Bare Ground, Inter-Canopy Gaps, and Soil Aggregate Stability

The National Resources Inventory (NRI) is a statistical survey of natural resource conditions and trends on non-Federal land in the United States. Non-Federal land includes privately owned lands, tribal and trust lands, and lands controlled by state and local governments.

The NRI rangeland results presented here address conditions inventoried from 2004 through 2011. In the future, the NRI rangeland survey sample will include revisited sites. These data will allow estimates for change in rangeland resource conditions to be made.

Importance to the Nation

Bare ground, inter-canopy gap size, and soil aggregate stability data provide baseline information for rangeland ecosystems. These data support interpretations of the qualitative rangeland health summaries. Land managers and policymakers need this information to support strategic decisions and to identify the ecosystem processes that must be restored to improve the land to profitability, functional potential, and sustainability.

Introduction

The findings are presented here for bare ground, inter-canopy gaps, and soil aggregate stability. The primary purpose of these quantitative data is to establish a baseline for long-term monitoring. As the current NRI rangeland sample sites are revisited, changes from the baseline data will be evaluated to monitor long-term trends. These data can also be used now to help support general interpretations of the findings of the rangeland health assessments. For example, areas of east-central Texas that show high levels of departure from expected soil and site stability conditions but also have relatively low percentages of bare ground. Together, this information may be used to ask whether this reflects soil degradation despite relatively low inter-canopy gaps of the current vegetative cover in this region or past soil degradation with presently recovered vegetation cover.

Bare ground, inter-canopy gaps, and soil aggregate stability data reflect differences in both the land's potential and in its current condition. For example, bare ground percentages are generally higher and soil aggregate stability is generally lower in arid regions, such as the southwestern United States, due to lower potential plant production, which is limited by low precipitation and high evapotranspiration. Within each region, the potential of the land varies

with soil, topography and climate. This variability in land potential is reflected in the Ecological Site Descriptions.

Bare Ground

Bare ground is defined as soil that is not protected by plants (including lichens and moss), litter, standing dead vegetation, gravel, or rocks. Areas with high percentages of bare ground (soil) are at greater risk of runoff and erosion. Bare soil lacks protection from impacts of raindrops, detachment by wind, and temperature increases from exposure to the sun.

Inter-canopy Gaps

Open spaces between canopies of plants are more prone to wind and water erosion, especially when the gaps contain high percentages of bare ground. Wind velocity near the soil surface is higher in large gaps making the soil more vulnerable to saltation (the process of soil particles being lifted and returned to the surface, dislodging other particles) and redistribution. In large gaps, soil particles picked up by moving water have little to prevent them from being carried downslope. Wind and water erosion degrade the soil and in higher concentrations can impact both the hydrology of a site and its biotic community.

Soil Aggregate Stability

Soil aggregate stability is a recognized indicator of soil quality and rangeland health. Field tests of soil aggregate stability can provide an indication of current conditions—soil structure may begin to deteriorate rapidly as the soil surface is subjected to destructive forces such as repeated raindrop impacts, machinery traffic, cultivation, and trampling, particularly if there are no organic matter inputs (roots and litter) that support regeneration of soil aggregates. Wind and water erosion can also degrade and remove the more stable aggregates that often occur at the soil surface in rangeland, exposing less stable aggregates below.

Soil aggregates are comprised of groups of soil particles that are bound together by biological agents such as fungi, bacteria, blue-green algae (cyanobacteria), and root exudates. Potential soil aggregate stability is determined by soil texture (soil particle size) and mineralogy, and the type and amount of organic matter inputs. Stable soil aggregates are integral to optimum infiltration capacity and resistance to water erosion. Aggregate stability is a good indicator of soil organic matter content and biological activity, and is correlated with soil nutrient cycling. Unstable aggregates are susceptible to disaggregation and dispersal during rainstorms and

