve as a poor early-warning indicator because it detects only declines with plant mortality and is not likely to detect more subtle (but potentially important) reductions in plant vigor within plant communities. For example, decreasing plant cover or vigor, assuming that weather was not the cause, may indicate a need for intervention but would not be detected by frequency measures. Conversely, for specific plant species or functional groups (e.g., rare plants, invasive species, and woody species), methods such as frequency or density may be well suited to assessing increases in their status and making predictions about future distributions (Elzinga et al. 2001b).

Grazing and Climate Information

Interpreting and relating vegetation and ground cover data to livestock grazing requires information on grazing intensity and timing. Grazing intensity, including stocking rate, duration, and frequency, as well as timing of grazing relative to plant phenology, has consistently been identified as a factor affecting ecosystem and rangeland health (Briske et al. 2008; Vallentine 1990). We found that grazing information (Actual Use) was commonly available for BLM allotments (Table 1). Utilization information was less available. Although measuring utilization can be problematic (Jasmer and Holechek 1984), utilization information can be helpful for making causative links between grazing and vegetation changes. For example, heavy use by free-roaming ungulates, such as wild horses, can reduce plant cover or increase erosion. In such cases, Actual Use data indicating only moderate livestock numbers, coupled with Utilization and Vegetation Trend data indicating heavy use, could highlight the need to examine effects of free-roaming ungulates. In other cases, if livestock are the only known large herbivore grazers and both Actual Use and Utilization indicate only moderate livestock use, poor rangeland health may point to other causes, such as historic grazing intensity or energy development activities.

Climate and weather data, particularly inter- and intra-annual variation in precipitation, provide necessary context for interpreting vegetation and livestock grazing information. Grazing information, coupled with climatic data, can be used to retrospectively examine appropriateness of stocking rates. For instance, yearly rainfall amounts have a direct bearing on impacts of a given grazing intensity (Thurow and Taylor 1999), and timing of grazing relative to rainfall (and phenology) also determines how grazing affects plants (Briske and Richards 1995). Likewise, any long-term trends in vegetation cover would be strongly affected by lengthy drought periods, both with and without grazing. Improved and continued efforts to collect and ensure accuracy of grazing information, along with climate data collected by BLM offices or regularly retrieved from other sources (e.g., the National Oceanic and Atmospheric Administration), would aid interpretation of monitoring data. Similarly, assessments of long-term relationships between grazing and climatic patterns could provide insights into how rangelands might respond to future climate scenarios and suggest whether permitted grazing amounts may need to be adjusted to cope with altered climate patterns. This type of approach remains an active area of research due to the challenge of quantifying climatic factors across complex landscapes, with sometimes limited historical climate data.

Identification of At-Risk Areas

Almost one-quarter of experts specifically mentioned identification of areas at high risk of degradation to help prioritize monitoring. Although the BLM already classifies allotments as "Maintain" or "Improve" with the intention of prioritizing monitoring of the latter, more "at risk" sites, we did not find significant differences in data availability between the two allotment classifications. Moreover, a potential pitfall of this approach is that it may not include areas in good condition, and the resulting data may erroneously represent overall conditions as being worse than they really are. Alternative approaches, such as the "key area" approach, which entails monitoring representative areas that contain dominant livestock forage, also may not provide an accurate representation of the condition of a larger area. Potential remedies include 1) prioritizing and dedicating more resources to monitoring and 2) creating more efficient monitoring plans that are applied over a greater percentage of total land area. Recent efforts out of the BLM National Operations Center include development of an ecological site-based stratification and sampling approach to more effectively evaluate LHS status of a given allotment (Taylor et al. 2012). This approach attempts to reconcile that an allotment may be characterized by high variability in factors such as land form, species composition, land use history, and ultimately LHS status.

The identification and subsequent monitoring of at-risk areas can, however, play a positive role in a monitoring program provided that it does not replace efforts to create a more complete picture of overall rangeland status. On the one hand, areas in good or excellent condition may yield the best payoff of management and conservation efforts. On the other hand, areas that appear to be at or near thresholds of change (in a state-and-transition model framework) may be the ideal sites to more intensively manage, thereby maintaining and/or improving range conditions (Bestelmeyer 2006). Potential tools include on-the-ground indicators (e.g., bare ground, vegetation gaps, and biotic crusts that are sensitive to grazing), Geographic Information Systems analyses (e.g., use of stocking rate and ecological site information to identify areas more vulnerable or less resilient to grazing), and remote sensing. Remotely sensed data in particular can be used to assess ecosystem properties at multiple scales (Booth and Cox 2009; Bradley and O'Sullivan 2011; Homer et al. 2012; Rango et al. 2009), identify thresholds of change (Homer et al. 2012; Xian et al. 2012), and monitor changes in rangeland health conditions (see Xian et al. 2012).

