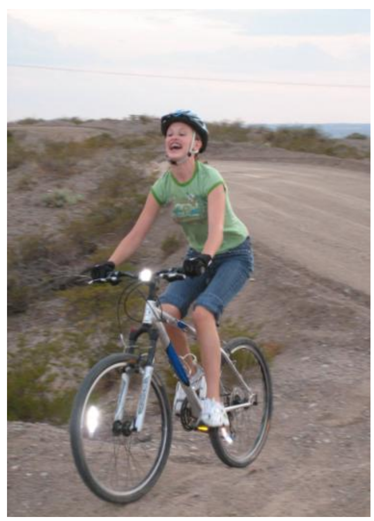
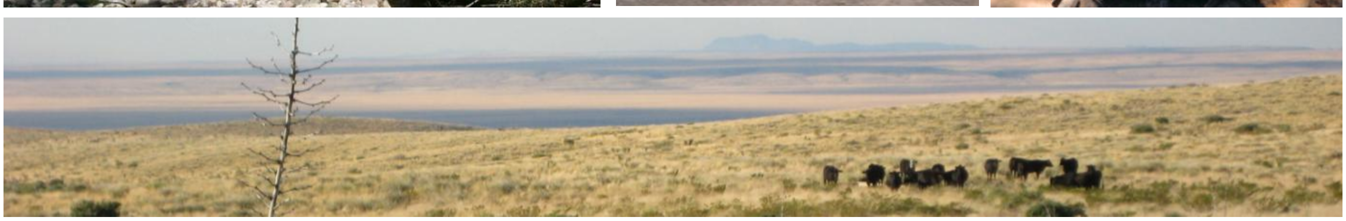
Terrestrial Indicators and Measurements: Selection Process & Recommendations

FINAL – August 9, 2010







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This report is the result of a collaborative process involving nearly resource professionals led by the following individuals: Jeff Herrick, Skye Wills, Jason Karl (USDA-ARS Jornada Experimental Range, Las Cruces, NM) and David Pyke (USGS Forest and Rangeland Ecosystem Science Center).

Executive Summary

Objective and background. The objective of this project was to identify a small set of core indicators and measurements that can be applied across rangeland, forest and riparian ecosystems managed by the BLM. A set of core indicators quantified using standardized measurements allows data to be integrated across field office, district and state boundaries.

These indicators can be used to support evaluation of most management objectives because they reflect fundamental changes in ecosystem health, as well as more specific changes in wildlife habitat, soil erosion, and livestock forage. For example, bare ground is generally related to changes in susceptibility to erosion, production and wildlife habitat quality. By adopting a clear definition of bare ground and a method for measuring it, it will be possible to make landscape-scale interpretations both within the BLM and across agency boundaries.

Habitat quality, in particular, was emphasized through the inclusion of vegetation indicators that can be combined to create 3D models of habitat structure. In some cases, the core indicators identified through this process may need to be supplemented by *additional* local and regional indicators to more fully address specific policy and management objectives.

The recommendations contained in this report are complementary to BLM efforts to increase consistency with USFS and NRCS protocols through the ongoing Oregon FIA-NRI Pilot and other initiatives. Because the indicators and measurements are already widely accepted and applied by other agencies and NGO's, adoption will facilitate aggregation across jurisdictions.

General Approach. Indicators were selected through a five-step participatory process involving both BLM and outside experts. Nearly 200 individuals participated during a three month period from August – November 2008. The process drew heavily from lessons learned from the AIM program and related efforts in other agencies during the past 10 years. A total of 16 criteria were systematically applied to select the indicators. In 2010, standard methods were selected that met the following requirements: (1) well documented, and (2) widely used at the by BLM Field Offices. A third requirement, inclusion in at least one national monitoring program, was used for the core indicators.

Core Indicators and Measurements. ***Five Core indicators*** are recommended for application wherever BLM implements quantitative soil and/or vegetation trend monitoring***: (1) bare ground, (2) vegetation composition, (3) non-native invasive species, (4) plant species of management concern, and (5) vegetation height***. The indicators are also relevant to many assessment objectives. Of the five, the first four can be collected with the same method, and vegetation height is measured along the same transect. All can be addressed to some degree with remote sensing (where remote sensing is understood to include both satellite and aircraft), supported by ground measurements at a limited number of plots. Additionally, ***two 'Core-Contingent' indicators*** were identified: ***(1) stand density index (SDI), (2) proportion of soil surface in large intercanopy gaps.*** These indicators are always implemented unless there value can be reliable estimated without measurement. For example, SDI is zero if there are no trees present. ***Two 'Contingent' indicators*** were also identified***: (1) soil aggregate stability, and (2) significant accumulation of toxins.*** These indicators only need to be collected where reliable estimates cannot be generated from the core indicators and/or there is reason to believe they are necessary for site monitoring and assessment. For example, soil aggregate stability would only be included for sites experiencing or at risk of high erosion or when decreased soil stability was suspected. ***Four indicators are recommended for further study*** and potential future inclusion as Core or Contingent indicators***: fragmentation, soil carbon, erosion, and soil compaction.*** Indicators that were considered but not selected are discussed at the end of the report.

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General Approach

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Step 1. Define indicator selection criteria.

What? A set of 16 criteria (Table 1) were selected for application to an initial indicator list (Step 2). ***Who?*** An interdisciplinary group of BLM employees drawn primarily from the Washington Office and the National Operations Center. The process was facilitated by an ARS scientist, with support from a USGS scientist and manager. ***How?*** A facilitated group discussion was used to identify and define the criteria. The initial goal was to limit the criteria to less than 6 in order to minimize time required to apply them to the indicators. However, the group concluded that a large number of distinct criteria was required to represent the range of BLM indicator requirements. Attempts to combine the criteria were rejected because it made the criteria too complex and difficult to apply. The resulting 16 criteria were designed to be as comprehensive as possible, and are not necessarily independent of each other.

Table 1. Criteria used in the indicator selection process. Please see Step 4 for composition of groups applying indicators and Table 2 for how each criterion was used in the analysis.

	Description	**Rating type**	**Applied by**
1	Documented (scientifically) relationship to land health for most ecosystems in the domain (upland range, riparian or forest).	1-5 scale	General Group
2	Can be easily explained to public.	1-5 scale	General Group
3	Can be used to reflect (assess) current status. Reference values (i.e. the value or range of values expected for a site when it is at its ecological potential) exist for most ecosystems in the domain (upland range, riparian or forest).	1-5 scale	General Group
4	High signal:noise ratio (sensitive to detecting long-term trends and insensitive to short-term variability, such as differences associated with short-term weather patterns and time since disturbance).	1-5 scale	General Group
5	Repeatable. Method will provide consistent results by different observers. Low susceptibility to bias. Relatively easy to standardize measurement or observation of indicator across observers.	1-5 scale	General Group
6	Applicable to policy and management at multiple scales (plot to regional/national). Characterization of indicator at one scale can be extrapolated to other scales (assuming an appropriate sampling design) in order to facilitate interpretation of current health.	1-5 scale	General Group
7	Indicator can be easily and consistently applied to address multiple management objectives (including allotment, conservation, land use planning, etc...) and/or Congressional mandates.	1-5 scale	General Group
8	Remote sensing detection currently or soon possible at less than field cost at plot level with high resolution imagery (including image acquisition, ground truth/calibration and analysis).	1-5 scale	GIS/RS Expert Group
9	Remote sensing detection currently or soon possible at less than field cost at national level with satellite imagery (including image acquisition, ground truth/calibration and analysis)	1-5 scale	GIS/RS Expert Group
10	The cost, including field and analysis expense and time, necessary to obtain the required number of measurements with a sufficient level of precision, accuracy and repeatability (across years) is low.	1-5 scale	External Monitoring expert
11	Can be quantified with selected sampling design with sufficient level of precision at scale(s) relevant to policy and management.	1-5 scale	External Monitoring expert
12	Indicator can be extracted from existing BLM standardized and documented data acquisition protocols.	Yes/No	BLM-NOC
13	Indicator is being collected by FIA.	Yes/No	FIA Consult.
14	Indicator is being collected by NRI.	Yes/No	NRI Consult.
15	The set of indicators reflects multiple ecosystem functions (land health).	Synthetic	ID Group
16	The set of indicators can be collected with minimum number of methods (minimizing cost and complexity by selecting multiple indicators that can be collected with same method).	Synthetic	ID Group

Step 2. Identify initial indicator list.

What? A set of 18 indicators was selected for evaluation with the criteria identified in Step 1. ***Who?*** See Step 1. ***How?*** In order to avoid duplication of effort, the group started with existing national indicators identified by the USFS FIA (Forest Inventory and Analysis) program, the NRCS NRI (National Resources Inventory), the Heinz Center (State of the Nation's

Ecosystems), and the SRR (Sustainable Rangelands Roundtable). Similar indicators from these sources were combined. Indicators that clearly did not meet a number of the criteria were eliminated. Many of the 'indicators' listed by these sources (and included in the list) are in reality indicator groups or classes. Please see the introduction to the 'Indicator Recommendations' section for more detail.

Step 3. Rate the criteria.
What? Each criterion was rated on a 1-5 scale, where 1=minimally important and 5=extremely important for the BLM. ***Who?*** Responses were solicited from one individual each at state and national levels representing each of the following BLM programs: Range, Soil/Water/Air, Forestry, Wildlife, Minerals, Recreation, Fire, Emergency Stabilization & Rehabilitation, Invasive Species, Wild Horse & Burros, Riparian/Wetlands, Botany, Cultural, and Planning (28 individuals). Responses from an additional 15 individuals with experience in multiple programs were also solicited. ***How?*** An Excel spreadsheet with drop-down menus for the rating of each criterion was sent on October 17, 2008 (Appendix 1). A reminder was sent approximately 2 weeks later. Of the 44 individuals, a total of 30 (68%) provided responses by November 7. In addition to rating the criteria, each evaluator was asked to include their job title, select their three primary fields of expertise from a drop-down list, and rate their knowledge of rangeland, forest and riparian systems, and statistical design and remote sensing on a 1-5 scale, where 1=not familiar and 5=expert.