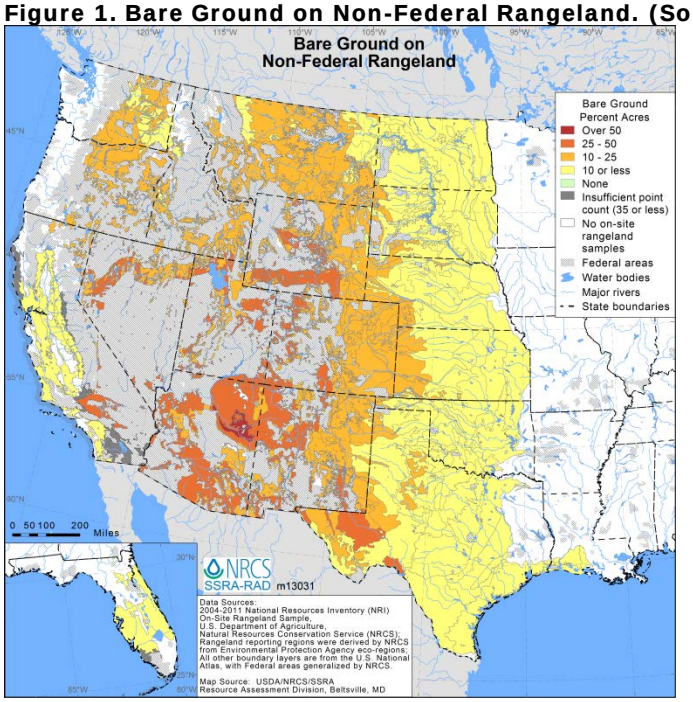
may form a hard physical crust on some soils when the soil dries. Physical crusts can restrict plant seedling emergence and are associated with decreased infiltration, higher runoff, and soil loss.

Key Findings

- Values reflect differences in both site potential and current status. Bare ground (Tables 1-2) and inter-canopy gap values (Table 3) are inherently higher and soil aggregate stability (Table 4) is lower in more arid parts of the country. Lichen crust or moss cover provide protection to the soil in inter-canopy gaps (Table 5) on a small proportion of non-Federal rangeland.
- At the national level, these patterns reflect two factors: (1) potential production (and therefore plant cover and soil stabilizing organic matter inputs) is lower in more arid regions; and (2) resilience, or the capacity of these systems to resist and recover from historic degradation, is also lower in arid regions.
- Interpreting spatial patterns in these variables together with results of the rangeland health assessments can be used to help identify the general types of management interventions that are more likely to have a positive impact in different parts of the country. Specific management recommendations require interpretation of both types of data in the context of additional information and knowledge about specific locations within each region.
- The percent of non-Federal rangeland with high levels of bare ground (Tables 1-2) and/or covered by inter-canopy gaps of at least 1 meter or 2 meters (Table 3) are more extensive in arid regions. Larger gaps are generally associated with higher rates of wind and water erosion and lower ability of the soil to capture and retain moisture from rainfall and melting snow. Gap openings are susceptible to invasion by exotic species. Inter-canopy gaps with high percentages of bare ground (Table 3) are especially vulnerable to erosion and establishment of opportunistic and/or invasive plants.
- Soil aggregate stability data (Table 4) provide indications of a soil's ability to resist erosion, absorb rain fall and snow melt, and provide structure and nutrients needed to support plants. Soil aggregate stability is rated from 1 to 6, where ratings of 5 and 6 are associated with more stable soils and healthier soil functions. Although ratings of 4 or less can indicate areas of concern, these data should not be used alone to make conclusions concerning the health of these areas. The lower the stability ratings the more unstable the aggregates. The result is less stable soil aggregates which can be less resistant to water and wind erosion.
- The average bare ground on non-Federal rangeland is highest in Arizona, Nevada, New Mexico, Utah, Colorado and Wyoming where the average percent is 37.8 (±2.7), 28.5

(±3.4), 26.2 (±2.1), 21.5 (±1.8), 20.1 (±1.1), and 19.1 (±1.9) percent, respectively (Table 1, Figure 1).

Figure 1. Bare Ground on Non-Federal Rangeland. (Source: Table 1)



- In Arizona, Nevada, and New Mexico, the amount of non-Federal rangeland that is at least 50 percent bare ground is 34.5 (±4.6), 18.3 (±5.5), and 15.1 (±3.0) percent, respectively (Table 2, Figure 5).

Figures 2-5. Non-Federal Rangeland that is at Least 20, 30, 40, or 50 Percent Bare Ground (Source: Table 2)