Monitoring Teams and Participatory Monitoring

Yearly monitoring may be difficult to accomplish because it typically requires significant time investment for travel to remote areas and conducting field sampling methods. One potential remedy is regular but less frequent monitoring by state- or regional-level field monitoring teams that emphasize centralized training and the use of consistent methodologies across the state/region. One model for this approach is the Utah Division of Wildlife Resources Range Trend Studies program, which uses a centralized state-level field team to collect trend data at designated key areas throughout the state (http://wildlife.utah.gov/range). Monitoring of vegetation variables occurs on a 5-yr cycle for each land unit such that only a subset of land units must be monitored in a given year. If adopted by the BLM, this type of approach could facilitate regular monitoring by ensuring appropriate expertise and consistency in the execution of field methods. This approach could free time for rangeland management specialists to make more frequent qualitative observations and measure complementary short-term variables (e.g., yearly utilization) over greater land areas. More time also could be dedicated to nurturing relationships with permittees and gleaning information from their experience and knowledge of the land. To be effective, this type of data-intensive approach would require that a data storage and analysis plan be in place (James et al. 2003). Use of monitoring teams may not constitute a dramatic shift in monitoring approach for the BLM; in some cases, allotment permittees already contract with private organizations to monitor BLM allotments (C. Addy, personal communication).

Another model for increasing monitoring capacity is participatory monitoring by livestock operators. Permittees typically are already engaged in the management of their allotments, working closely with BLM personnel to determine pasture rotations, annual grazing adjustments, and other management actions that are too specific to be covered under the more general grazing permit (which specifies maximum animal unit months and grazing dates at the scale of the whole allotment). The BLM could further engage permittees by formally involving them in the monitoring process. Accordingly, the BLM has a Memorandum of Understanding (MOU WO 220-2004-1) with the Public Lands Council of the National Cattlemen's Beef Association to foster and provide guidance for participatory monitoring of BLM land by permittees/lessees. Participatory monitoring has been shown to be effective for rangelands (Curtin 2002; Herrick et al. 2010a) in part because ranchers can provide site-specific information that aids the monitoring process (Knapp and Fernandez-Gimenez 2009). Monitoring that is done collaboratively (e.g., participation by both BLM and permittees) also increases transparency of the monitoring process, facilitating trust building among participants (Cundill and Fabricius 2009; Fernandez-Gimenez et al. 2008). The Pinedale, Wyoming, BLM field office initiated a participatory monitoring program in 2004 (http://www.blm.gov/wy/st/en/field_offices/Pinedale/range/4Cs.html). The program ran successfully for 4 yr until grazing was suspended due to energy development. There are current plans to resume the program because of strong interest by permittees (R. C. Lopez, personal communication). Several handbooks on participatory monitoring are available (e.g., Peterson 2006; Flintan and Cullis 2010).

IMPLICATIONS

Effective monitoring programs require long-term data to be collected regularly and with consistent methodology over time. Although BLM monitoring could be improved on both accounts, encouragingly, the primary methods being used by BLM offices are largely consistent with methods recommended by rangeland experts. Thus, in cases where sound, historic data exist, methodologies should arguably be retained for future sampling efforts to facilitate long-term data analysis (Sergeant et al. 2012). Consistency of monitoring approaches across allotments or regions, along with collection of local-level data that are amenable to broader-scale analyses, would aid landscape-scale management, such as conservation and maintenance of ecosystem services, which transcend field office and political boundaries. Thus, protocols may require supplementation with additional, more standardized methods. Cases where little historic data exist represent excellent opportunities to revise protocols for standardization across sites and regions.

Many handbooks, guides, and research programs are available to guide BLM monitoring efforts (e.g., BLM 1999; Elzinga et al. 2001a, 2001b; Herrick et al. 2005, 2009; USDA-NRCS 2009). Both deciding among the many methods/approaches and implementing landscape-scale coordinated monitoring efforts will require decision making at and guidance from levels higher than individual BLM field offices. Coordinated efforts could include unified prioritization strategies and monitoring teams (discussed above). Collaborations between research and management could also help reconcile the benefits of using consistent methodology across broad scales vs. the need to use a diversity of methods to effectively sample ecologically variable sites across broad scales.

ACKNOWLEDGMENTS

Thank you to Mike "Sherm" Karl, Philip Cooley, Bill Andersen, Craig MacKinnon, Bob Hopper, Jon Sadowski, Tim Carrigan, John Reitsma, Mike Pellant, Pat Clark, Steve Smith, Steve Knick, and Zack Bowen for their insights and advice and to the state and district BLM staff who provided their cooperation and assistance. Thank you to Chris Campton for assistance with field office data collection. We also thank the university and federal range scientists whose insights helped us develop and refine many of the ideas we have presented here. Fee Busby, Sue Phillips, Mike "Sherm" Karl, and two anonymous reviewers provided helpful comments on earlier drafts. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the US government.

