Chapter 4. Assessing Ecological Integrity Using Multiscale Information from Bureau of Land Management Assessment and Monitoring Programs

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Abstract

The Bureau of Land Management manages 246 million surface acres (100 million hectares) across the United States for multiple uses and sustained yield. Ensuring protection of ecological systems in the context of multiple, and often conflicting, resource uses and values is a challenge. Ecological integrity and land health are terms used by the Bureau of Land Management to describe the condition of ecological systems. Ecological integrity refers to the ability of ecological systems to support and maintain a community of organisms that is similar in composition, structure, and function to natural habitats within the region. We present a framework and process for assessing ecological integrity in terrestrial systems that accommodates the multiple-use mission of the Bureau of Land Management and is designed to inform future management actions. The nine steps in the assessment process are specifying the management question, identifying target resources and key stressors, defining spatial and temporal scales of analysis, selecting and evaluating indicators, defining the natural and acceptable range of variation for indicators, collecting and analyzing data, reporting results, using the results to inform and evaluate management actions, and repeating the assessment. We illustrate the process through a conceptual example outlining how the ecological integrity of rangelands across the western United States could be quantified. We propose a suite of six field-based indicators and six complementary broad-scale indicators to provide multiscale information on the composition, structure, and function of rangelands. Data on 11 of the 12 proposed indicators are already being collected through the agency's Assessment, Inventory, and Monitoring program. The framework and process presented here can help the BLM quantify ecological integrity to inform future planning and management actions in multiple-use landscapes.

Introduction

The Bureau of Land Management (BLM) manages 246 million surface acres (100 million hectares) across the United States for multiple use and sustained yield in accordance with the Federal Land Policy and Management Act of 1976 (43 USC §1701). Multiple use refers to a combination of resource uses that take into account both the Nation's present needs and the long-term needs of future generations of the American public (U.S. Department of the Interior, 2001). Resource uses are diverse, and may include livestock grazing, timber harvest, energy production, recreation, and conservation of wildlife, historical, and cultural resources. Sustained yield refers to the ability of lands to achieve and maintain in perpetuity high-level output of various renewable natural resources (U.S. Department of the Interior, 2001). Providing vegetation for livestock and wildlife foraging into the future is one important aspect of sustained yield on lands managed by the BLM. As part of its multiple use and sustained yield mission, the BLM is also charged with protecting the quality of scientific, scenic, historical, ecological, environmental, air, atmospheric, water resource, and archeological values of the public lands it manages (Federal Land Policy and Management Act of 1976 [43 USC §1701]).

Ensuring protection of ecological systems in the context of multiple, and often conflicting, resource uses and values is a challenge. A landscape approach to resource management (hereafter landscape approach) is a strategy that may help to achieve diverse and potentially conflicting resource objectives within and across landscapes (see chapter 2). Key principles of a landscape approach include collecting monitoring information at multiple spatial and temporal scales, focusing on threats and vulnerabilities of key resources, and explicitly acknowledging tradeoffs inherent in meeting different resource objectives within and among landscapes (Sayer and others, 2013). Quantifying the condition of ecological systems across spatial scales and monitoring changes in condition over time in response to different management actions may help managers and stakeholders better understand risks, opportunities, and tradeoffs associated with different resource use decisions.

There are many ways in which the condition or health of ecological systems can be measured. The Fundamentals of Rangeland Health (43 CFR §4180.1), land health standards, and land health evaluations (Bureau of Land Management, 2001) are specific terms used in BLM policy. The BLM seeks to manage lands in a manner consistent with maintaining or making progress toward achieving four Fundamentals of Rangeland Health: (1) properly functioning physical condition of watersheds, (2) ecological processes such as hydrologic and nutrient cycling that support healthy biotic populations and communities, (3) water quality that complies with State standards and achieves BLM objectives such as meeting wildlife needs, and (4) restoration or maintenance of habitat for Federal threatened and endangered species, Federal proposed or candidate species, and other special status species (43 CFR §4180.1). Land health standards are ecological goals that conform to the Fundamentals of Rangeland Health and have been established at State or regional levels to reflect the characteristics of rangelands within that area. Land health evaluations establish the degree to which land health standards are being achieved by measuring specific indicators relevant to the land health standards of each State or region (Bureau of Land Management, 2001).

Another term often used to describe the condition or health of ecological systems is ecological integrity (for example, Karr and Dudley, 1981; Parrish and others, 2003). Ecological integrity is defined by the BLM as "the ability of ecological systems to support and maintain a community of organisms that have the species composition, diversity, and functional organization comparable to those of natural habitats within the ecoregion range or area" (p. 30 in Toevs and others, 2011). This definition embodies three components of ecological systems: composition, structure, and function (Noss, 1990). Composition refers to the identity, variety, and diversity of elements in a collection. Structure refers to the physical organization or pattern of a system both horizontally and vertically (for example, the size and proximity of vegetation patches and the height of vegetation in those patches). Function refers to the evolutionary processes (for example, gene flow and adaptation), ecological roles (for example, resource use patterns of species and predator-prey dynamics) and ecosystem processes (for example, nutrient cycling) that are foundational to the system (Petchey and Gaston, 2006). Fire, drought, and interactions within and among species (such as insect outbreaks and disease) are processes relevant to the structuring of many ecological communities. Deviation in or absence of key functions can drive systemic changes. For example, an increase in invasive grasses may shorten the fire return interval of and eliminate shrubs from a community (Chambers and others, 2007).

Ecological integrity is the ability of ecological systems to support and maintain a community of organisms that have a species composition, diversity, and functional organization comparable to those of natural habitats within the ecoregion range or area (Toevs and others, 2011).

The National Park Service, U.S. Department of Agriculture Forest Service (Forest Service), and many other agencies and conservation organizations now consider ecological integrity in their management decisions. The mission of the National Park Service is to preserve unimpaired the natural and cultural resources and values of the National Park System for future generations (National Park Service Organic Act of 1916 [16 USC §1]). Recent changes to the regulations governing land management planning by the Forest Service also require the agency to maintain or restore the ecological integrity of ecosystems (U.S. Department of Agriculture Forest Service 2012 Planning Rule [36 CFR §219.9(a)]). These policies and recent efforts to develop consistent indicators of ecological integrity (Vickerman and Kagan, 2014) reflect increasing recognition across resource management agencies and conservation organizations of the need to develop standardized methods for quantifying ecological integrity in terrestrial systems across spatial scales, as has been accomplished in aquatic systems (see for example, Karr and others, 1987; Hawkins and others, 2000; Borja and others, 2008).

In this chapter, we first discuss similarities and differences between ecological integrity and land health. We then describe a framework and process for assessing the condition of terrestrial systems. Our framework is intended to be a simple tool that helps to ensure that a comprehensive suite of indicators are considered, and that the scope and limitations of the assessment are clear. The assessment itself may seek to evaluate land health or ecological integrity depending on the management context, the reference conditions to which current systems are compared, and the suite of indicators considered. The steps in the assessment process are consistent with the BLM Assessment, Inventory, and Monitoring (AIM) process, and are applicable to assessments of both land health and ecological integrity. We apply the framework and process to the conceptual example of assessing the ecological integrity of rangelands across the western United States. We propose that a combination of six core terrestrial indicators used in the westwide landscape monitoring component of the BLM AIM program, five broad-scale indicators identified through the BLM Rapid Ecoregional Assessment (REA) program (see chapter 3), and an additional broad-scale indicator of biomass or productivity can be used to quantify the ecological integrity of rangelands across the western United States.

Relation Between Ecological Integrity and Land Health

The concepts of land health and ecological integrity both describe the condition of ecological systems. However, the specific reference conditions and indicators used to assess land health and ecological integrity may differ. Reference conditions used for comparison with the current status of the system fall along a continuum of human influence and may reflect natural conditions, societally-desired conditions, or both.