Figure 2. At Least 20%

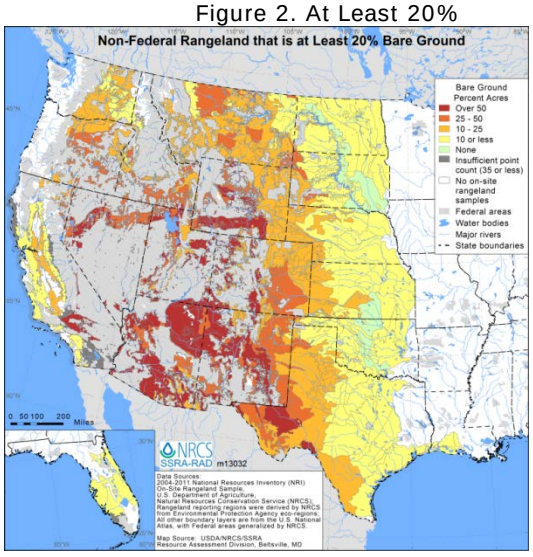


Figure 3. At Least 30%

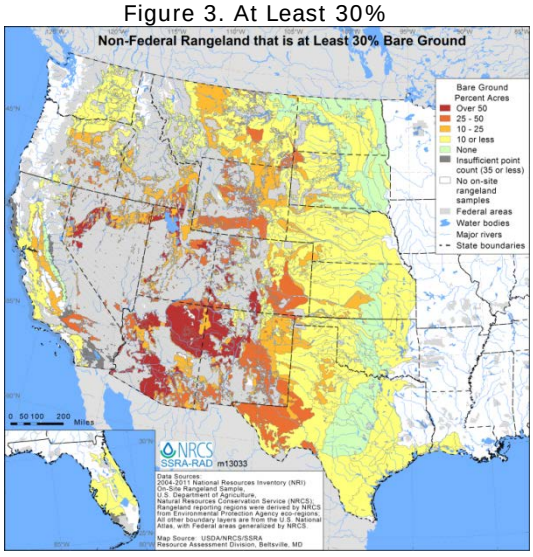


Figure 4. At Least 40%

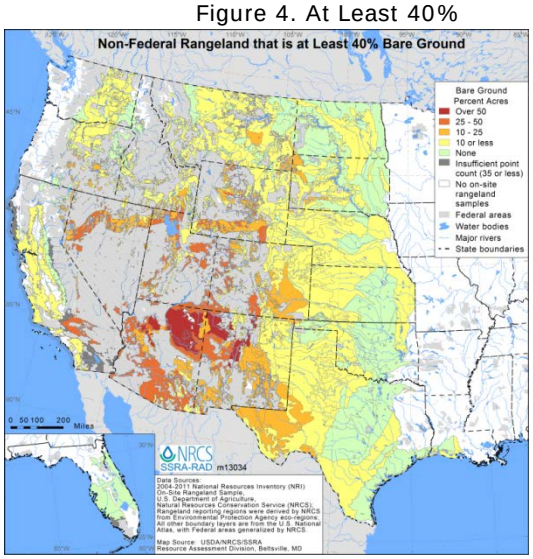
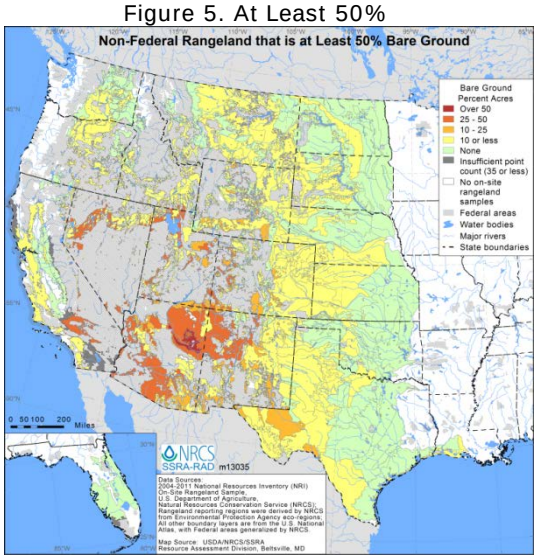


Figure 5. At Least 50%



- Areas where large (at least 2-meter) canopy gaps account for at least 20 percent of the land are more susceptible to erosion and opportunity for establishment of invasive plant species. In Arizona, Utah, Nevada, and California, these areas make up 49.2 (±4.3), 36.9 (±6.0), 34.5 (±7.0), and 31.7 (±5.4) percent, respectively, of non-Federal rangeland (Table 3, Figure 7).