LITERATURE CITED

Bernhardt, E. S., E. B. Sudduth, M. A. Palmer, J. D. Allan, J. L. Meyer, G. Alexander, J. Follastad-Shah, B. Hassett, R. Jenkinson, R. Lave, J. Rumps, and L. Pagano. 2007. Restoring rivers one reach at a time: results from a survey of U.S. river restoration practitioners. *Restoration Ecology* 15:482–493.

Bestelmeyer, B. T. 2006. Threshold concepts and their use in rangeland management and restoration: the good, the bad, and the insidious. *Restoration Ecology* 14:325–329.

[BLM] Bureau of Land Management. 1996. Utilization studies and residual measurements, Interagency Technical Reference 1734-3. Denver, CO, USA: Bureau of Land Management National Applied Resource Sciences Center.

[BLM] Bureau of Land Management. 1999. Sampling vegetation attributes, Interagency Technical Reference 1734-4. Denver, CO, USA: Bureau of Land Management National Applied Resource Sciences Center.

[BLM]. Bureau of Land Management 2012. National Bureau of Land Management Website. Available at: http://www.blm.gov/wo/st/en/prog/grazing.html. Accessed 13 December 2012.

Booth, D. T., and S. E. Cox. 2009. Dual-camera, high-resolution aerial assessment of pipeline revegetation. *Environmental Monitoring and Assessment* 158:23–33.

Bradley, B. A., and M. T. O'Sullivan. 2011. Assessing the short-term impacts of changing grazing regime at the landscape scale with remote sensing. *International Journal of Remote Sensing* 32:5797–5813.

Briske, D. D., J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Willms. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology & Management* 61:3–17.

Briske, D. D., and J. H. Richards. 1995. Physiological responses to defoliation: a physiological, morphological, and demographic evaluation. *In:* D. J. Bedunah and R. E. Sosebee [eds.]. Wildland plants: physiological ecology and developmental morphology. Denver, CO, USA: Society for Range Management.

Connelly, J. W., S. T. Knick, C. E. Braun, W. L. Baker, E. A. Beever, T. Christiansen, K. E. Doherty, E. O. Garton, S. E. Hanser, D. H. Johnson, M. Leu, R. F. Miller, D. E. Naugle, S. J. Oyler-McCance, D. A. Pyke, K. P. Reese, M. A. Schroeder, S. J. Stiver, B. L. Walker, and M. J. Wisdom. 2011. Conservation of Greater Sage-Grouse. *In:* S. T. Knick and J. W. Connelly [eds.]. Studies in avian biology, 38, ecology and conservation of a landscape species and its habitats. Berkeley, CA, USA: University of California Press. p. 549–646.

Cundill, G., and C. Fabricius. 2009. Monitoring in adaptive co-management: toward a learning based approach. *Journal of Environmental Management* 90:3205–3211.

Curtin, C. G. 2002. Integration of science and community-based conservation in the Mexico/U.S. borderlands. *Conservation Biology* 16:880–886.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 2001a. Measuring and monitoring plant populations. Denver, CO, USA: Bureau of Land Management National Applied Resource Sciences Center. BLM Technical Reference 1730-1.

Elzinga, C. L., D. W. Salzer, J. W. Willoughby, and J. P. Gibbs. 2001b. Monitoring plant and animal populations. Malden, MA, USA: Blackwell Science.

Fernandez-Gimenez, M. E., H. L. Ballard, and V. E. Sturtevant. 2008. Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. *Ecology and Society* 13:1–22.

Flintan, F., and A. Cullis. 2010. Participatory rangeland management in pastoral areas. London, UK: Save the Children.

Herrick, J. E., V. C. Lessard, K. E. Spaeth, P. A. Shaver, R. S. Dayton, D. A. Pyke, L. Jolley, and J. J. Goebel. 2010a. National ecosystem assessments supported by scientific and local knowledge. *Frontiers in Ecology and the Environment* 8:403–408.

Herrick, J. E., J. W. van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume 2. Las Cruces, NM, USA: Jornada Experimental Range.

Herrick, J. E., J. W. van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2009. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume 1. Las Cruces, NM, USA: Jornada Experimental Range.

Herrick, J. E., S. Wills, J. Karl, and D. A. Pyke. 2010b. Terrestrial indicators and measurements: selection process and recommendations. Available at: http://jornada.nmsu.edu/sites/default/files/AIM_Terrestrial_Indicators_Selection.pdf</ italic. Accessed 11 October 2012.