Many definitions of ecological integrity, including the BLM definition, compare the current state of the system to that of natural areas within the region (for example, Karr and Dudley, 1981; Parrish and others, 2003; Toevs and others, 2011). The most conservative interpretation of natural area is what is often termed true reference conditions: the range of conditions that would be expected for a region in the absence of human perturbation. However, the term natural areas may also refer to ecological systems that have been affected by humans to some degree but are perceived to function largely without anthropogenic influences, especially given that there are few if any places today that remain unaffected by human activity (see chapter 5).

Ecological integrity and land health both describe the condition of ecological systems, but may be assessed using different indicators and reference conditions.

The BLM employs a variety of reference conditions to evaluate land health standards, including lands that are not grazed by domestic livestock (but are grazed by native herbivores), plant communities that are desired by management because they will satisfy multiple uses and sustain production of renewable resources, and well-managed rangelands that are grazed by domestic livestock and have nearly intact hydrologic cycles, nutrient cycling, and energy flow (M. Karl, written commun., 2016). This diversity of potential comparison systems illustrates a continuum ranging from pristine systems to systems with increasing degrees of human modification.

For clarity, we propose that the term ecological integrity be applied to assessments in which the current state of the system is being compared to the state of the system that would be expected in the absence of human perturbations (that is, the natural range of variation). It may be necessary to use historical information (for example, estimated conditions prior to EuroAmerican settlement) or information from systems that have been minimally affected by human use (Stoddard and others, 2006) to estimate the natural range of variation of ecological integrity metrics. However, a natural benchmark is the goal.

A second relevant reference condition for many public lands is the state of the system that considers the goals society has identified for the system. We refer to this as a societally determined reference condition (and associated acceptable range of variation), and we emphasize its importance for interpreting and applying ecological integrity assessments to agency planning and management actions. Most public lands managed by the BLM and the Forest Service have been designated for multiple uses, and thus a benchmark that acknowledges this multidimensional management goal is relevant. Balancing maintenance of vegetation condition and providing adequate vegetation for grazing by both wildlife and domestic livestock is one common management decision that considers socially determined acceptable ranges of variation. Examples of societally determined reference conditions include the best available ecological conditions given the current state of the landscape and the expected ecological condition if the best possible management practices were followed for some time (Stoddard and others, 2006).

In ecological integrity assessments, societally determined reference conditions that differ from natural reference conditions (for example, areas consisting primarily of non-native forage plants) will highlight changes in the composition, structure, or function of systems that have accompanied these new societal goals. In some cases, society has decided that the appropriate benchmark is the natural state of the system in the absence of human influence (for example, designated Wilderness Areas are managed to leave them unimpaired and to preserve their wilderness character [16 USC §1131]). In these cases, the societally determined benchmark and the natural benchmark are the same, and the management goal may be to achieve ecological integrity. A societally determined reference condition may often be appropriate as the primary comparison for land health assessments, provided it is consistent with achieving the Fundamentals of Rangeland Health (43 CFR §4180.1).

After reference conditions have been identified, one must select indicators of ecological integrity or land health. In ecological integrity assessments, indicators ideally are identified on the basis of conceptual models of the system and encompass aspects of the composition, structure, and function of systems or elements at different levels of biological organization (for example, genes, species, ecosystems, and ecoregions). Assessments of land health use established indicators of land health for each state or region (Bureau of Land Management, 2001, 2009). There are 19 sets of land health standards, and more than 100 suggested indicators (M. Karl, unpub. data, 2015). In Colorado, for example, indicators for the health standard for upland soils include canopy and ground cover, litter, soil organic matter, and plant species diversity (Bureau of Land Management, 1997).

The interacting nature of ecological processes operating at different spatial and temporal scales suggests that the most comprehensive assessments of either land health or ecological integrity will use data collected at multiple spatial scales (see chapter 2 for a discussion of ecological patterns and processes across different spatial scales). For example, complementary information about vegetation structure may be gained by measuring both the percent cover of vegetation within a patch and the size and proximity of vegetation patches across a landscape. To date, land health assessments have focused primarily on metrics assessed at local scales (J. Taylor, written commun., 2015), although indicators have been identified at broader scales (M. Karl, unpub. data, 2015).

A Framework for Assessing Ecological Integrity Across Scales in Terrestrial Systems

We present a framework for assessing ecological integrity that is a 3 x 4 matrix that managers may use to help identify the scope and limitations of ecological integrity assessments and help ensure consideration of (1) all components of integrity (composition, structure, and function) and (2) key levels in the ecological hierarchy (fig. 4−1). Using the organizing framework, it is possible to consider a total of 12 combinations of ecological levels and system components in any given ecological integrity assessment. Considering that within each 'cell' in the matrix, there are likely multiple indicators and potentially different spatial and temporal scales to consider (see next section), it becomes apparent that assessments that consider all possible combinations of system components and ecological levels will rarely be possible. Explicitly identifying which system components and levels in the ecological hierarchy will be considered helps to characterize the scope and limitations of any individual ecological integrity assessment.

The framework may also be used to help identify indicators, data sources, and methods that may be most relevant and feasible for a given ecological integrity assessment. At the ecoregion and ecosystem levels of the hierarchy, remotely sensed imagery is a common data source. Geographic Information Systems technology is often used to assess composition (for example, the diversity of vegetation communities), structure (for example, the proximity or size distribution of natural vegetation patches), and function (for example, fire frequency) within and across ecoregions. At the ecosystem level, field-collected data are often used together with remotely sensed data (Noss, 1990). If, for example, a primary focus of the assessment is the effect of invasive species on the ecological integrity of shortgrass prairie ecosystems, an indicator may be the change in the proportion of non-native plant species sampled at shortgrass prairie sites across a gradient of human modification. If the assessment is focused at the species level (for example, the effect of energy development on migratory behavior of mule deer), data often are collected through targeted research or surveys (for example, detection of movement patterns with radiotelemetry, Sawyer and others, 2009b). Continuing with the mule deer example, indicators might include the change in migration speed or the probability of use of different migratory routes through areas with different development densities (for example, Sawyer and others, 2009a). At the genetic level, new analysis techniques are greatly facilitating addressing questions about the genetic structure of populations and species across landscapes (Waits and Paetkau, 2005; Beja-Pereira and others, 2009; Luikart and others, 2010). Findings from broad-scale

Ecological hierarchy

Components of integrity	Ecoregion	Ecosystem	Species	Genes
Composition	Diversity of natural community types	Proportion of native species in rangeland ecosystems	Species abundance	Genetic and trait diversity
Structure	Size distribution of patches of intact natural vegetation	Structural connectivity of rangeland patches	Age structure of population	Effective population size
Function	Extent and frequency of fires	Productivity of rangeland ecosystems	Rates of herbivory by species, functional connectivity of species	Rates of gene flow among populations

Figure 4–1. Conceptual framework for quantifying ecological integrity, with example ecological attributes for each level in the hierarchy and component of integrity. The blue box indicates the area of focus for the example assessment described in this chapter.

indicators can be supplemented with local research or monitoring information to more fully assess local effects. For example, managers working on the above mule deer migration example may seek genetic evidence to evaluate the potential for future development to genetically isolate populations, particularly if substantial changes in movement patterns are likely.

Using the Framework to Assess Ecological Integrity on Rangelands Across the Western United States

The process for assessing the condition of a species or system (fig. 4–2) may be organized into a series of steps within the general BLM AIM process of developing, designing, implementing, and repeating monitoring or assessments (Taylor and others, 2014, see also fig. 3–4). We illustrate the steps for assessing ecological integrity using a conceptual example related to management of rangelands across the western United States. We also note aspects of the process that would vary if the goal of the assessment was to quantify land health instead of ecological integrity.