Figures 6-7. Non-Federal Rangeland Where Canopy Gaps of at Least 1 or 2 Meters Account for at Least 20 Percent of the Land (Source: Table 3)

Figure 6. Gaps at Least 1 Meter

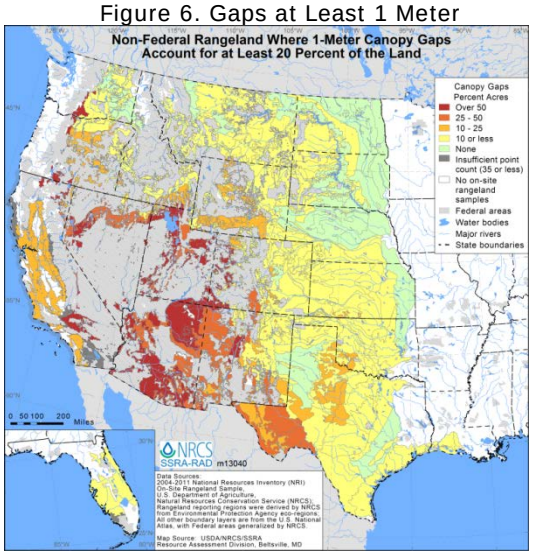
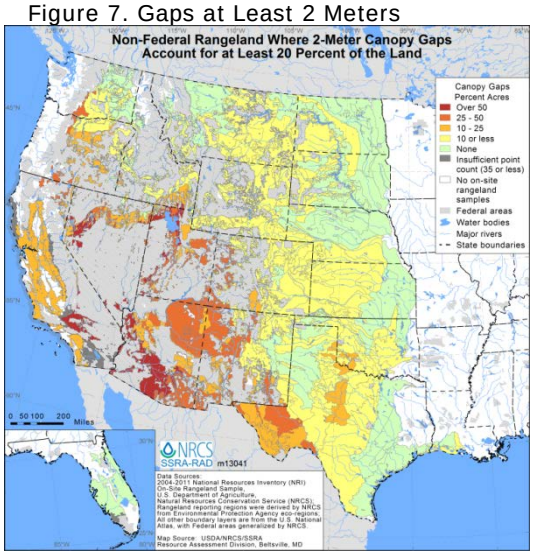


Figure 7. Gaps at Least 2 Meters



- Areas with canopy gaps are even more vulnerable to erosion and establishment of invasive species when the inter-canopy gaps have higher amounts of bare ground. In Arizona, Nevada, Utah, and California, areas where 2-meter canopy gaps account for at least 20 percent of the land and inter-canopy gaps are at least 50 percent bare ground comprise 31.8 (±3.9), 18.2 (±5.3), 15.0 (±3.6), and 8.6 (±3.7)percent, respectively, of non-Federal rangeland (Table 3, Figure 9).

- Lichen crust or moss cover provides protection to the soil in inter-canopy gaps, but Table 5 shows that the percent of non-Federal rangeland benefitting from this type of protection is low.

Figures 8-9. Non-Federal Rangeland Where Canopy Gaps of at Least 1 or 2 Meters Account for at Least 20 Percent of the Land and Inter-Canopy Gaps are at Least 50% Bare Ground (Source: Table 3)