Step 4. Rate the indicators against the criteria.
What? Each indicator was rated against each criterion separately for each of 3 land cover types: rangeland (including grassland, shrubland and savanna), forest (including woodland), and riparian. A 1-5 scale (1=strongly disagree that the indicator meets the criterion, and 5=strongly agree) was used for the majority of the criteria (see 'Rating Type' in Table 1). ***Who?*** Responses were solicited from a broad range of individuals with knowledge and experience in monitoring one or more of the land cover types relative to one or more of the programs listed in Step 3. Criteria 1-7 were evaluated by a 'General Group' of experts representing BLM, USFS, NPS, NRCS, ARS, USGS and academia. Criteria 8-9 were evaluated by a smaller group of GIS and remote sensing experts ('GIS/RS' in Table 1). An expert from the TNC with over 20 years of monitoring program design experience was invited to evaluate Criteria 10-11 due to high level of statistical knowledge required. Criteria 12-14 were evaluated by consulting with experts associated with each of the three agencies. Criteria 15-16 were applied by the interdisciplinary group in Step 5. ***How?*** An Excel spreadsheet with drop-down menus for the rating of criteria 1-7 and 8-9 was sent on October 17, 2008 (Appendix 1). A reminder was sent approximately 2 weeks later. Where possible, the spreadsheet included a recommended field method for measuring or evaluating the indicator. Of the 101 individuals asked to address Criteria 1-7, a total of 56 (55%) provided responses by November 7. Of the 14 individuals asked to address Criteria 8-9, a total of 10 (71%) provided responses by November 7. In addition to rating the criteria, each evaluator was asked to include their job title, select their three primary fields of expertise from a drop-down list, and rate their knowledge of rangeland, forest and riparian systems, and statistical design and remote sensing on a 1-5 scale, where 1=not familiar and 5=expert. Respondents had the option to select 'Don't Know' for any criterion/indicator combination they did not feel qualified to evaluate. They could also elect to evaluate one two or

all three of the land cover types. Our preliminary analysis indicates that there were few significant differences between evaluators based on knowledge, expertise or job title.

Step 5. Develop and apply system for integrating indicator ratings from each criterion.
What? The large number of criteria prevented us from applying a standard weighting system, like the Rank Order Centroid (ROC). ROC would have given an extremely small weight to the majority of the criteria. The diversity and complexity of the criteria prevented the sole use of a simple arithmetic mean of criteria rating x indicator rating for each criterion.

Instead, we developed a hybrid, systematic approach using a combination of the arithmetic mean of a normalized criteria rating x indicator rating for the criteria that were rated on a 1-5 scale, and a filter for those rated Yes/No. We also selected 3 criteria for which the indicator had to exceed a minimum average rating for each of the three cover types, or be very highly rated for at least one cover type. ***Who?*** The calculations were performed by a post-doctoral research associate. The decisions of how to integrate the indicator ratings were made by the BLM interdisciplinary team (see Step 1).

How?

5.1. Reviewed responses and comments to determine how well the criteria were understood by group of individuals evaluating the criteria, and by the groups applying the criteria to the indicators.
5.2. Reviewed criteria to decide whether the criteria should be applied as an average rating, a filter (Yes/No or minimum average rating for each cover type), or both (Table 2).
5.3. Normalized criteria to a 0-1 scale by dividing by 5. There is just one criteria rating for all three cover types. The normalized criteria ratings ranged from 0.51-0.91.
5.4. Generated an average normalized score for each of the 16 criteria. The weight of each criterion was multiplied by the average rating for each indicator.
5.5. Generated an average score for each indicator using Criteria 1-11 for each of the three cover types, and an overall average (Figures 1-3).
5.6. Applied the filters (based on Criteria 1, 4, 5 and 12-14; see Table 2) to select sub-set of indicators. Each criterion was required to pass the filter for all three cover types, or to be very highly rated for at least one cover type (Figure 4).
5.7. Applied Criteria 15-16 to remaining indicators.
5.8. Based on Criterion 15, identified an additional indicator (vegetation height) and used interdisciplinary group to generate ratings.
5.9. Documented reasons for selecting or rejecting each indicator, as described below.

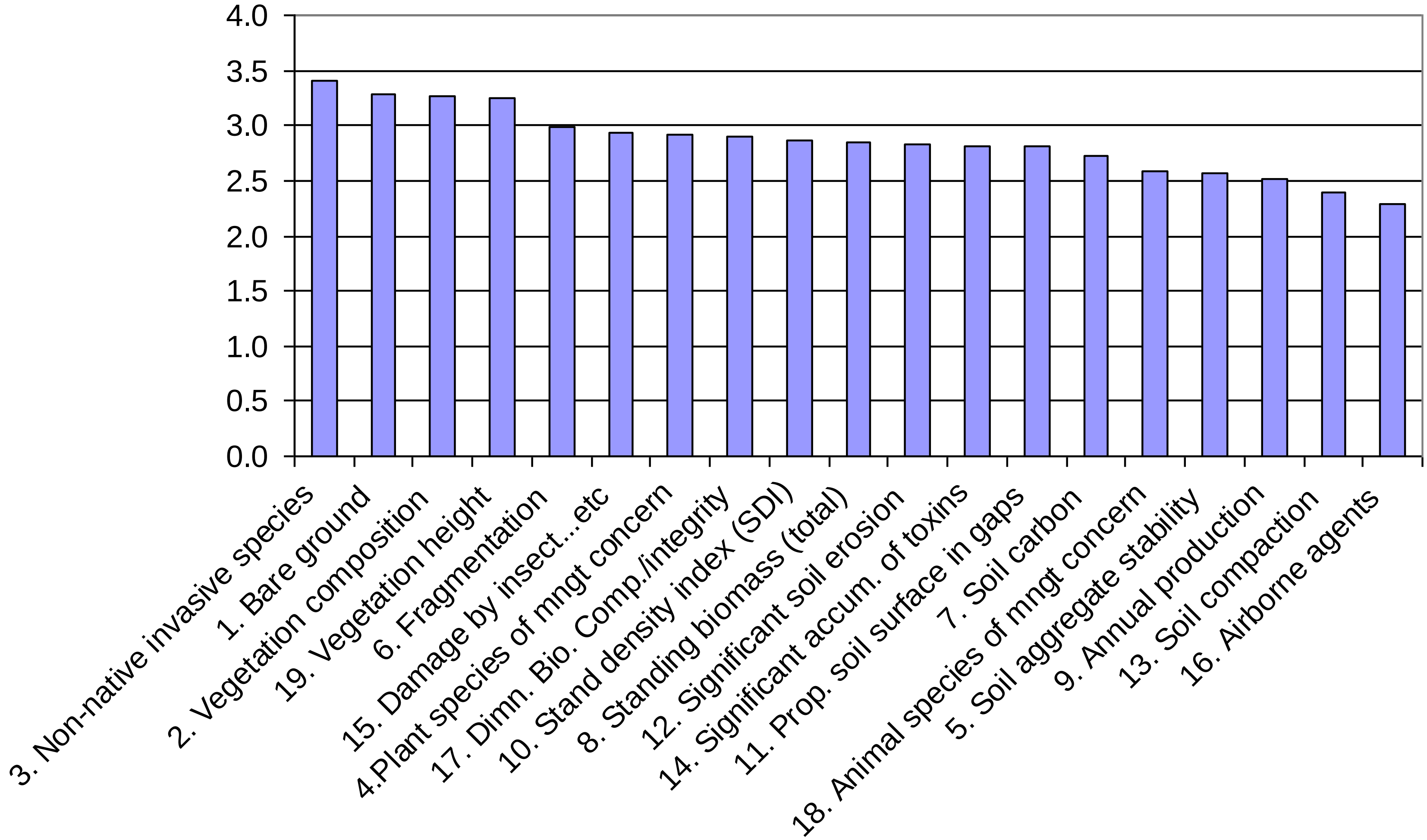

Figure 1. Overall average score (rating x criteria weight) of criteria 1 – 11 for all land cover types (range, forest, and riparian) for 19 indicators.