Specify Management Question

Developing an assessment of ecological integrity or land health requires first identifying an explicit management question within a more general management and policy context. The management question will reflect the mission and regulatory requirements of the organization, and will differ according to management goals and responsibilities for the area, the size of the area being assessed, and other factors. At the local level, for example, a manager may assess land health as part of the process of renewing an individual grazing permit. At the level of field, district, or State offices, the goal of the assessment may be to evaluate achievement of natural resource objectives in resource management plans. At the national level, the goal may be to quantify the ecological integrity of all lands managed by the BLM to inform national policy and meet agency reporting requirements. Assessments of ecological integrity may complement land health assessments by providing a broader perspective and context, particularly when assessments encompass large areas or lands within a more protective management category (for example, the National Landscape Conservation System). It may also be possible to evaluate land health and ecological integrity simultaneously, with associated economies of time and funds.

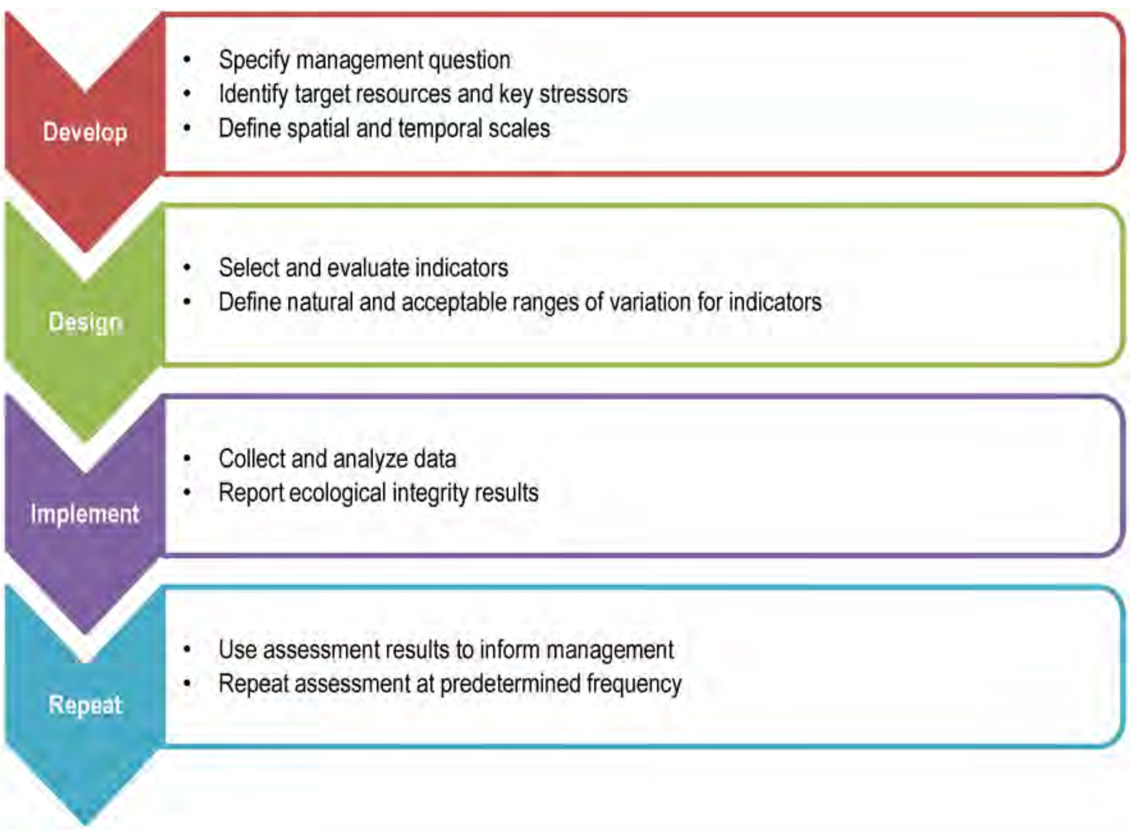

Figure 4–2. Steps for assessing ecological integrity, which are consistent with the broader AIM process (see also chapter 3).

In our example, the management question is: What is the ecological integrity of rangelands across the western conterminous United States? This question is separate from but related to the requirement of BLM to report periodically on the condition and trend in condition of rangelands that the agency manages (Public Rangelands Improvement Act of 1978 [43 USC §1903]). Consequently, the assessment would focus at the ecosystem level and include indicators of the composition, structure, and function of rangelands (fig. 4–1). Ecosystems considered to be rangeland by the BLM include grasslands, savannas, shrublands, deserts, tundra, alpine plant communities, marshes, wet meadows, and oak and pinyon-juniper woodlands (Karl and others, 2016).

We explore the management question, What is the ecological integrity of rangelands across the western conterminous United States?, to illustrate the steps for assessing ecological integrity.

Identify Target Resources and Key Stressors

Management goals and relevant State and Federal laws and policies (for example, BLM land health standards, Federal Endangered Species Act [16 U.S.C. §§ 1531-1544]) will inform selection of target resources. A conceptual model of the system guides identification of the major natural and anthropogenic processes that may affect key resources (Woodley, 2010).

In our example, we focus on soils and terrestrial vegetation. Soils and terrestrial vegetation are two resources now widely monitored across rangeland ecosystems managed by the BLM to measure progress toward attaining land health standards (Taylor and others, 2014). We illustrate a conceptual model developed for one rangeland community type (short grass prairies) in one ecoregion (the Southern Great Plains, Assal and others, 2015). The model identified soils, climate, fire, grazing, development, insects and disease, and invasive species as major factors and processes affecting the flora, fauna, and landscape structure of short grass prairies in the region (fig. 4–3).

Assessments of ecological integrity likely will measure resources sensitive to multiple stressors, and may quantify the stressors themselves as well. Resources sensitive to stressors over which there is management control (for example, livestock grazing) may be the most helpful in informing future management actions intended to improve the ecological status and condition of the lands. However, understanding the influence of unmanaged processes and patterns on target resources is important for accurately assessing the potential effects of management actions.

Define Spatial and Temporal Scales

The spatial extent of the assessment and the temporal and spatial scales of analysis will be informed by the management question, management jurisdictions (such as field office boundaries), and conceptual models of the system. The boundary of an assessment may be administrative (such as BLM State or district office boundaries) or environmental (such as ecoregional boundaries). The extent of the assessment area and the analysis scale used will reflect scales at which stressors act on elements of ecological systems or scales at which management actions typically are applied. Spatial mapping units may be determined by the resolution of available remotely sensed data (for example, 30- x 30-meter (m) pixels of most nationwide land cover datasets). Relevant temporal scales may be defined by seasonal field sampling, reporting periods (for example, required annual reports), the cycle of key ecological processes, or the timeframe within which resources respond to stressors (for example, the length of time it may take for an area to recover from overgrazing).

In our example, the spatial extent of the assessment is the western United States defined using state boundaries. Both local and broad-scale indicators will be considered (see next step) both because rangeland ecosystems occur in different spatial configurations (for example, small patches compared to vast areas of relatively homogeneous vegetation cover) and because anthropogenic and natural processes affecting rangelands operate at multiple scales. For example, livestock stocking rates may vary by individual grazing allotments, land use allocations occur at the scale of larger areas within BLM resource management plan boundaries, and patterns of development may vary by region.

Select and Evaluate Indicators

Detailed design of the assessment begins with selecting and evaluating indicators. Indicators should reflect key ecological attributes of a resource—the biological characteristics, ecological processes or physical interactions that define the resource and whose alteration beyond some threshold could lead to degradation or loss of the resource in the near future (Parrish and others, 2003, Unnasch and others, 2009). Examples of key ecological attributes include the extent of a community, reproduction rates of a species, and genetic diversity of a population (fig. 4–1).