Figure 8. 50% Bare Ground in Gaps of at Least 1 Meter

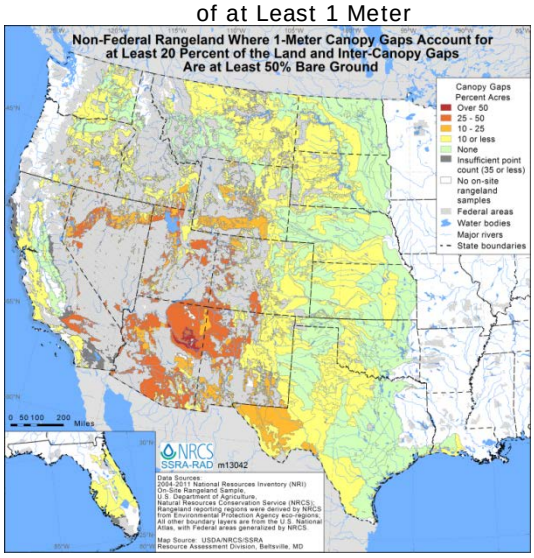
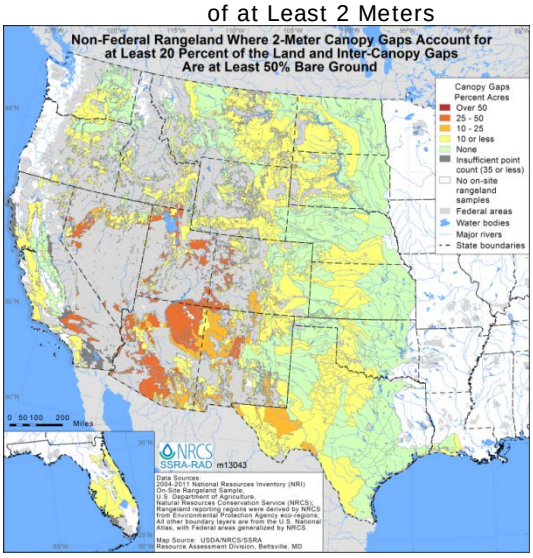
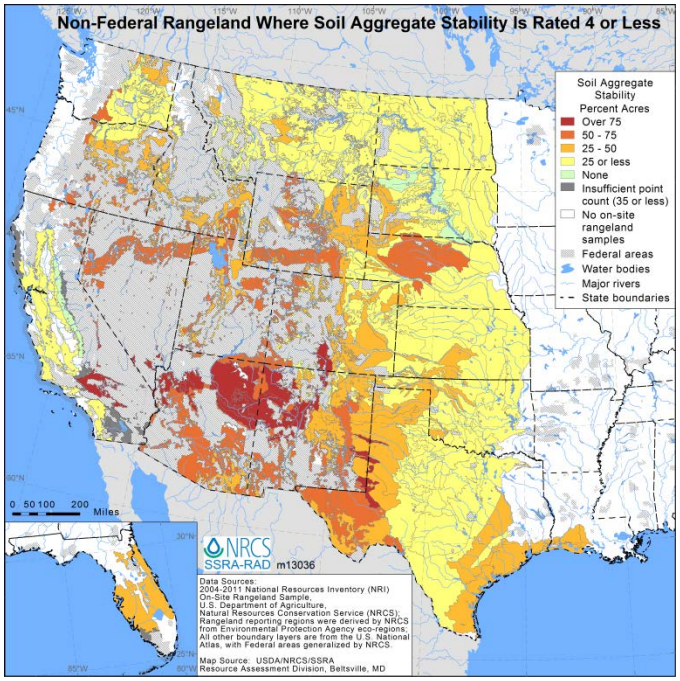


Figure 9. 50% Bare Ground in Gaps of at Least 2 Meters



- Soil aggregate stability ratings[1] of 4 or less are indicators of less stable soil. Nationally, 32.6 (±0.9) percent of non-Federal rangelands have soil aggregate stability ratings of 4 or less (Table 4, Figure 10).

Figure 10. Non-Federal Rangeland Where Soil Aggregate Stability[1] is 4 or Less Indicating Unstable Soil (Source: Table 4)



[1] Soil aggregate stability ratings:

1 = 50% of structural integrity lost, (melts) within 5 seconds of immersion in water and less than 10% remains after 5 dipping cycles or soil too unstable to sample (falls through the sieve).

2 = 50% of structural integrity lost (melts) 5–30 seconds after immersion and less than 10% remains after 5 dipping cycles.

3 = 50% of structural integrity lost, (melts) 30–300 seconds after immersion or less than 10% remains on the sieve after five dipping cycles.

4 = 10–25% of original soil material remains on the sieve after five dipping cycles

5 = 25–75% of original soil material remains on the sieve after five dipping cycles

6 = 75–100% of original soil material remains on the sieve after five dipping cycles

Tables and Results

Estimates presented here are based upon rangeland data collected on-site as part of the National Resources Inventory (NRI), a sample survey using scientific statistical principles and procedures. These results are based upon NRI rangeland data collected in the field on rangeland during the period 2004 to 2011 and address current conditions. These estimates cover non-Federal rangeland in 17 western states (extending from North Dakota south to Texas and west) and to a limited extent in Florida and Louisiana.

Margins of error are reported for each NRI estimate and must be considered at all scales of analysis. The margin of error is used to construct the 95 percent confidence interval for the estimate. The lower bound of the interval is obtained by subtracting the margin of error from the estimate; the upper bound is obtained by adding the margin of error to the estimate. A 95 percent confidence interval means that in repeated samples from the same population, 95 percent of the time the true underlying population parameter will be contained within the lower and upper bounds of the interval. In the following tables, if there are instances where the margin of error is greater than or equal to the estimate, the confidence interval includes zero and the estimate should not be used. In those cases, the estimate in the table is replaced by the word "Trace."