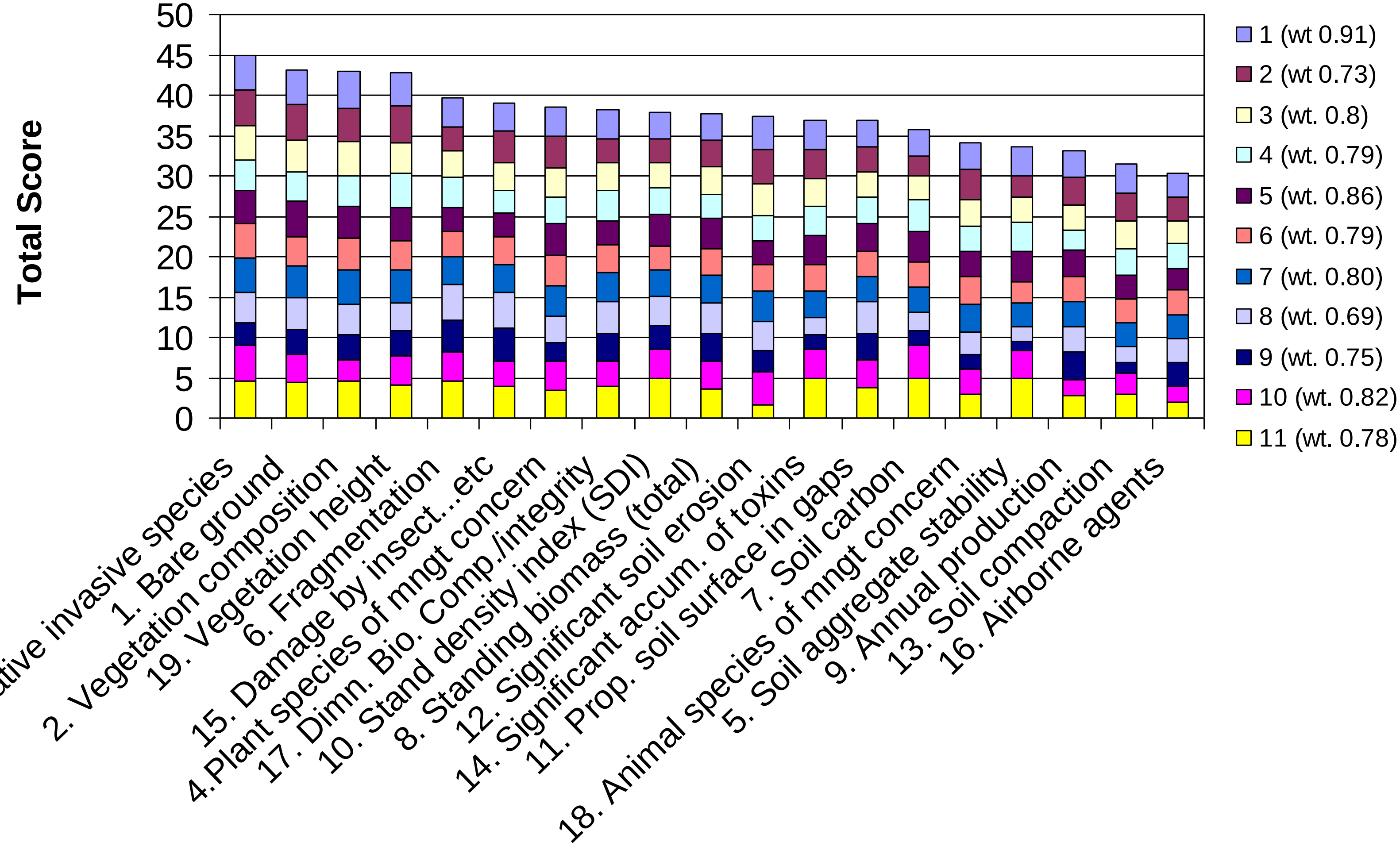

Figure 2. Total score of each indicator. Average score for each indicator given by criteria (1 – 11). Weight of each criterion given in parenthesis.

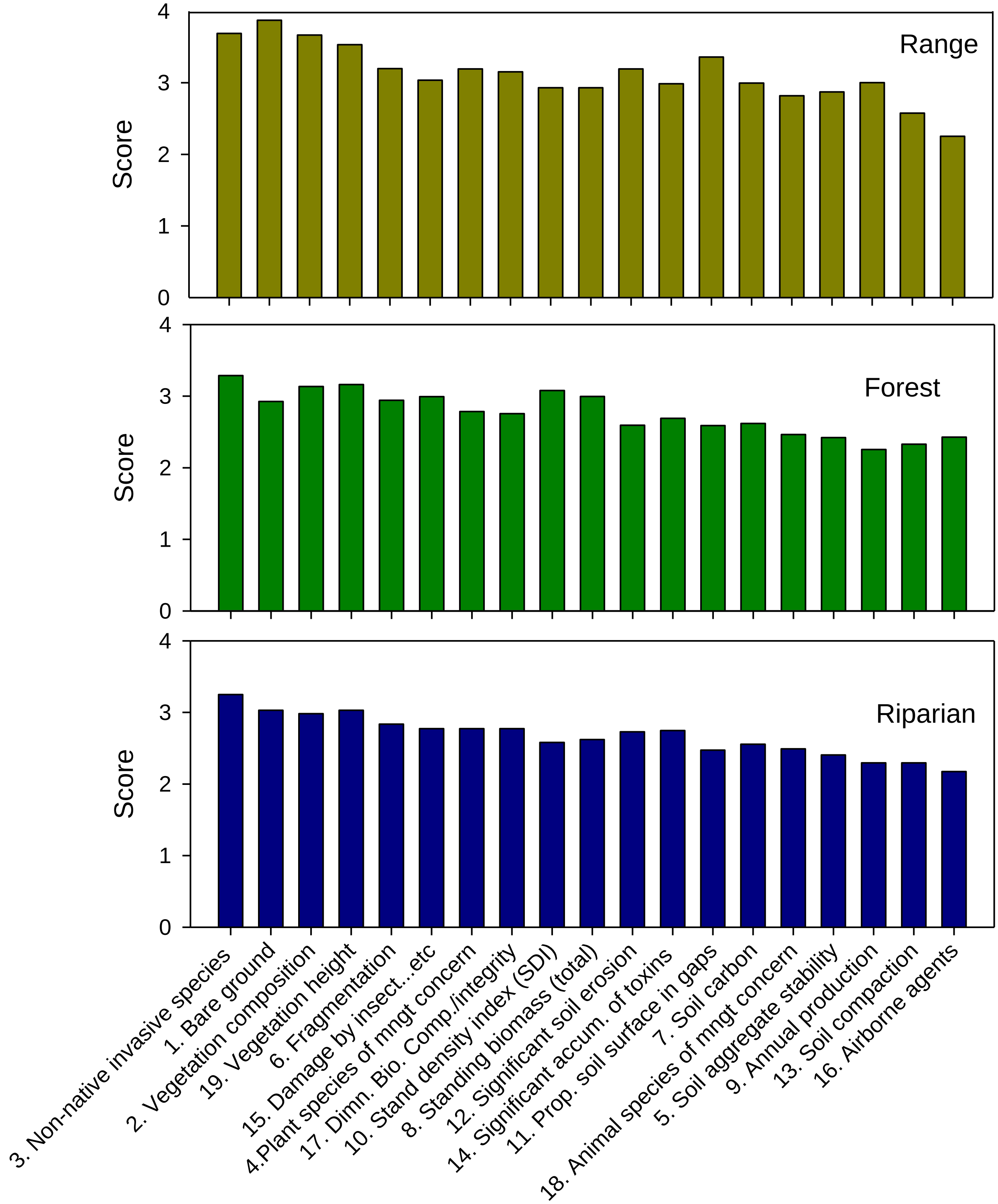

Figure 3. Average indicator score for each land cover type.

Table 2. Explanation for why some criteria selected as filters for including or excluding indicators from consideration (see Step 5.6 and Table 1). For the purposes of developing an overall rating for each indicator (Figure 1), the average rating for each criterion (below) was normalized by dividing by 5.

Criterion (see Table 1)	Average rating	Use	Explanation for why some criteria selected as filters
1	4.6	Filter (minimum median rating of 4) Rating	Top rated, reflecting broad consensus that indicators need to be rated relatively highly against this criterion.
2	3.6	Rating	
3	4.0	Rating	
4	3.9	Filter (minimum median rating of 4) Rating	This is a key criterion identified by virtually every indicator selection list we reviewed. Indicators must have a relatively high signal:noise ratio in order to detect change.
5	4.0	Filter (minimum median rating of 4) Rating	Top rated, reflecting broad consensus that indicators need to be rated relatively highly against this criterion. This is a key criterion identified by virtually every indicator selection list we reviewed. It adds credibility to the data and helps ensure that the core indicators can be compared across programs.
6	3.5	Rating	
7	4.0	Rating	
8	3.5	Rating	
9	3.8	Rating	
10	4.1	Rating	
11	3.9	Rating	
12	2.5	Filter (indicator must be included in ≥1 of 12-14 set)	These three criteria elicited yes/no answers so they could not be seamlessly integrated in the rating system. Because all three were rated low, it was concluded that it was inappropriate to apply each as a filter. However, the adoption of the indicator by at least one of the agencies generally indicates a national level of acceptance and at least partial protocol standardization.
13	2.8		
14	2.9		
15	4.5	See Step 5	
16	4.2	See Step 5	

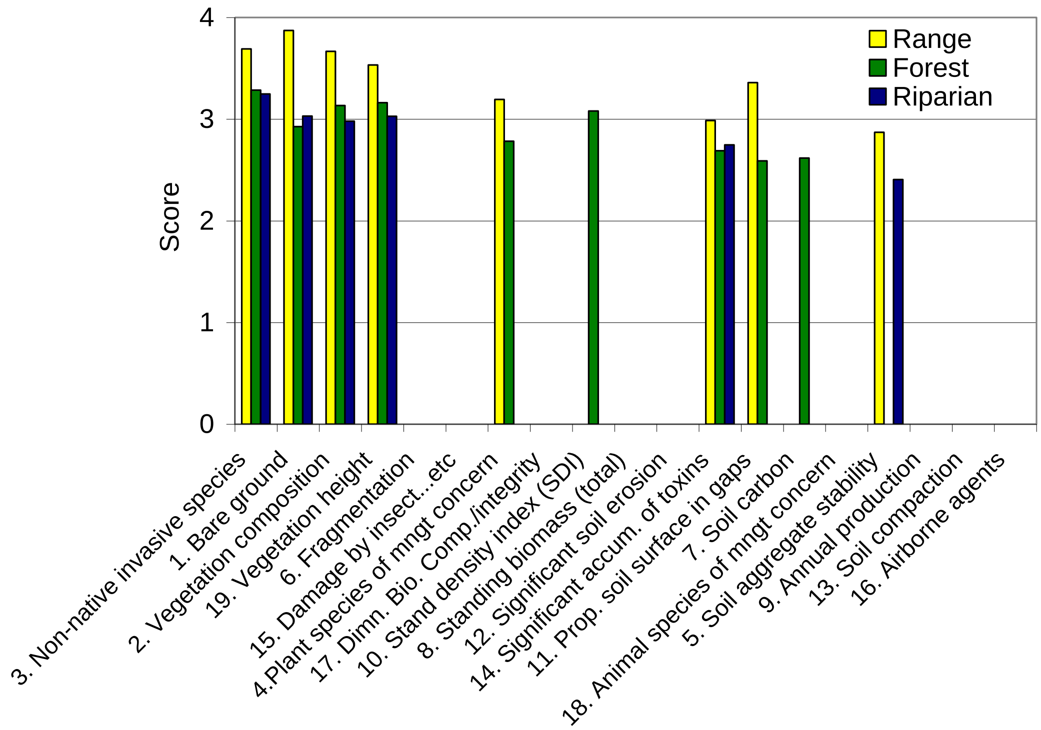

Figure 4. Average score across all criteria for indicators that passed all three filters (based on *criteria* 1, 4, and 5 – please see Table 1 for criteria) for at least one land cover type. The scores across all 11 criteria are less than 4 because average scores for these three criteria tended to be higher than for many of the other criteria.