In our example, 11 of the 12 indicators are currently measured by the BLM AIM program or were quantified in REAs. The BLM AIM program has identified a core set of indicators for quantifying the status, condition, and trend of renewable resources on lands managed by the BLM (Toevs and others, 2011, Taylor and others, 2014). The core terrestrial indicators are measured on 50-m long transects at all AIM field monitoring sites using standardized methods, and include indicators of system composition, structure, and

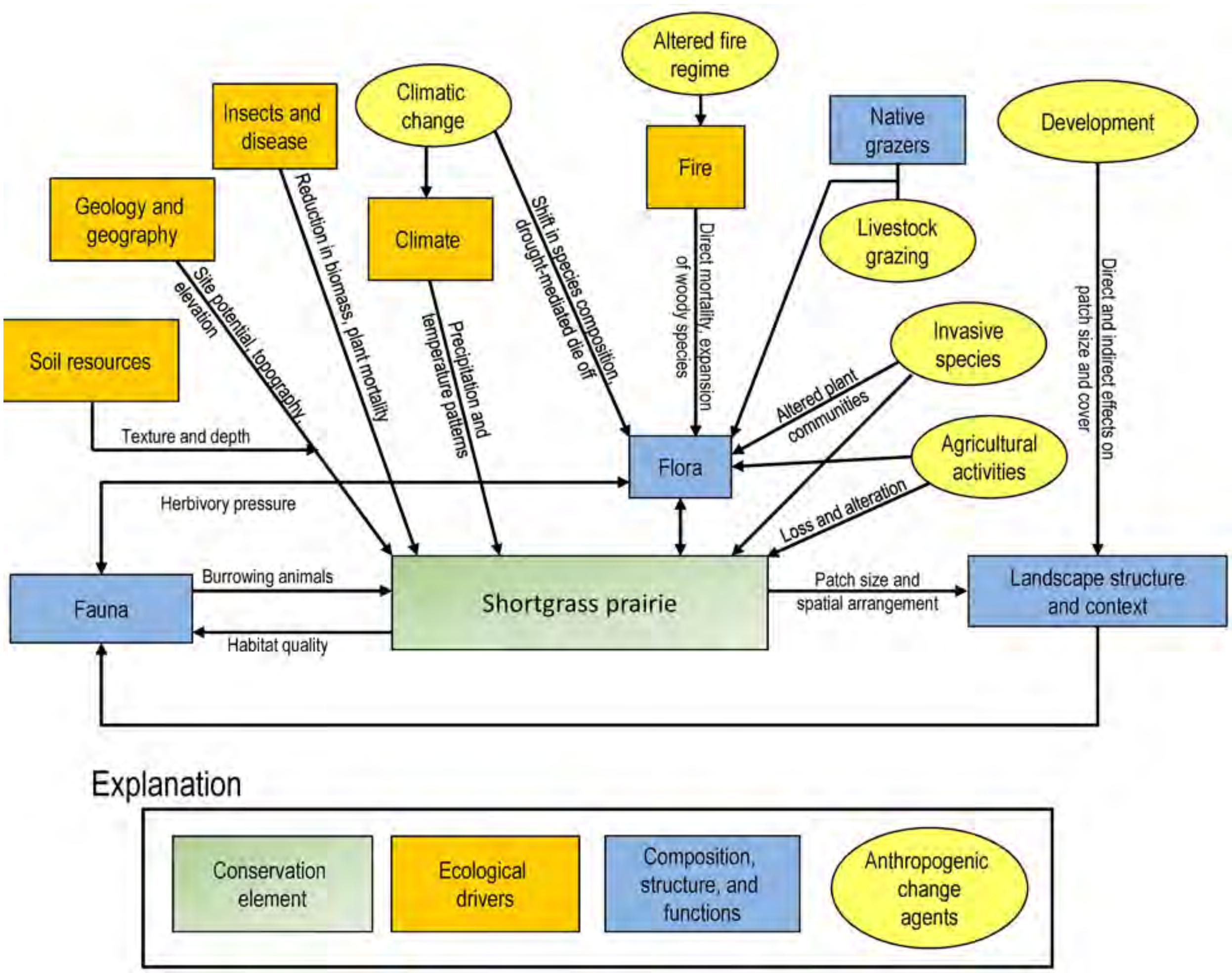

Figure 4–3. Conceptual model highlighting the major ecological drivers and anthropogenic stressors affecting shortgrass prairies in the Southern Great Plains ecoregion (figure modified from the Southern Great Plains Rapid Ecoregional Assessment [Assal and others, 2015]).

function (Herrick and others, 2009; MacKinnon and others, 2011; Taylor and others, 2014). Core indicators have also been identified for streams and rivers, and are in development for lakes and ponds (Miller and others, 2015).

AIM monitoring sites are chosen using a statistically valid sampling design that allows inference to be drawn about values of the terrestrial indicators across larger extents (such as ecological sites or ecoregions), particularly as sampling density increases over time. We note that there will also always be a role for localized, fine-scale monitoring to understand and evaluate effects of specific local decisions. Environmental processes and anthropogenic disturbances operating at broad scales also affect terrestrial and aquatic ecosystems, suggesting a need to consider spatially and temporally extensive indicators of system status and condition as well (see chapters 2 and 3).

REAs compile broad-scale data on the status and condition of natural resources at the level of ecoregions, and have been completed or are in progress across much of the western United States (fig. 4–4). The broad-scale information in REAs complements local data and facilitates resource planning and management by the BLM and other partners across jurisdictional boundaries. Regularly updating REAs or other broad-scale assessments would provide information on resource status and condition into the future (see chapter 3). Our example management question encompasses some areas for which REAs have not yet been completed (fig. 4–4), but other data sources (such as LANDFIRE Existing Vegetation Type) provide continuous vegetation cover across the western United States.

***In our example*,** we propose quantifying the ecological integrity of rangelands across the western United States using six core terrestrial AIM indicators, four broad-scale indicators derived from REAs (chapter 3), and one additional broad-scale indicator of rangeland biomass or productivity (table 4–1). The AIM core terrestrial indicators and the broad-scale indicators derived from REAs originally were selected by researchers, managers, and stakeholders on the basis of their feasibility