Homer, C. G., C. L. Aldridge, D. K. Meyer, and S. J. Schell. 2012. Multi-scale remote sensing sagebrush characterization with regression trees over Wyoming, USA: laying a foundation for monitoring. *International Journal of Applied Earth Observation and Geoinformation* 14:233–244.

James, L. F., J. A. Young, and K. Sanders. 2003. A new approach to monitoring rangelands. *Arid Land Research and Management* 17:319–328.

Jasmer, G. E., and J. L. Holechek. 1984. Determining grazing intensity on rangeland. *Journal of Soil and Water Conservation* 39:32–35.

Karl, J., B. Unnasch, J. Herrick, J. Gillam, and M. Kanaga. 2012. LandscapeToolbox rangeland methods guide. Available at: http://www.landscapetoolbox.org. Accessed 21 September 2012.

Kettenring, K. M., and C. Reinhardt Adams. 2011. Lessons learned from invasive species control experiments: a systematic review. *Journal of Applied Ecology* 48:970–979.

Kiesecker, J. M., T. Comendant, T. Grandmason, E. Gray, C. Hall, R. Hilsenbeck, P. Kareiva, L. Lozier, P. Naehu, A. Rissman, M. R. Shaw, and M. Zankel. 2007. Conservation easements in context: a quantitative analysis of their use by the Nature Conservancy. *Frontiers in Ecology and the Environment* 5:125–130.

Knapp, C. N., and M. E. Fernandez-Gimenez. 2009. Knowledge in practice: documenting rancher local knowledge in northwest Colorado. *Rangeland Ecology & Management* 62:500–509.

Nichols, M. H., G. B. Ruyle, and I. R. Nourbakhsh. 2009. Very-high-resolution panoramic photography to improve conventional rangeland monitoring. *Rangeland Ecology & Management* 62:579–582.

Pellant, M., P. Shaver, D. A. Pyke, and J. E. Herrick. 2005. Interpreting indicators of rangeland health. Version 4. Denver, CO, USA: Bureau of Land Management, National Science and Technology Center. Technical Reference 1734-6.

Peterson, E. 2006. B-1169. Implementing a cooperative permittee monitoring program. Laramie, WY, USA: University of Wyoming Cooperative Extension Service.

Pool, J. R. 2010. An end to grazing lease litigation: an examination of alternative dispute resolution schemes that could resolve the overgrazing dispute on state and federally owned rangelands in the western United States. *Pace Environmental Law Review* 325:1–29.

Rango, A., A. Laliberte, J. E. Herrick, C. Winters, K. Havstad, C. Steele, and D. Browning. 2009. Unmanned aerial vehicle-based remote sensing for rangeland assessment, monitoring, and management. *Journal of Applied Remote Sensing* 3:1–15.

Sergeant, C. J., B. J. Moynahan, and W. F. Johnson. 2012. Practical advice for implementing long-term ecosystem monitoring. *Journal of Applied Ecology* 49:969–973.

Taylor, J., G. Toevs, J. Karl, M. Bobo, M. Karl, S. Miller, and C. Spurrier. 2012. AIM-monitoring: a component of the BLM assessment, inventory, and monitoring strategy. BLM/OC/ST-13/001+1735. Denver, CO, USA: US Department of the Interior, Bureau of Land Management, National Operations Center.

Thurow, T. L., and C. A. Taylor. 1999. Viewpoint: the role of drought in range management. *Journal of Range Management* 52:413–419.

Toevs, G. R., J. W. Karl, J. J. Taylor, C. S. Spurrier, M. S. Karl, M. R. Bobo, and J. E. Herrick. 2011. Consistent indicators and methods and a scalable sample design to meet assessment, inventory, and monitoring information needs across scales. *Rangelands* 33:14–20.

[USDA-NRCS] US Department of Agriculture–Natural Resources Conservation Service. 2009. National range and pasture handbook. Available at: http://www.glti.nrcs.usda.gov/technical/publications/nrph.html. Accessed 3 January 2011.

Vallentine, J. F. 1990. Grazing management. San Diego, CA, USA: Academic Press.

Webb, R. H., D. E. Boyer, and R. M. Turner [eds.]. 2010. Repeat photography: methods and applications in the natural sciences. Washington, DC, USA: Island Press.

West, N. E. 2003. History of rangeland monitoring in the USA. *Arid Land Research & Management* 17:495–545.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2007. Adaptive management: the U.S. Department of the Interior technical guide. Washington, DC, USA: US Department of the Interior, Adaptive Management Working Group.

Xian, G., C. Homer, and C. Aldridge. 2012. Assessing long-term variations in sagebrush habitat—characterization of spatial extents and distribution patterns using multi-temporal satellite remote-sensing data. *International Journal of Remote Sensing* 33:2034–2058.