Indicator and Method Recommendations

This section summarizes the results of the process described above. As discussed above, many of the 'indicators' listed below are in reality indicator groups or classes, allowing for some flexibility in defining the specific indicators depending on objectives. The key is to standardize the *methods* for collecting each of these indicators or indicator groups. This will ensure that specific indicators can be calculated from the data collected. General methods are listed below. Specific protocols will be defined in the next step of this process.

Core Indicators

These indicators are recommended for application wherever BLM implements quantitative soil and/or vegetation monitoring. We believe that these indicators are sufficiently generic and widely accepted that they could be applied together with other agencies and NGO's to standardize data collection across jurisdictions. All but two of these indicators passed all filters in all three cover types. Stand Density Index (SDI) had low median ratings for range and riparian cover types. Plant Species of Management Concern did not pass the filter for Riparian due to a median rating for Criterion 4 (high signal:noise ratio) of less than 4. The first four indicators can be generated from one method (line-point intercept) supplemented with a plot-level species inventory, and vegetation height can be collected in conjunction with the point-intercept data. Consequently, this core set addresses Criterion 16. Finally, for indicators 1-4 and 6, comparable indicators can be generated using remote sensing, with the notable exception of understory species (indicators 2-4), provided that the remote sensing is supported by field data. Additional explanation based on evaluator comments and the literature is included following each indicator.

(1) **Bare ground.** Bare ground is widely accepted as one of the most sensitive indicators of resource condition in rangelands. Where it appears in riparian and forest systems, it is generally an indicator that the system has been significantly modified. The incremental cost for collecting bare ground is minimal where there is little bare ground.

(2) **Vegetation composition.** Vegetation composition, including the cover of particular groups of species, has historically been applied in some form in virtually every monitoring program across all three cover types. When used together with cover (which is generated from the same data) it is sensitive to most changes in the status of nearly every terrestrial ecosystem and is critical for FRCC (Fire Regime Condition Classification). This indicator (or group of indicators) is also useful when determining the status of key species in plant communities that provide forage for all classes of herbivores.

(3) **Non-native invasive species.** The presence and cover of non-native species is essentially a component of vegetation composition. It requires no additional effort to collect. It is listed as a separate indicator because of its national, regional and local importance.

(4) **Plant species of management concern.** The presence and cover of plant species of management concern is also a component of vegetation composition. It requires no additional effort to collect. It is listed as a separate indicator because it is specifically required for BLM reporting.

(5) **Vegetation height.** Vegetation height is necessary to characterize vegetation structure. When used together with the proportion of the soil surface in large canopy gaps, it can be used to characterize vegetation structure for wildlife habitat and wind erosion**.** Although not commonly quantified using remote sensing at the present time, data acquisition (LIDAR) and analysis (stereoscopic) technologies already exist that will soon be ready for broad-scale application.

Core-Contingent Indicators

These are indicators that are always measured in the field unless they can be reliably estimated without measurement. For example, the tally of trees for SDI is zero if there are no trees present. Likewise, the proportion of the soil surface in large, inter-canopy gaps is generally zero in closed canopy forests. In these situations, the core-contingent indicators would not need to be measured.

(1) **Stand density index (SDI).** This indicator should be used when trees are present at monitoring locations. SDI has been identified by the BLM as the most useful indicator for forests. This indicator is necessary to monitor changes in tree populations and can be used to document both invasion and loss of woody species. It is also important because the line-point intercept method, which is ideal for cost-effectively collecting precise, repeatable bare ground, herbaceous and shrub cover indicators, is not optimal for trees. SDI ensures that high quality data will be collected on changes in trees.

(2) **Proportion of soil surface in large inter-canopy gaps.** This indicator is necessary to estimate wind erosion and provides data that can be used together with height measurements to create 3-dimensional models of vegetation structure necessary for wildlife habitat characterization. This field-measured indicator should be evaluated where at least one inter-canopy gap longer than 30cm is observed to exist on the transects used to measure bare ground and vegetation composition. This ensures that time will not be wasted measuring them in forests and highly productive range and riparian sites. This indicator met all filters for range and forest, but did not meet any filter for the riparian land use.

Contingent Indicators

Contingent indicators are only implemented if there is reason to believe they are necessary for monitoring or assessing the site. These indicators are only measured when there is reason to believe that there is a problem related to the indicator. Therefore, measurement of these indicators is contingent: they are recommended except where specific conditions are met. For example, soil aggregate stability would only need to be measured in areas that are currently experiencing (or have in the past) significant soil erosion or reductions in soil stability. All of these indicators were highly rated and passed all filters for at least 2 of the 3 cover types.

(1) Soil aggregate stability. This field-measured indicator reflects changes in soil erodibility and is sensitive to changes in soil organic matter cycling. It should be evaluated where a model (based on bare ground, average precipitation, and a broad texture class (sand, loam or clay) predicts that stability is less than a minimum value. This ensures that time will not be wasted on measurements of highly stable soils. This indicator passed all filters except for criteria 1 and 4 filters in the forest land cover type. Its overall (all land cover types) average rating (3.05) was somewhat low because it received low ratings for the remote sensing criteria: criterion 8 (1.79) and criterion 9 (1.17), reflecting its limitation in remote sensing-based monitoring systems.

(2) Significant accumulation of toxins. This indicator is important because it reflects major threats to human and environmental health. It should be evaluated where there is reason to believe that a significant accumulation of toxins exists. It was not included as a core indicator because (a) it is extremely expensive and would be very impossible to measure with existing budgets, (b) it is likely to be near zero on the majority of BLM lands, and (c) in most cases, it should be possible to predict where a significant accumulation of toxins is likely to occur. This indicator met all three filters for all three land cover types, but, like aggregate stability, is impossible to detect with remote sensing. Standardized methods for sampling and measuring toxins need to be adopted in order for meaningful reporting and comparisons with data from other agencies (especially EPA) to occur.

Recommended Methods/Measurements for Core and Contingent Indicators

Adoption of a consistent set of assessment, inventory and monitoring methods will allow the BLM to combine and compare data collected in different areas, and data collected to address different objectives. The following methods were selected based on the following requirements: (1) well documented, and (2) widely used by BLM Field Offices. A third requirement, inclusion in at least one national monitoring program, was used for the core indicators. Table 3 lists each method and the core/contingent indicators it measures, and provides references describing each method's complete protocol.

The protocols should be carefully followed in order to ensure that data collected from different areas can be compared or combined. Table 4 lists modifications that can be made while preserving the ability to aggregate data. All modifications should be documented as metadata with the dataset.

(1) Line-point intercept (LPI) with plot-level species inventory

Core Indicators: bare ground, vegetation composition, non-native invasive species, plant species of management concern

Line-point intercept is a widely-used, rapid method for measuring vegetation and soil surface cover. Vegetation cover by species and soil surface type is measured by dropping a pin (or pointer) at fixed intervals (i.e., points) along transects and recording all species that intercept the pin as well as the soil surface where the pin touches the ground. Precautions taken in standard LPI protocols contribute to it being one of the least biased of cover measures (Elzinga et al. 1998).

While LPI, when performed correctly, can give unbiased estimates of cover for vegetation species, its sensitivity is proportional to the number of points that are measured per plot location. For this reason, LPI can miss species that are uncommon or patchily distributed in a plot, , though, on average, it will accurately record cover of all species. To address the invasive non-native and plant species of management concern core indicators, LPI should be supplemented with a species inventory of a fixed-area plot. Plots need to be large enough to capture the full diversity of the site: 150ft (45.6m) diameter circular plots are recommended to be compatible with NRI data.

The plot-level species inventory should used to add species to the list already generated using LPI. Plots should be searched by one individual for at least 15 minutes, and then searching should continue until new species detections are more than two minutes apart. Unknown species should be marked with a flag and identified after the search is complete. Setting a minimum time-limit on the searching within the plot ensures the plot is adequately sampled, and stopping when a specified time between new detections has been reached limits the additional cost of implementing the plot-level inventory and ensures the species list is a good estimate of actual diversity at the site.

(2) Vegetation height

Core Indicator: vegetation height

The vegetation height method used by the NRCS Natural Resource Inventory (NRI) is a fast and unbiased way to measure vertical structure of vegetation. The NRI vegetation height method records the height and species of the tallest vegetation (any living or dead plant part) within a small-radius (15cm or approximately 6in, NRI 2009) of points at fixed intervals along the same transects as used for LPI.