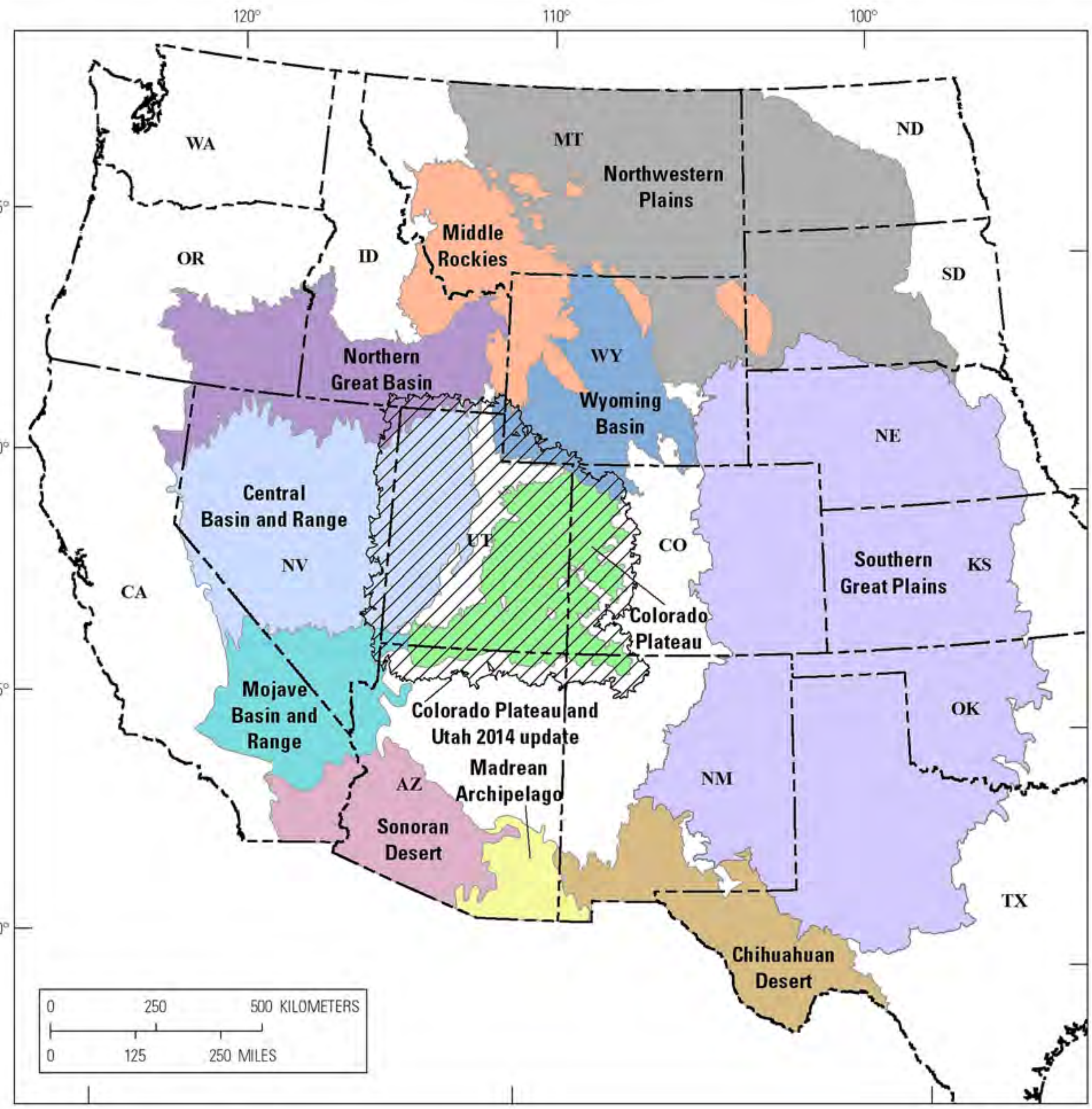

Figure 4–4. Bureau of Land Management Rapid Ecoregional Assessments that are in progress or have been completed across the western conterminous United States (Bureau of Land Management, 2016).

of measurement and utility for informing BLM management. The core terrestrial AIM indicators are measured in the field, and consist of the amount of bare ground, vegetation composition, invasive plants, plants of management concern, vegetation height, and the proportion of the soil surface in large, intercanopy gaps. The broad-scale indicators are derived primarily from satellite imagery and cover broad spatial extents at a spatial resolution of 30- x 30-m pixels to 90- x 90-m pixels. Four broad-scale indicators were identified through REAs: the distribution and amount, patch size, and structural connectivity of communities considered to be rangelands by the BLM, and the amount and distribution of development in and near rangelands. A fifth broad-scale indicator, the normalized difference vegetation index, is one index of rangeland biomass or productivity. The normalized difference vegetation index is available as a standard global product derived from satellite imagery that is strongly and consistently related to aboveground biomass and productivity (Pettorelli and others, 2005).

Standard methods have been established to measure the AIM core terrestrial indicators (MacKinnon and others, 2011). Some guidance for quantifying broad-scale indicators is available from completed REAs (see chapter 3). Data on the amount and location of natural community types considered to be rangelands by the BLM are available from REAs and

Table 4–1. Proposed indicators, the spatial extent at which they are assessed (local or regional), and example reference conditions for quantifying the compositional, structural, and functional components of ecological integrity on rangelands across the western United States. Indicators are listed under the ecological integrity component(s) about which they provide the most information, but many indicators also provide some information about other components of ecological integrity.

Indicator	Composition	Structure	Function	Explanation and relation to the four Fundamentals of Rangeland Health	Example sources for reference conditions
Amount of bare ground		Local	Local	AIM[1] core terrestrial indicator measuring local structure and related to watershed function, ecological processes, water quality, and habitat quality.	AIM monitoring of minimally-disturbed areas
Vegetation composition	Local			AIM core terrestrial indicator related to watershed function and habitat quality.	Ecological site description
Invasive plants	Local			AIM core terrestrial indicator related to watershed function, habitat quality, and ecological processes.	Relative to an absence of invasive species
Plants of management concern	Local			AIM core terrestrial indicator related to watershed function, habitat quality, and ecological processes.	Ecological site description
Vegetation height		Local	Local	AIM core terrestrial indicator measuring local structure and related to habitat quality.	AIM monitoring of minimally-disturbed areas
Proportion of soil surface in large intercanopy gaps		Local	Local	AIM core terrestrial indicator measuring local structure and related to watershed function, ecological processes, water quality, and habitat quality.	AIM monitoring of minimally-disturbed areas
Vegetation amount, by type	Regional			Broad-scale indicator quantifying the amount of identified ecological communities and related to watershed function and habitat quality.	Landfire Biophysical Settings
Vegetation distribution, by type		Regional		Broad-scale indicator quantifying the distribution of identified ecological communities and related to watershed function and habitat quality.	Landfire Biophysical Settings
Patch size		Regional		Broad-scale indicator quantifying the size distribution of vegetation patches and related to habitat quality.	Landfire Biophysical Settings
Structural connectivity		Regional		Broad-scale indicator quantifying the proximity (structural connectivity) of vegetation patches and related to watershed function and habitat quality.	Landfire Biophysical Settings
Development			Regional	Broad-scale indicator quantifying the pattern of development occurring within rangeland communities (see chapter 5) and related to watershed function, ecological processes, and water quality.	Relative to an absence of development
Biomass/ productivity			Regional	Standard index derived from satellite imagery that provides information on above-ground biomass and productivity and is related to ecological processes.	Normalized difference vegetation index of minimally-disturbed areas

[1]Assessment, Inventory, and Monitoring, a Bureau of Land Management program.

nationwide land cover datasets. A standardized indicator of development is now available across the western United States (see chapter 5). Indicators of patch size and structural connectivity may be calculated using consistent methods applied to REA or nationwide land cover datasets. The BLM and USGS are currently (2017) working to standardize methods and datasets for quantifying these broad-scale indicators.

A final step in choosing indicators is to confirm that they are sensitive to the stressors of interest identified in the conceptual model (see fig. 4–3) at the chosen temporal and spatial scales of interest. Ideally, sensitivity of the indicators to the stressors of interest will have been documented in the peer-reviewed literature. For example, grazing intensity by domestic livestock is widely known to affect the species composition and proportion of invasive species present in grasslands (DiTomaso and others, 2000). If sensitivity has not been documented, new analyses relating known changes in the presence and intensity of stressors to changes in the indicators, ideally under experimentally controlled conditions, may be needed to ensure that the results of the ecological integrity assessment are defensible.

Define Natural and Acceptable Ranges of Variation for Indicators

Quantifying the condition of a system requires comparison to a reference condition. For an assessment of ecological integrity, the current value of indicators ideally is compared to the natural range of variation for that indicator under true reference conditions (that is, in areas with no human influence). Established alternatives to true reference conditions are minimally-disturbed condition (the condition of systems in the absence of significant human disturbance) and historical condition (the condition of systems at a specified point in their history, often prior to EuroAmerican settlement, Stoddard and others, 2006). Within the BLM, the best source of information on reference conditions is likely to be ecological site descriptions (Bureau of Land Management, U.S. Department of Agriculture [USDA] Forest Service, and USDA Natural Resources Conservation Service, 2010, Taylor and others, 2014). AIM monitoring data collected in minimally-disturbed systems also may provide information on natural variation of the measured indicators. Most REAs have considered minimally-disturbed or estimated historical condition in lieu of true reference conditions, with estimated historical conditions often derived from LANDFIRE Biophysical Settings (BpS) (LANDFIRE, 2010). When estimating natural ranges of variation, it is also important to consider potential future ranges of variation under changing climate conditions (Millar and others, 2007, Keane and others, 2009).

A societally determined acceptable range of variation for system indicators is a second relevant reference against which to compare the current state of systems managed explicitly for multiple uses. This acceptable range of variation takes into account societal goals established for the system through policy (for example, compliance with land health standards and endangered species laws) and the current landscape context of the system. An acceptable range of variation may be defined on the basis of measurements of a system believed to be in the best available or best attainable condition (Stoddard and others, 2006) given the landscape in which the system occurs and the regulatory context within which the system is managed. In the case of ecological integrity assessments, the purpose of this second benchmark is to provide additional context regarding the landscape, planning, and policy context in which the system occurs. For land health assessments, a societally determined acceptable range of variation may be the primary benchmark for the assessment as long as it is consistent with achieving the Fundamentals of Rangeland Health (43 CFR §4180.1).

For ecological integrity assessments, it is also necessary to specify the indicator values below which a system will be considered to lack integrity for that indicator. The values may be the upper or lower bound of the natural range of variation for each indicator, or may reflect indicator values likely to allow persistence of target species or communities into the future (Parrish and others, 2003). The values may also reflect current policy or management guidelines.

In our example, a relevant management goal across sagebrush-dominated shrublands in much of the western United States is conservation of greater sage-grouse (Stiver and others, 2015). Development in or near greater sage-grouse habitat may be detrimental to populations, and detrimental anthropogenic disturbances occurring within 3 kilometers of greater sage-grouse habitat degrade habitat suitability (Knick and others, 2013; Stiver and others, 2015). A target of maintaining anthropogenic disturbances at or below 3 percent of the landscape within priority greater sage-grouse habitat has been suggested (Sage-grouse National Technical Team, 2011), and caps of 3 to 5 percent disturbance have been implemented in an effort to allow persistence of greater sage-grouse populations (for example, State of Wyoming, 2011; Bureau of Land Management, 2015). As a result, in areas that may provide habitat for greater sage-grouse, acceptable ranges of variation for patch size and connectivity indicators might be defined on the basis of sites with less than 3 to 5 percent development. Different ecological, conservation and management issues apply to other community types and locations, suggesting that community types within ecoregions are likely to be the appropriate strata for defining natural and acceptable ranges of variation and associated lower limits of integrity for most indicators.

Collect and Analyze Data

In our example, the ecological integrity assessment focuses on use of existing (primarily BLM) data rather than collection of new data. AIM westwide monitoring has been operating since 2011, and is beginning to provide the density of samples needed to infer information about the composition, structure, and function of rangelands managed by the BLM across the western United States (Taylor and others, 2014; Karl and others, 2016). Similarly, 11 REAs have been completed or are in progress in the western conterminous United States, providing example approaches and methods needed to quantify the amount, patch size, and connectivity of rangelands across the west (see chapter 3). The current effort to quantify terrestrial development across the conterminous western United States (see chapter 5) provides consistent information on development across all western lands. The normalized difference vegetation index, an index of vegetation biomass and productivity, is calculated from open source online satellite imagery at increasingly fine spatial and temporal resolutions (as fine as 10- × 10-m pixels or as frequently as daily [but not both], depending on the sensor).

Report Ecological Integrity Results

Presentation of assessment results requires deciding on a format for presenting the condition of individual indicators (for example, Cardoso and others, 2007; Tierney and others, 2009), and, if desired, combining individual indicators into a more comprehensive index of ecological integrity (for example, Glennon and Porter, 2005). Presenting results for individual indicators and for comprehensive indices is common in the literature (for example, Karr and others, 1986, Cardoso and others, 2007, Diffendorfer and others, 2007, Tierney and others, 2009). The target audience and context in which the information will be used will help inform the best presentation format.

Ecological integrity results may be presented as the degree of departure from reference conditions (table 4–2). This approach is simple and informative. Presenting ecological integrity results categorically (for example, good, caution, significant concern, Tierney and others, 2009) using breakpoints that are meaningful both biologically and to management is another option that can convey additional information to managers, stakeholders, and the public. Ideally, passing a breakpoint will automatically trigger a management response, which might include additional monitoring, research, or management actions (Mitchell and others, 2014).

In our example, we present hypothetical results using degree of departure from reference conditions at the level of our original management question—the entire western conterminous United States (table 4–2). However, natural and acceptable ranges of variation, breakpoints for indicators, and management actions for addressing identified deficiencies may differ among ecoregions. Thus it may be helpful, particularly for land managers, to report assessment results at ecoregion levels as well (see Mitchell and others, 2014 for an example). Because of the multiple-use mandate of the BLM, it may be helpful to present findings relative to departure from both the natural and acceptable ranges of variation. Given the prominent role of the Fundamentals of Rangeland Health in driving management, monitoring, and reporting activities within the BLM, it also may be appropriate to highlight how each of the ecological integrity indicators relates to the Fundamentals of Rangeland Health (table 4–1).

Use Assessment Results to Inform Management

Once the assessment has been completed, the final steps include using the assessment results to inform and evaluate management actions and repeating the assessment as needed. The BLM is committed to implementing adaptive management that is informed by the best available science (Clement and others, 2014). The assessment process outlined here is grounded in well-established principles of environmental monitoring and assessment, and is intended to include key resources over which there is management control or concern. As a result, the assessment process is designed to explicitly inform management actions focused on maintaining or improving ecological integrity within the context of the multiple-use mandate of the BLM.

In our example, conceptual models identify known or hypothesized stressors (such as grazing), and thus inform potential management responses to those stressors (such as changing allowed grazing intensities if land health standards are not met). The process of identifying stressors also acknowledges that local managers have a reasonable level of control over some processes (for example, local grazing intensities) but not others (for example, a changing climate). The reporting format explicitly identifies the degree to which current values of each indicator depart from reference conditions, and whether the indicators were measured at local or broad scales. In some cases, it may be helpful to analyze and present results at finer spatial scales (for example, ecoregions or field office boundaries) to guide management responses.

Repeat Assessment at Predetermined Frequency

An initial ecological integrity assessment will usually identify the degree of departure from reference conditions for each indicator, informing the type and amount of management that may be needed to improve the integrity of the system. Repeated assessments can be used to evaluate the extent to which management actions are correlating with indicator values that are closer to their natural and acceptable ranges of variation. The frequency at which the assessment is repeated will be informed by factors similar to those identified for defining relevant temporal scales, including the ecology of the system and the time frames in which management decisions are made and management responses are likely to be detected.

Using the Ecological Integrity Framework and Assessment Process to Facilitate Implementing a Landscape Approach in the Bureau of Land Management

The early adoption of ecological integrity as a goal for aquatic systems in the United States through implementation of the Clean Water Act of 1972 (33 USC §1251) and early definition of a standard method for assessing integrity in aquatic systems (Karr and Dudley, 1981; Karr and others, 1986) may have fostered widespread use of ecological (or biotic) integrity assessments for managing aquatic systems. There is a comparable desire and policy foundation for considering ecological integrity in management of terrestrial systems in the United States (Vickerman and Kagan, 2014), including on Federal lands (for example, National Park Service Organic Act of 1916 [16 USC §1], USDA Forest Service 2012 Planning Rule [36 CFR §219]). However, quantitative application of

Table 4–2. One model for presenting results of an ecological integrity assessment for rangelands across the western United States. Results include the name of the indicator, the component(s) of ecological integrity (composition, structure, or function) described by the indicator, the spatial scale at which each indicator is assessed (local or regional), and the degree to which the current value of each indicator departs from reference conditions for the Western United States. Note: these data are fictional representations of the proportional area of rangelands in each departure category, and are intended for illustration only.

0–10 percent departure from reference conditions	10–20 percent departure	20–30 percent departure	30–40 percent departure	Greater than 40 percent departure

Indicator	Composition	Structure	Function	Western United States
Amount of bare ground		Local	Local	
Vegetation composition	Local			
Invasive plants	Local			
Plants of management concern	Local			
Vegetation height		Local	Local	
Proportion of soil surface in large intercanopy gaps		Local	Local	
Vegetation amount	Regional			
Vegetation distribution			Regional	
Patch size		Regional		
Structural connectivity		Regional		
Development			Regional	
Biomass/productivity			Regional	

the ecological integrity concept in terrestrial systems has been limited (but see Fraser and others, 2009; Tierney and others, 2009; Mitchell and others, 2014), likely due in part to the difficulty in identifying and measuring representative indicators across what are often larger systems with less defined boundaries compared to freshwater systems. In addition, application of the concept of ecological integrity to multiple-use contexts, in which some resource objectives directly conflict with protection of pristine systems, is not well understood (Wurtzebach and Schultz, 2016).