(3) Number and diameter of trees in a fixed-area plot

Contingent Indicator: stand density index (SDI)

Densities of trees in different size classes are used to calculate SDI. While there are a number of different ways that SDI can be calculated and even some rapid methods for estimating SDI in the field, these methods can produce slightly different results for the same stand. Instead, the recommended method simply requires collecting the number and diameter of trees in fixed-area plots. Diameter at breast height (DBH) is recorded for single-stemmed trees, and diameter at root crown (DRC) is recorded for multi-stemmed species. These data are used to calculate density by size class. SDI can be calculated as needed to maintain consistency with national programs and as data are aggregated.

Following the FIA protocol (US Forest Service 2007), trees smaller than 5.0-in (12.5 cm) DBH/DRC are measured and tallied in 1/300-ac circular plots of 6.8 ft (2.1 m) radius. Trees greater than or equal to 5.0 in DBH/DRC are measured and recorded from 1/24-ac circular plots of 24.0 ft (7.3 m) radius. The 1/300-ac plots are located concentrically within the 1/24-ac plots, and plots should be set at the center point of a sampling site as well as at the end of each of the transects used for line-intercept sampling. The diameter and species of each tree within the plot must be recorded. The center of a tree must be within the boundary of the circular plots to be included[1].

(4) Canopy-gap intercept

Contingent Indicator: Proportion of soil surface in large intercanopy gaps
Canopy-gap intercept measures the proportion of a transect covered by large gaps between plant canopies. Canopy gaps are measured along the transect tape measure by recording the start and stop location of each gap above a minimum size. The length of each gap is calculated and the sum of the lengths is divided by the transect length to obtain the proportion of soil surface in large intercanopy gaps. The minimum gap size as well as what types of vegetation (e.g., shrubs, perennial grasses, annual grasses, forbs) are considered in the canopy versus which are considered as part of canopy gaps must be consistent for canopy-gap measurements to be aggregated. The NRI protocol uses a 1-foot (30 cm) minimum gap with any live or standing dead plant material considered as part of the canopy. A canopy element (stops gap) is defined as any vegetation that covers at least 50% of any 1-in (2.5 cm) segment.

(5) Soil aggregate stability

Contingent Indicator: soil aggregate stability
The soil stability test described by Herrick et al. (2005) and NRI is a relatively simple method that measures the stability of soil when exposed to rapid wetting. This method yields information on soil structural development and resistance to erosion.

(6) Soil sample collection and analysis for toxins

Contingent Indicator: significant accumulation of toxins

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[1] Distance from the plot center is used to determine whether or not a tree is within the plot. If at least two people are sampling the plot, distances can be quickly checked using a tape measure. If one person is sampling, measuring distances with a tape is not efficient. In these cases, distances can be measured with devices like a laser rangefinder if there are no obstructions blocking visibility of trees or an ultrasonic distance measurer (e.g., the Haglöf DME 201) that can measure distances when obstructions exist.

> The presence and concentration of toxins should be measured through standardized sampling of soils at a site. The US Forest Service's Forest Inventory and Analysis (FIA) program includes a protocol for collecting and analyzing samples at the soil surface and at two standard soil depths - 0 to 4 in (0 to 10 cm) and 4 to 8 in (10 to 20 cm) - to test for accumulation of toxins. Under the FIA protocol, three soil surface samples are taken and a single sample is taken at the other depths using a soil corer. Samples are not composited (i.e., multiple samples are not combined and mixed prior to analysis) between plots, but are composited within plots.

Modifications of Recommended Methods and the Ability to Aggregate Indicators

The methods recommended above are implemented in carefully prescribed ways in protocols like NRI and FIA to minimize variability (e.g., due to measurement error, differences between observers) and maintain the ability to aggregate data for regional- and national-level analyses. To maximize the potential for aggregating measurements of the core and contingent indicators, the core methods should be implemented in the same manner throughout BLM. Occasionally, however, constraints exist that necessitate modification of the way these core and contingent indicator methods will be applied.

The core and contingent indicator methods can be modified in various ways, and depending on what is modified, the ability to aggregate data may or may not be affected. In general, modifying the definitions of what is recorded or how it is recorded will result in measurements that cannot be aggregated with other data because the *meaning* of the data are not consistent. For example, the line-point intercept method requires that a plant hit be recorded only if a raindrop would hit the plant part. Points that fall within the plant canopy but do not intercept a leaf or stem are not recorded.

Alternatively, data that have been collected using the same definitions but that vary with respect to aspects like how many transects are sampled, the length of the transects, and the size of fixed-area plots can be aggregated. This is because modifications like these affect only the within-plot variability, and while the *variance* of the measurements may be affected (which will affect the confidence of an assessment and the number of observations required to detect change), the *meaning* of the measurements has not been altered. Table 4 provides examples of what aspects of each of the recommended methods can and cannot be modified and still achieve data that can be aggregated to answer larger-scale questions.

Table 3. Recommended methods and measurements for core, core-contingent, and contingent indicators.

Method	Indicator(s)	Description	Source/Reference
For core indicators			
Line-point intercept with plot-level species inventory	• Bare ground • Vegetation composition • Non-native invasive species • Plant species of management concern	Line-point intercept is a rapid and accurate method for quantifying cover of vegetation and bare ground. However, because line-point intercept can underestimate cover of uncommon species, this method is supplemented with searches of a 150-ft (45.6-m) diameter standard plot for at least 15 minutes and until new species detections are more than 2 minutes apart.	NRCS (2009) for LPI and species inventory, Herrick et al. (2005) for LPI
Vegetation height	• Vegetation height	Height of tallest leaf or stem (living or dead) within a 6in (15cm) radius recorded for points along a transect.	NRCS (2009)
For core-contingent indicators			
Number and diameter for all trees within a fixed-area plot	• Stand density index	Stand density index is a composite measure of tree density based on the number of trees per acre and their size compared to a hypothetical maximum SDI for a given forest type. Diameter of trees is measured at DBH for single-stemmed species and DRC for multi-stemmed species within 6.8-ft (2.1-m) radius plots for trees < 5in (12.5cm) DBH/DRC and within 24-ft (7.3-m) radius plots for trees >= 5in (12.5cm) DBH/DRC.	US Forest Service (2007), Ducey and Valentine (2008)
Canopy gap intercept	• Proportion of soil surface in large inter-canopy gaps	Canopy gap intercept measures the proportion of a line covered by large gaps between plant canopies and is an important indicator of the potential for erosion. Use 1ft (30cm) minimum gap.	NRCS (2009), Herrick et al. (2005)
For contingent indicators			
Soil stability	• Soil aggregate stability	This test measures the soil's stability when exposed to rapid wetting and provides information on integrity of soil aggregates, degree of structural development, resistance to erosion, and soil biotic integrity.	NRCS (2009), Herrick et al. (2009)
Soil sample collection	• Significant accumulation of toxins	Presence and concentrations of toxins are assessed through collection of three samples from the soil surface and at one sample at depths of 0 to 4in (0 to 10cm) and 4 to 8in (10 to 20cm) using a soil corer and following the FIA protocol.	US Forest Service (2007)

Table 4. Modifications that can and cannot be made to recommended methods in order to preserve the ability to aggregate local data to larger scales.

Method	**What *Can* be Modified**	**What *Cannot* be Modified**
Line-point intercept with plot-level inventory	• Number and spatial distribution of transects* • Length of transects • Number of points per transect • Additional information about species at all or subset of points (e.g. dead vs. live hit).	• Foliar vs. total canopy cover (must use foliar) • Definition of litter vs. standing dead (litter is detached; standing dead is included in canopy cover) • Size threshold between soil and rock (5mm or about 1/4") • Size of fixed plot (circular plot of 150 ft diameter recommended) • Amount of time fixed plot searched (searches should be at least five minutes and continue until new species detections are more than 2 minutes apart
Vegetation height	• Number and spatial distribution of transects* • Length of transects • Number of points per transect • Number of species or functional groups for which height is recorded (provided that tallest is *always* recorded)	• Radius of circle within which maximum height is determined (6" or 15cm)
Stand density index (SDI)	• Location of fixed-radius sub plots within larger plot	• Method for calculating SDI from plot inventory: quadratic mean diameter method is required for core indicators • Whether fixed- or variable-size plots are used (the core indicators protocol uses fixed-area plots) • Size of fixed plots (6.8-ft and 24-ft radius sub-plots)
Canopy gap intercept	• Number and spatial distribution of transects* • Length of transects • Minimum gap can be decreased	• Definition of canopy necessary to stop a gap (50% cover on any 1" segment) • Inclusion of annual grasses and forbs • Minimum gap cannot be increased • What happens at beginning/end of transect (gaps defined to end).
Soil stability	• Number of sampling locations within a plot • Where samples are selected along transect (provided that it is systematic or random)	• Whether or not subsurface samples are collected (can help interpretation where surface disturbance is common) • Time thresholds for determining stability class (see reference in Table 3).
Soil sample collection	• Number of locations sampled within each plot • Whether or not samples composited within plot • Configuration of sample locations within plot • Additional depths (>8 in) or subdivision of recommended depths	• Depths at which samples are collected (samples should be collected at soil surface and at depths of 0 to 4 in and 4 to 8 in)

*Transects should be independent (not contiguous or intersecting).

Recommended for Potential Future Inclusion as Core or Contingent Indicators

The following indicators are recommended for future consideration. There were no overriding reasons to reject them except that standardized data collection or sampling protocols have yet to be developed.

(1) **Fragmentation.** Fragmentation is recommended by virtually every organization concerned with monitoring wildlands, and it was a very highly rated indicator. A large number of metrics have been published. However, there is little consensus in the literature or among managers relative to which metric should be applied. Until a standardized metric is developed, it cannot be recommended for application to BLM lands. This was illustrated in our ratings as this indicator did not pass the criterion 5 (repeatability) filter. In its 2008 'State of the Nation's Ecosystems' report, the Heinz Center proposes a "Pattern of 'Natural' Landscapes" indicator based on the size and abundance of 'core natural' patches (those surrounded by at least 240 acres of other "natural" lands.