The BLM is not required by policy or law to consider ecological integrity in its management. Rather, the agency manages on the basis of multiple use and sustained yield (43 USC §1701) and the Fundamentals of Rangeland Health (43 CFR §4180.1). We suggest, however, that evaluating ecological integrity is possible with little additional monitoring effort (11 of 12 proposed indicators are already quantified in REAs or through AIM monitoring). Further, assessing ecological integrity would provide complementary information to land health assessments and contribute to both managers and the public gaining a broader understanding of the condition of ecological systems across all Federal lands. The ecological integrity assessment process outlined here is consistent with the AIM monitoring process, facilitating integration of ecological integrity assessments into the existing monitoring and assessment programs of the BLM. In addition, using results from ecological integrity assessments together with information on current and authorized land uses can help identify tradeoffs resulting from different resource management actions, a key aspect of implementing a landscape approach to resource management on lands managed by the BLM (see chapter 2).

References Cited

Allred, B.W., Smith, W.K., Twidwell, Dirac, Haggerty, J.H., Running, S.W., Naugle, D.E., and Fuhlendorf, S.D., 2015, Ecosystem services lost to oil and gas in North America: Science, v. 348, p. 401–402.

Assal, T.J., Melcher, C.P., and Carr, N.B., eds., 2015, Southern Great Plains Rapid Ecoregional Assessment—Pre-assessment report: U.S. Geological Survey Open-File Report 2015–1003, 284 p., accessed December 8, 2016, at https://dx.doi.org/10.3133/ofr20151003.

Beja-Pereira, Albano, Oliveira, Rita, Alves, P.C., Schwartz, M.K., and Luikart, Gordon, 2009, Advancing ecological understandings through technological transformations in noninvasive genetics: Molecular Ecology Resources, v. 9, p. 1279–1301.

Bureau of Land Management, 1997, Decision record and finding of no significant impact for adoption of standards for public land health and guidelines for livestock grazing management in Colorado: Bureau of Land Management, accessed June 12, 2016, at https://www.blm.gov/style/medialib/blm/wo/Information_Resources_Management/policy/blm_handbook.Par.61484.File.dat/h4180-1.pdf.

Bureau of Land Management, 2001, Bureau of Land Management handbook for rangeland health standards: Bureau of Land Management, accessed January 12, 2017, at http://www.blm.gov/pgdata/etc/medialib/blm/wo/Information_Resources_Management/policy/blm_handbook.Par.61484.File.dat/h4180-1.pdf.

Bureau of Land Management, 2008, Colorado standards for public land health: Bureau of Land Management, accessed October 18, 2015, at http://www.blm.gov/co/st/en/BLM_Programs/grazing/rm_stds_guidelines.html.

Bureau of Land Management, 2009, Manual 4180, Land health manual for the Bureau of Land Management: Bureau of Land Management, accessed March 2, 2016, at http://www.blm.gov/style/medialib/blm/wo/Information_Resources_Management/policy/blm_manual.Par.23764.File.dat/4180.pdf.

Bureau of Land Management, 2015, Record of decision and approved resource management plan amendments for the Great Basin region, including the greater sage-grouse sub-regions of Idaho and southwestern Montana, Nevada and Northeastern California, Oregon, Utah: Bureau of Land Management, accessed October 20, 2015, at http://www.blm.gov/wo/st/en/prog/more/sagegrouse.html.

Bureau of Land Management, 2016, Rapid Ecoregional Assessments: Bureau of Land Management, accessed March 7, 2016, at http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html.

Bureau of Land Management, USDA Forest Service, and USDA Natural Resources Conservation Service, 2010, Interagency ecological site handbook: Bureau of Land Management, accessed February 28, 2016, at http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=33943.wba.

Boone, R.B., Taylor, J.J., Swift, D.M., Evangelista, P.H., and Hollowed, Ed, 2011, Developing a resource management and monitoring protocol for a semiarid landscape with extensive oil and gas development potential: Denver, Colo., Bureau of Land Management, National Operations Center, Technical Note 439, 52 p., accessed September 16, 2015, at http://www.blm.gov/nstc/library/pdf/TN439.pdf.

Borja, Angel, Bricker, S.B., Dauer, D.M., Demetriades, N.T., Ferreira, J.G., Forbes, A.T., Hutchings, Pat, Jia, Xiaoping, Kenchington, Richard, Marques, J.C., and Zhu, Changbo, 2008, Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide: Marine Pollution Bulletin, v. 56, p. 1519–1537.

Cardoso, Pedro, Borges, P.A.V., and Gaspar, Clara, 2007, Biotic integrity of the arthropod communities in the natural forests of Azores: Biodiversity and Conservation, v. 16, p. 2883–2901.

Carr, N.B., Wood, D.J.A., Bowen, Z.H., and Haby, T.S., 2015, Broad-scale assessments of ecological landscapes—Developing methods and applications: U.S. Geological Survey, Fact Sheet 2015–3007, 4 p., accessed October 19, 2015, http://pubs.usgs.gov/fs/2015/3007/pdf/fs2015-3007.pdf.

Chambers, J.C., Roundy, B.A., Blank, R.R., Meyer, S.E., and Whittaker, A., 2007, What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*?: Ecological Monographs, v. 77, no. 1, p. 117–145.

Clement, J.P., Belin, A.d'A., Bean, M.J., Boling, T.A., and Lyons, J.R., 2014, A strategy for improving the mitigation policies and practices of the Department of the Interior: Washington, D.C., A report to the Secretary of the Interior from the Energy and Climate Change Task Force, 25 p.

Diffendorfer, J.E., Fleming, G.M., Duggan, J.M., Chapman, R.E., Rahn, M.E., Mitrovich, M.J., and Fisher, R.N., 2007, Developing terrestrial, multi-taxon indices of biological integrity: an example from coastal sage scrub: Biological Conservation, v. 140, p. 130–141.

DiTomaso, J.M., 2000, Invasive weeds in rangelands: Species, impacts, and management: Weed Science, v. 28, p. 255–265.

Fraser, R.H., Olthof, I., and Pouliot, D., 2009, Monitoring land cover change and ecological integrity in Canada's national parks: Remote Sensing of Environment, v. 113, p. 1397–1409.

Glennon, M.J., and Porter, W.F., 2005, Effects of land use management on biotic integrity: An investigation of bird communities: Biological Conservation, v. 126, p. 499–511.

Hawkins, C.P., Norris, R.H., Hogue, J.N., and Feminella, J.W., 2000, Development and evaluation of predictive models for measuring the biological integrity of streams: Ecological Applications, v. 10, p. 1456–1477.

Herrick, J.E., Van Zee, J.W., Havstad, K.M., Burkett, L.M., and Whitford, W.G., 2009, Monitoring manual for grassland, shrubland and savanna ecosystems: Las Cruces, N. Mex., U.S. Department of Agriculture, Agricultural Research Service, Jornada Experimental Range, accessed June 25, 2015, at http://www.ars.usda.gov/Research/docs.htm?docid=24068.

Karl, M.G. "Sherm", Kachergis, Emily, and Karl, J.W., 2016, Bureau of Land Management Rangeland Resource Assessment—2011: U.S. Department of the Interior, Bureau of Land Management, 112 p.

Karr, J.R., and Dudley, D.R., 1981, Ecological perspective on water quality goals: Environmental Management, v. 5, p. 55–68.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J, 1986, Assessing biological integrity in running waters: a method and its rationale: Illinois Natural History Survey Special Publication 5, 28 p.

Keane, R.E., Hessburg, P.F., Landres, P.B., and Swanson, F.J., 2009, The use of historical range of variability (HRV) in landscape management: Forest Ecology and Management, v. 258, p. 1025–1037.