(2) **Soil carbon**. Soil carbon is used to estimate carbon sequestration. Given the increasing focus on global climate change, this indicator is likely to be required. However, it is extremely expensive to measure in the field and the existing models poorly predict soil carbon in rangeland, forest and riparian ecosystems. The USFS currently collects limited data only on its limited FIA Phase III plots, and the NRCS is engaged in pilot studies designed to contribute to a possible future sampling plan through NRI. In the meantime, model estimates based on cover and soils for agricultural lands can be applied. Until a standardized sampling plan is developed and the budget exists, it cannot be recommended for application to BLM lands. This indicator did not pass the criterion 4 (high signal:noise ratio) in the range or riparian cover type ratings.

(3) **Area with significant soil erosion (Sign. soil erosion).** This is arguably one of the most important indicators of land degradation. However, no standardized quantitative method exists to evaluate it. Both NRI and FIA have related indicators that are based on qualitative observations. Quantitative models based on the core indicators and baseline soils information are under development. When they are released, this indicator should be added. This indicator did not pass criterion 4 (high signal:noise ratio) and 5 (repeatability) for any land cover type ratings.

(4) **Soil compaction.** This is an important indicator for all three land cover types, but it is variable and requires multiple samples resulting in high measurement costs. Because soil bulk density is required for carbon estimates, it may be added when carbon protocols are finalized. This indicator did not pass criteria 4 (high signal:noise ratio) and 5 (repeatability) for any land cover type ratings.

Not Recommended

The following indicators are not recommended because they failed one (and generally more than one) of the filters and usually had low overall ratings in for all three of the land cover types. None of them can be consistently captured across all three land cover types using remote sensing.

(1) Diminished biological components/integrity (Dimn. Bio. Comp./integrity). This is collected as a qualitative indicator by both FIA and NRI. It is unnecessary because it can be addressed quantitatively through the core indicator, vegetation composition.
(2) Airborne agents. This is a qualitative indicator of a driver or stressor. It is effectively attempting to interpret other indicators (e.g. plant stress) to assign a cause. While it may be applied to specific species where relationships are well understood (e.g. ozone damage in forests), it is not appropriate as a core indicator.
(3) Damage by insects, disease, etc… (Damage by insect…etc.). See explanation for 'airborne agents'.
(4) Animal species of management concern. This is an extremely important indicator, but not suitable as a standard core indicator because sampling time and methods are all species dependent. It needs to be addressed as a supplementary indicator on a species-specific basis.
(5) Standing biomass (total). This indicator is potentially valuable to address a number of monitoring objectives. However, most of these long-term objectives can be addressed more cost-effectively using a combination of cover, composition and height. It can, of course, a very valuable indicator of *short-term* forage availability for wildlife and livestock.

Conclusions

The systematic, participatory selection process resulted in 4 classes of indicators: core, contingent core, potential future, and not recommended. The core and core contingent indicators may serve as the starting point for the development of common monitoring strategies across multiple offices and regions in BLM, and for coordination with other agencies and organizations. In some cases, these indicators will need to be supplemented by more specific indicators to address specific questions.

Acknowledgements

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Abbreviations

ARS	Agricultural Research Service
BLM	Bureau of Land Management
FIA	Forest Inventory and Analysis (USFS)
GIS	Geographic Information Systems
LPI	Line-point Intercept
NOC	National Operations Center (BLM)
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NRI	Natural Resources Inventory (NRCS)
SDI	Stand density index
RS	Remote Sensing
USGS	United States Geological Survey

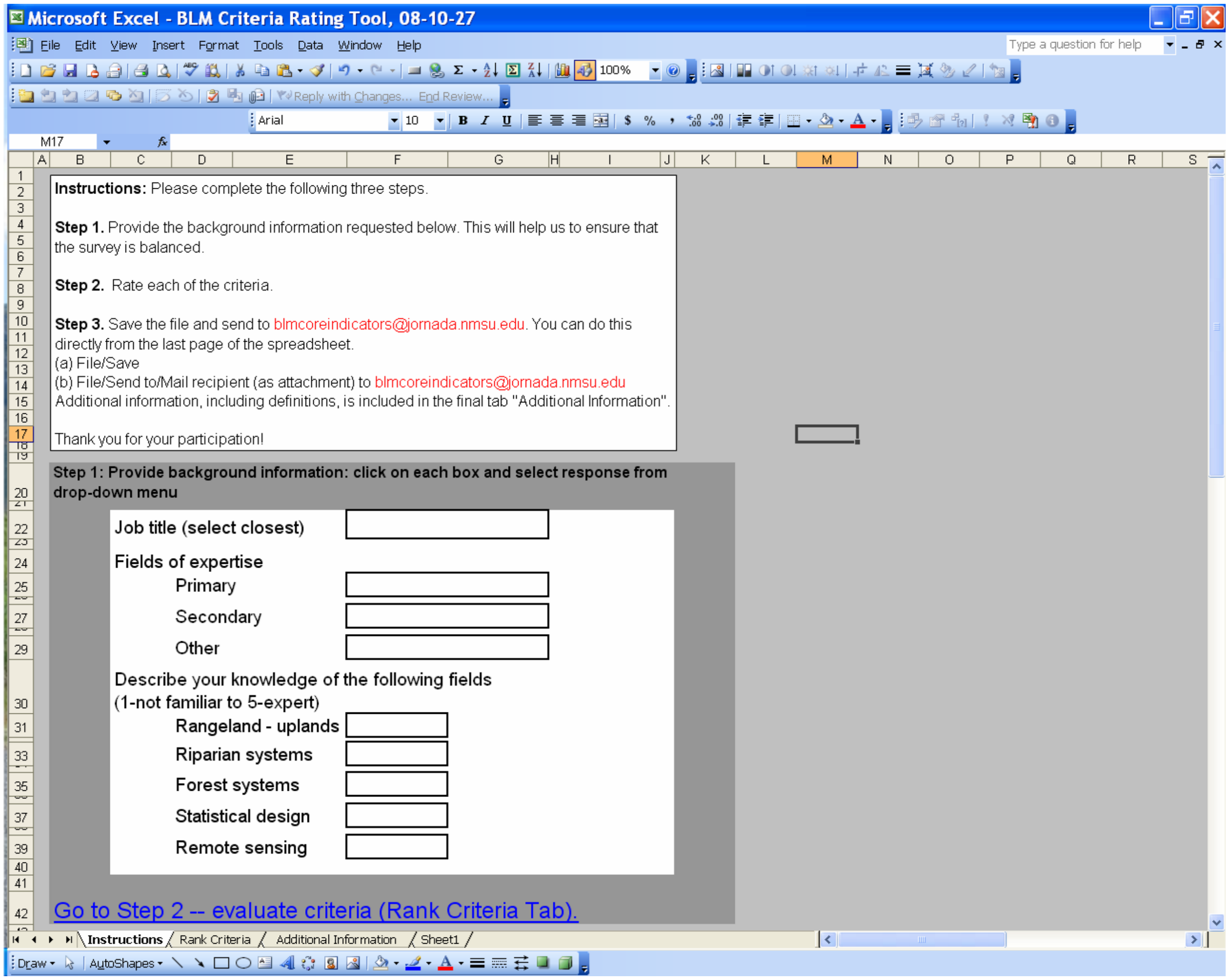
Appendix 1. Examples of the Criteria and Indicator Rating Tools

An email letter explaining the BLM core indicator selection project and the rating process was sent to all evaluators. A separate Microsoft Excel file was sent to each group. Both criteria and indicator evaluators were first asked to fill out background information (Table A1.1). Evaluators selected from a list of possible responses (Figure A1.1).

Table A1.Background information collected from criteria and indicators.

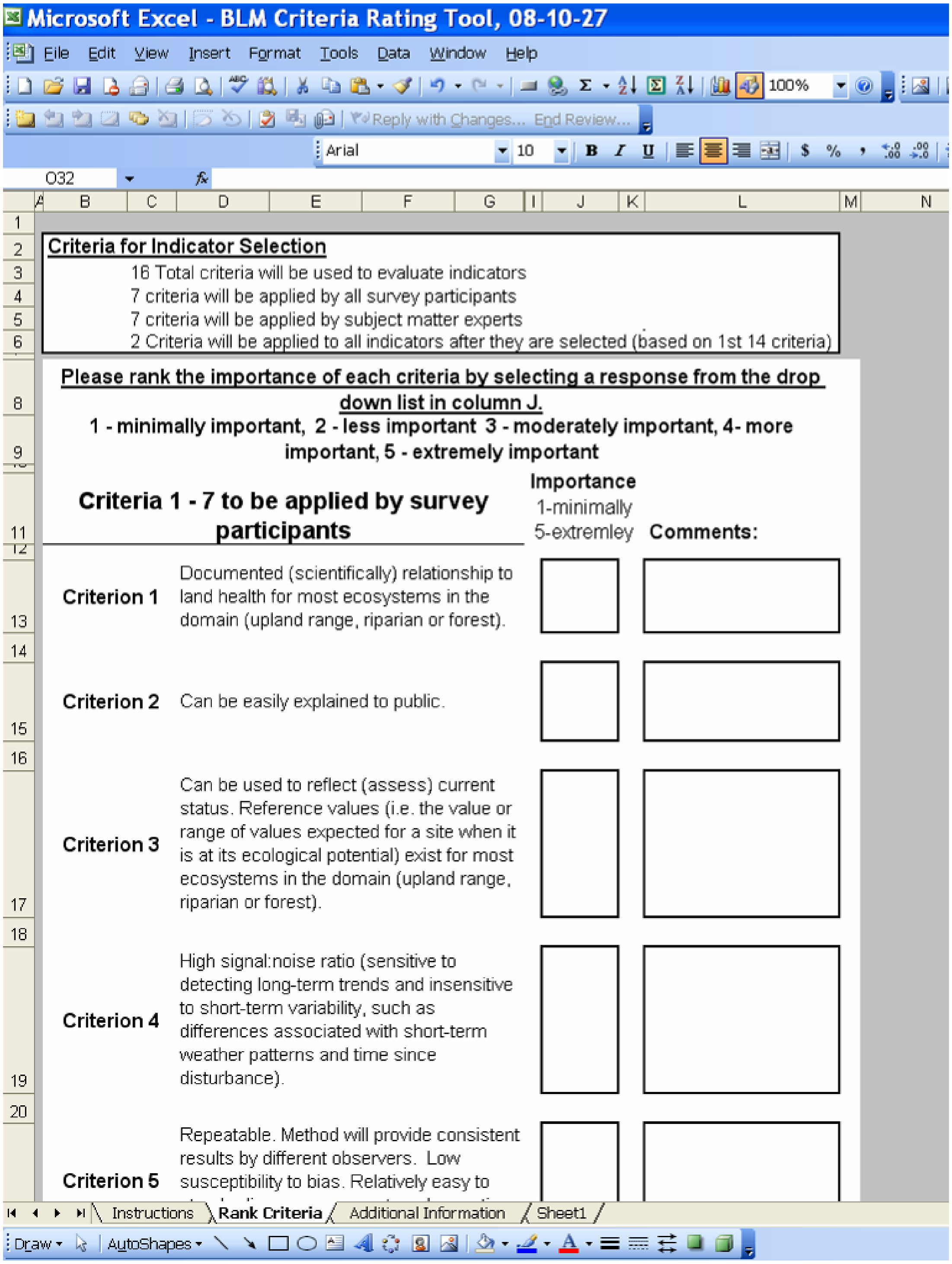
Information	Response Options	
Job		
	Botany (430) Ecologist (408) Environmental Engineer Forestry (460) General Biol. Sci. (401) Geographer (404) Geology (1350) Hydrology (1315) Management Series (0340)	Natural Resource Specialist Range Scientist Range Technician Rangeland Management (454) Recreation Specialist (188) Soil Conservation (457) Soil Scientist (470) Wildlife Biology (486) Zoology (410) Other (please list in cell to right of this cell)
Field of Expertise		
Primary Secondary Other	Botany Ecology Environmental Engineering Fire ecology/fuels Forestry Hydrology Range	Recreation Rehabilitation Remote sensing/GIS Riparian/wetland Soils Wildlife Other (please list in cell to right of this cell)
Describe you knowledge of the following fields		
Rangeland – uplands Riparian systems Forest systems Statistical design Remote sensing	1 – not familiar 2 3 4 5 - expert	

Figure A1.1. Example of the Instructions tab for Criteria Rating Tool. This worksheet provides instructions and entry of background information. Step 1 is identical for the Indicator Rating Tool.



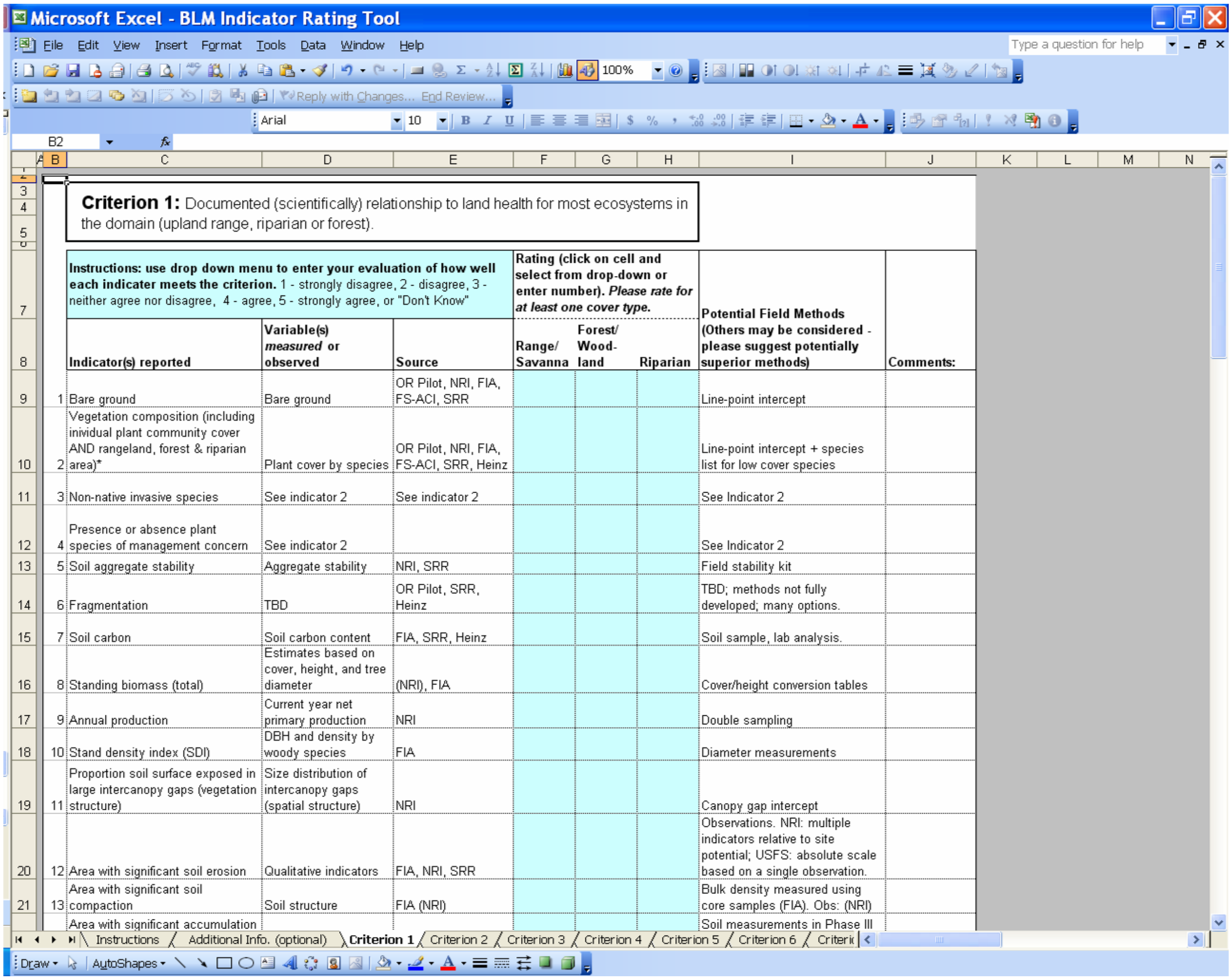
Criteria evaluators were then asked to rate the importance of each criterion by selecting from a drop down list with (1 - minimally important, 2 - less important, 3 - moderately important, 4- more important, 5 - extremely important). A place was provided to give comments on each criterion (Figure A1.2).

Figure A1.2. Example of Criteria Rating worksheet. Please see Table 1 for complete list of criteria.



Indicator evaluators were asked to rate each indicator by how well it met each individual criterion; 1 - strongly disagree, 2 - disagree, 3 -neither agree nor disagree, 4 - agree, 5 - strongly agree, or "Don't Know (Figure A1.3). Evaluators had the option of rating one, two, or three land cover types for each criterion. There were three files with three sets of criteria: criteria 1 – 7, criteria 8 & 9, and criteria 10 & 11.

Figure A1.3. Example from the Indicator Rating tool. This worksheet is for criterion 1. Each criterion was rated on a separate worksheet.



Criterion 1: Documented (scientifically) relationship to land health for most ecosystems in the domain (upland range, riparian or forest).

Instructions: use drop down menu to enter your evaluation of how well each indicater meets the criterion. 1 - strongly disagree, 2 - disagree, 3 - neither agree nor disagree, 4 - agree, 5 - strongly agree, or "Don't Know"

Rating (click on cell and select from drop-down or enter number). ***Please rate for at least one cover type.***

	Indicator(s) reported	**Variable(s) *measured* or observed**	**Source**	**Range/ Savanna**	**Forest/ Wood-land**	**Riparian**	**Potential Field Methods (Others may be considered - please suggest potentially superior methods)**	**Comments:**
1	Bare ground	Bare ground	OR Pilot, NRI, FIA, FS-ACI, SRR				Line-point intercept	
2	Vegetation composition (including inividual plant community cover AND rangeland, forest & riparian area)*	Plant cover by species	OR Pilot, NRI, FIA, FS-ACI, SRR, Heinz				Line-point intercept + species list for low cover species	
3	Non-native invasive species	See indicator 2	See indicator 2				See Indicator 2	
4	Presence or absence plant species of management concern	See indicator 2					See Indicator 2	
5	Soil aggregate stability	Aggregate stability	NRI, SRR				Field stability kit	
6	Fragmentation	TBD	OR Pilot, SRR, Heinz				TBD; methods not fully developed; many options.	
7	Soil carbon	Soil carbon content	FIA, SRR, Heinz				Soil sample, lab analysis.	
8	Standing biomass (total)	Estimates based on cover, height, and tree diameter	(NRI), FIA				Cover/height conversion tables	
9	Annual production	Current year net primary production	NRI				Double sampling	
10	Stand density index (SDI)	DBH and density by woody species	FIA				Diameter measurements	
11	Proportion soil surface exposed in large intercanopy gaps (vegetation structure)	Size distribution of intercanopy gaps (spatial structure)	NRI				Canopy gap intercept	
12	Area with significant soil erosion	Qualitative indicators	FIA, NRI, SRR				Observations. NRI: multiple indicators relative to site potential; USFS: absolute scale based on a single observation.	
13	Area with significant soil compaction	Soil structure	FIA (NRI)				Bulk density measured using core samples (FIA). Obs: (NRI)	
	Area with significant accumulation						Soil measurements in Phase III	