Knick, S.T., Hanser, S.E., and Preston, K.L., 2013, Modeling ecological minimum requirements for distribution of greater sage-grouse leks: Implications for population connectivity across their western range, USA: Ecology and Evolution, v. 3, p. 1539–1551.

LANDFIRE, 2010, LANDFIRE Biophysical Settings layer (2010 update): U.S. Geological Survey, accessed October 20, 2015, at http://landfire.cr.usgs.gov/viewer/.

Luikart, Gordon, Ryman, Nils, Tallmon, D.A., Schwartz, M.K., and Allendorf, F.W., 2010, Estimation of census and effective population sizes: the increasing usefulness of DNA-based approaches: Conservation Genetics, v. 11, p. 355–373.

MacKinnon, W.C., Karl, J.W., Toevs, G.R., Taylor, J.J., Karl, Michael, Spurrier, C.S., and Herrick, J.E., 2011, BLM core terrestrial indicators and methods: Denver, Colo., Bureau of Land Management, National Operations Center, Technical Note 440, accessed June 18, 2015, at http://www.blm.gov/nstc/library/pdf/TN440.pdf.

Mitchell, B.R., Tierney, G.L., Schweiger, E.W., Miller, K.M., Faber-Langendoen, Don, and Grace, J.B., 2014, Getting the message across: Using ecological integrity to communicate with resource managers, *in* Guntenspergen, G.R., ed., Application of threshold concepts in natural resource decision making: New York, Springer-Verlag, p. 199–230.

Millar, C.I., Stephenson, N.L., and Stephens, S.L., 2007, Climate change and forests of the future: managing in the face of uncertainty: Ecological Applications, v. 17, p. 2145–2151.

Noss, R.F., 1990, Indicators for monitoring biodiversity—A hierarchical approach: Conservation Biology, v. 4, p. 355–364.

Parrish, J.D., Braun, D.P., and Unnasch, R.S., 2003, Are we conserving what we say we are? Measuring ecological integrity within protected areas: Bioscience, v. 53, p. 851–860.

Pellant, Mike, Shaver, Patrick, Pyke, D.A., and Herrick, J.E., 2005, Interpreting indicators of rangeland health, ver. 4: Denver, Colo., Bureau of Land Management, National Science and Technology Center, Technical Reference 1734-6, BLM/WO/ST-00/001+1734/REV05, 122 p.

Petchey, O.L., and Gaston, K.J., 2006, Functional diversity: back to basics and looking forward: Ecology Letters, v. 9, p. 741–758.

Pettorelli, Nathalie, Vik, J.O., Mysterud, Atle, Gaillard, J.M., Tucker, C.J., and Stenseth, N.C., 2005, Using the satellite-derived NDVI to assess ecological responses to environmental change: Trends in Ecology and Evolution, v. 20, p. 503–510.

Sage-grouse National Technical Team, 2011, A report of national greater sage-grouse conservation measures: Bureau of Land Management, accessed October 20, 2015, at http://www.blm.gov/style/medialib/blm/co/programs/wildlife.Par.73607.File.dat/GrSG%20Tech%20Team%20Report.pdf.

Sawyer, Hall, Kauffman, M.J., Nielson, R.M., and Horne, J.S., 2009a, Identifying and prioritizing ungulate migration routes for landscape-level conservation: Ecological Applications, v. 19, p. 2016–2025.

Sawyer, Hall, Kauffman, M.J., Nielson, R.M., and Horne, J.S., 2009b, Influence of well pad activity on the winter habitat selection patterns of mule deer: Journal of Wildlife Management, v. 73, p. 1052–1061.

Sayer, Jeffrey, Sunderland, Terry, Ghazoul, Jaboury, Pfund, J.-L., Sheil, Douglas, Meijaard, Erik, Venter, Michelle, Boedhihartono, A.K., Day, Michael, Garcia, Claude, van Oosten, Cora, and Buck, L.E., 2013, Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses: Proceedings of the National Academy of Sciences of the United States of America, v. 110, p. 8349–8356.

State of Wyoming, 2011, Executive Order 2011–5: Greater sage-grouse core area protection: State of Wyoming, accessed October 20, 2015, at http://will.state.wy.us/sis/wydocs/execorders/EO2011-05.pdf.

Stiver, S.J., Rinkes, E.T., Naugle, D.E., Makela, P.D., Nance, D.A., and Karl, J.W., eds., 2015, Sage-grouse habitat assessment framework: A multiscale assessment tool: Denver, Colo., Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Technical Reference 6710–1, accessed October, 20, 2015, at http://www.blm.gov/style/medialib/blm/wo/blm_library/tech_refs.Par.34086.File.dat/TR_6710-01.pdf.

Stoddard, J.L., Larsen, D.P., Hawkins, C.P., Johnson, R.K., and Norris, R.H., 2006, Setting expectations for the ecological condition of streams: The concept of reference condition: Ecological Applications, v. 16, p. 1267–1276.

Taylor, Jason, Kachergis, Emily, Toevs, Gordon, Karl, Jason, Bobo, Matthew, Karl, Michael, Miller, Scott, and Spurrier, Carol, 2014, AIM-Monitoring: A component of the BLM Assessment, Inventory, and Monitoring Strategy: Denver, Colo., U.S. Department of the Interior, Bureau of Land Management, National Operations Center, accessed June 18, 2015, at http://www.blm.gov/style/medialib/blm/wo/blm_library/tech_notes.Par.24137.File.dat/TN_445.pdf.

Tierney, G.L., Faber-Langendoen, Don, Mitchell, B.R., Shriver, W.G., and Gibbs, J.P., 2009, Monitoring and evaluating the ecological integrity of forest ecosystems: Frontiers in Ecology and the Environment, v. 7, p. 308–316.

Toevs, G.R., Taylor, J.J., Spurrier, C.S., MacKinnon, W.C., and Bobo, M.R., 2011, Bureau of Land Management Assessment, Inventory, and Monitoring Strategy: For integrated renewable resources management: Denver, Colo., Bureau of Land Management, National Operations Center, accessed June 15, 2015, at http://www.blm.gov/style/medialib/blm/wo/Information_Resources_Management/policy/ib_attachments/2012.Par.53766.File.dat/IB2012-080_att1.pdf.

Unnasch, R.S., Braun, D.P., Comer, P.J., Eckert, G.E., 2008, The Ecological Integrity Assessment Framework: A framework for assessing the ecological integrity of biological and ecological resources of the National Park System, Report to the National Park Service: National Park Service, accessed December 7, 2016, at http://www.natureserve.org/biodiversity-science/publications/ecological-integrity-assessment-framework-framework-assessing.

U.S. Department of the Interior, Bureau of Land Management, and Office of the Solicitor, eds., 2001, The Federal Land Policy and Management Act, as amended: Washington, D.C., U.S. Department of the Interior, Bureau of Land Management Office of Public Affairs, 69 p., accessed October 18, 2015, at https://www.blm.gov/or/regulations/files/FLPMA.pdf.

Vickerman, Sara, and Kagan, J.S., 2014. Assessing ecological integrity across jurisdictions and scales: accessed September 3, 2015, at http://www.defenders.org/publication/eco-integrity-measures-across-jurisdictions-and-scales.

Waits, L.P., and Paetkau, David, 2005, Noninvasive genetic sampling tools for wildlife biologists: A review of applications and recommendations for accurate data collection: Journal of Wildlife Management, v. 69, p. 1419–1433.

Woodley, Stephen, 2010, Ecological integrity: A framework for ecosystem-based management, *in* Cole, D.N., and Yung, Laurie, eds., Beyond naturalness: rethinking park and wilderness stewardship in an era of rapid change: Washington D.C., Island Press, p.106–124.

Wurtzebach, Zachary and Schultz, Courtney, 2016, Measuring ecological integrity: history, practical applications, and research opportunities: Bioscience, v. 66, no. 6, p. 446–457.