Appendix 2. Tests for Potential Indicator Selection Bias Associated with Expertise and Level of Knowledge

In order to test for potential bias in the rating tool, indicator ratings were grouped based on information provided by each evaluator. For each evaluator, one indicator score was calculated by creating a weighted average score based on the criteria applied (1-7 in Table 1). Tests for difference between areas of expertise and levels of knowledge were completed using the Kruskal-Wallis test (a non-parametric equivalent to a one-way ANOVA). While there were some occasions of significant differences, all p-values were greater than 0.01. In those cases with statistically significant differences, there were no clear trends in the score given and the level or type of expertise reported. The differences in range land cover type indicator ratings are shown in Figure A2.1 for self-reported levels of rangeland – upland knowledge (1 – not familiar to 5 – expert). Three indicators (11. Proportion of soil surface in gaps, 18. Animal species of management concern, and 5. Soil aggregate stability) were given significantly different ratings between level of rangeland-upland knowledge. However, there is no clear trend from low to high level of knowledge for any indicator rating. For example, the scores for indicator 18. 'animal species of management concern' were highest for a response of 3 and 4, and lowest for those least (2) and most (5) familiar with the indicator. Indicator 11, ' proportion of surface in gaps' had the opposite pattern; higher ratings for knowledge levels 2 and 5 and lower ratings for knowledge level 3 and 4. Likewise, no consistent patterns were seen for levels of forest systems knowledge and indicator ratings for forest land cover types (Figure A2.2).

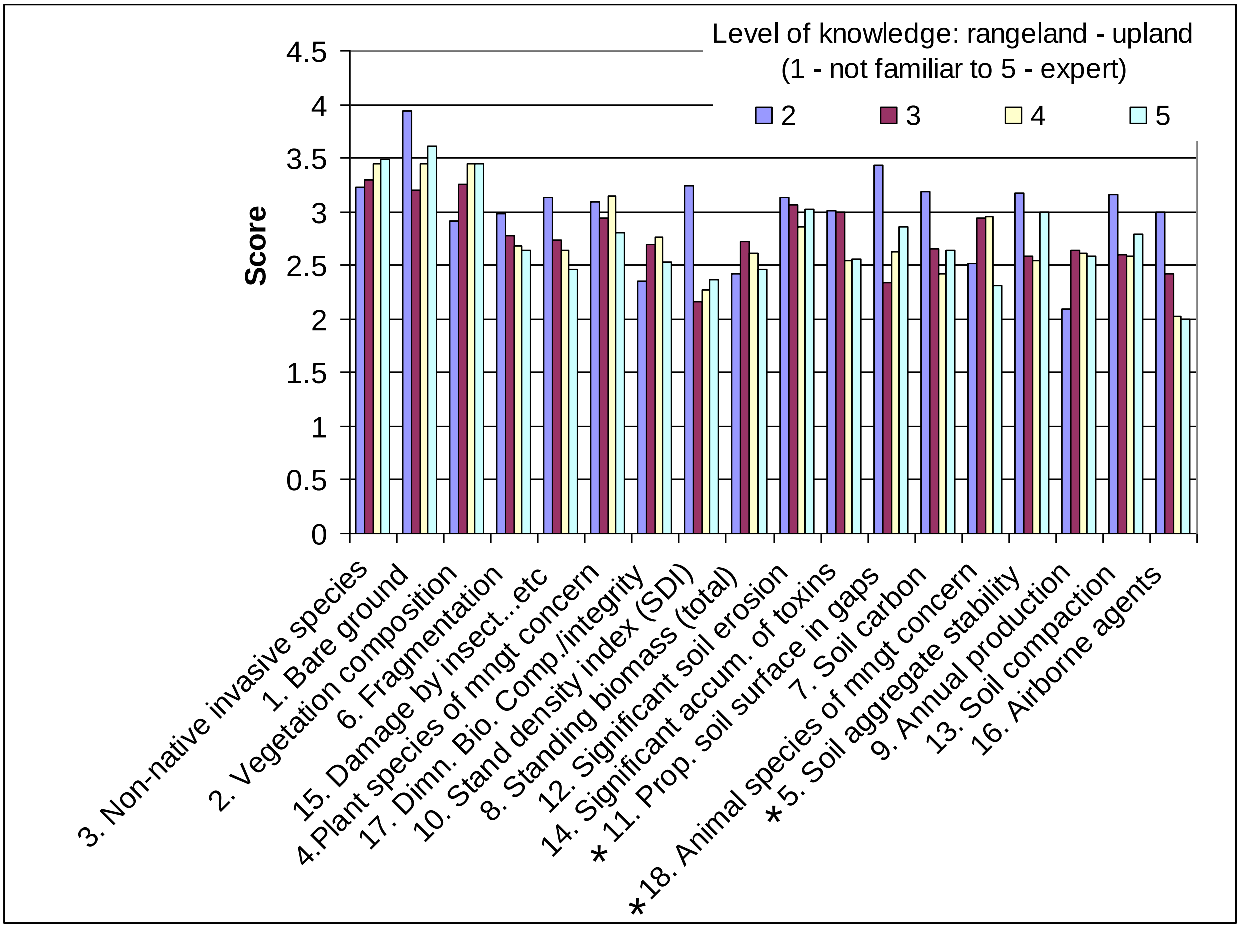


Figure A2.1. Indicator score for range land cover type given by evaluators self-reported level of rangeland-uplands knowledge (of options 1 – not familiar to 5 – expert, only 2 – 5 were chosen). * indicates indicators with ratings that were found to be statistically different ($p < 0.10$ in a Kruskal-Wallis test) between levels of knowledge.

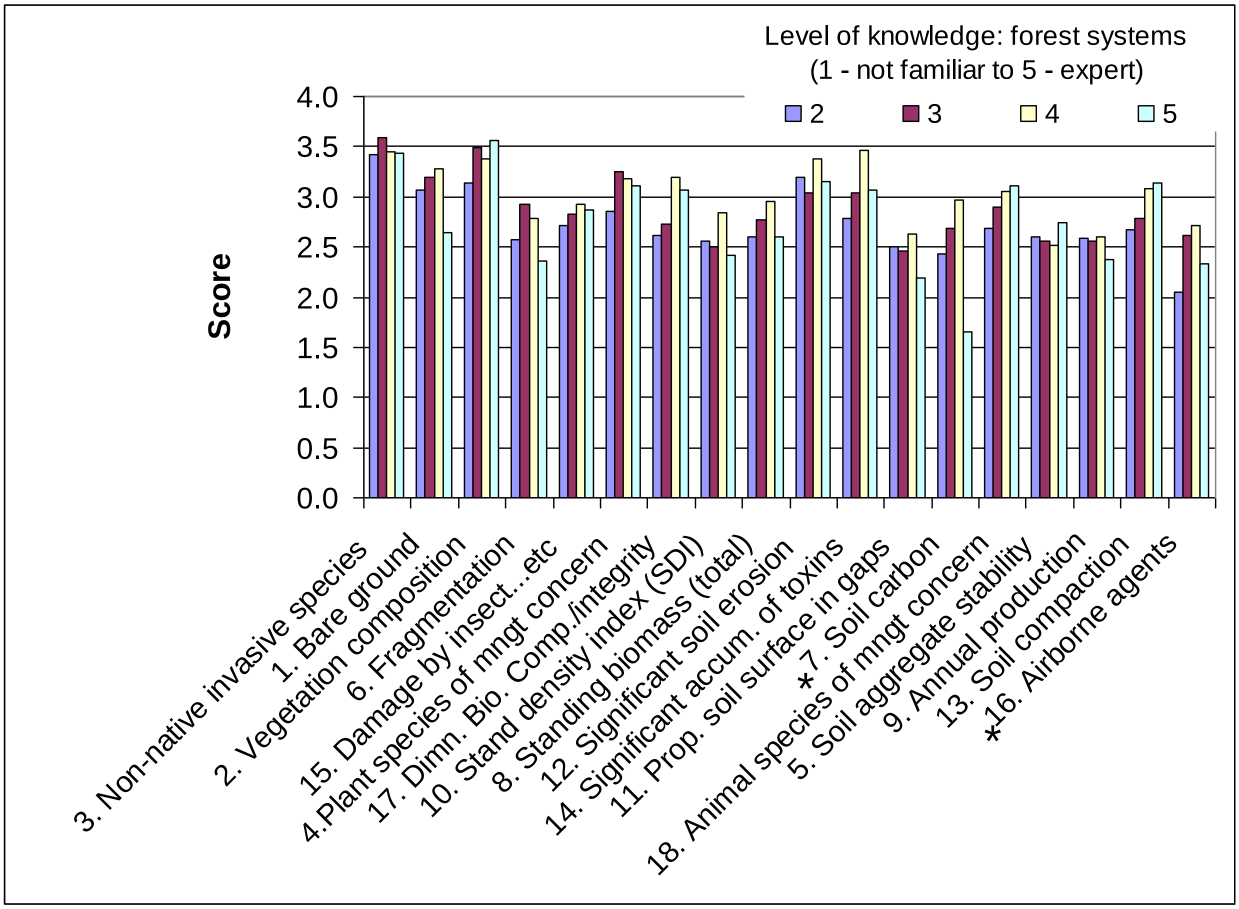


Figure A2.2. Indicator score for forest land cover type given by evaluators self-reported level of rangeland-uplands knowledge (of options 1 – not familiar to 5 – expert, only 2 – 5 were chosen). * indicates indicators with ratings that were found to be statistically different (p < 0.10 in a Kruskal-Wallis test) between levels of knowledge.