Table 1. Bare ground on non-Federal rangeland, by state, with margins of error

State	Average percent bare ground on non-Federal rangeland
Arizona	37.8 ±2.7
California	12.7 ±2.4
Colorado	20.1 ±1.1
Florida	4.0 ±1.5
Idaho	12.8 ±1.2
Kansas	4.7 ±0.4
Louisiana	Trace

Montana	12.4 ±1.1
Nebraska	5.0 ±0.6
Nevada	28.5 ±3.4
New Mexico	26.2 ±2.1
North Dakota	2.6 ±0.4
Oklahoma	3.5 ±0.4
Oregon	16.9 ±2.1
South Dakota	3.0 ±0.4
Texas	8.8 ±0.7
Utah	21.5 ±1.8
Washington	10.0 ±1.3
Wyoming	19.1 ±1.9
Nation	14.7 ±0.3

Table 2. Non-Federal rangeland that is at least 20, 30, 40, or 50 percent bare ground, by state, with margins of error

State	At least 20 %	At least 30 %	At least 40 %	At least 50 %
	Percent	Percent	Percent	Percent
Arizona	69.1 ±4.4	58.7 ±5.5	46.3 ±4.9	34.5 ±4.6
California	21.2 ±4.6	12.4 ±3.7	8.6 ±3.4	6.2 ±3.1

Colorado	40.6 ±3.0	22.9 ±3.0	12.5 ±2.1	5.5 ±1.6
Florida	5.3 ±4.7	Trace	0	0
Idaho	22.9 ±4.8	9.9 ±2.7	3.7 ±1.8	1.2 ±0.9
Kansas	4.4 ±1.5	1.9 ±0.8	Trace	Trace
Louisiana	Trace	Trace	0	0
Montana	20.9 ±3.8	9.0 ±2.2	3.8 ±1.3	1.9 ±1.0
Nebraska	5.3 ±1.9	1.9 ±1.1	Trace	Trace
Nevada	53.6 ±6.9	38.8 ±6.9	27.7 ±5.2	18.3 ±5.5
New Mexico	52.2 ±5.1	37.2 ±4.7	23.3 ±3.9	15.1 ±3.0
North Dakota	2.8 ±1.1	0.9 ±0.6	Trace	Trace
Oklahoma	2.7 ±1.3	0.7 ±0.6	Trace	Trace
Oregon	32.6 ±7.0	16.2 ±4.8	8.7 ±4.2	3.0 ±2.3
South Dakota	2.9 ±1.0	1.7 ±0.8	0.9 ±0.5	0.7 ±0.5
Texas	14.3 ±1.7	7.7 ±1.4	4.0 ±1.1	2.1 ±0.7
Utah	43.8 ±5.0	26.7 ±4.5	16.2 ±3.5	9.5 ±3.0
Washington	12.9 ±4.0	4.5 ±3.0	1.3 ±1.2	Trace
Wyoming	40.3 ±5.4	22.1 ±4.2	11.7 ±2.8	5.4 ±2.0
Nation	26.5 ±0.8	16.9 ±0.6	10.6 ±0.5	6.7 ±0.5

Table 3. Non-Federal rangeland where 1 or 2 meter inter-canopy gaps account for at least 20 percent of the land; and non-Federal rangeland where 1 or 2 meter inter-canopy gaps account for at least 20 percent of the land and the inter-canopy gaps are at least 50 percent bare ground, by state, with margins of error

State	At least 20% of the land has inter-canopy gaps of at least 1 meter	At least 20% of the land has inter-canopy gaps of at least 2 meter	At least 20% of the land has inter-canopy gaps of at least 1 meter and the inter-canopy gaps are at least 50% bare ground	At least 20% of the land has inter-canopy gaps of at least 2 meter and the inter-canopy gaps are at least 50% bare ground
	Percent	Percent	Percent	Percent
Arizona	66.5 ±3.6	49.2 ±4.3	41.4 ±4.5	31.8 ±3.9
California	37.0 ±6.1	31.7 ±5.4	9.5 ±4.0	8.6 ±3.7
Colorado	7.8 ±2.0	3.4 ±1.3	5.0 ±1.6	2.5 ±1.0
Florida	Trace	Trace	Trace	Trace
Idaho	5.4 ±2.3	2.4 ±1.7	2.0 ±1.2	Trace
Kansas	0.8 ±0.5	0.6 ±0.4	Trace	Trace
Louisiana	0	0	0	0
Montana	2.8 ±1.2	1.6 ±0.8	1.8 ±0.8	0.9 ±0.6
Nebraska	Trace	Trace	Trace	Trace
Nevada	48.1 ±7.9	34.5 ±7.0	23.8 ±4.9	18.2 ±5.3
New Mexico	21.9 ±2.5	14.3 ±2.0	15.0 ±2.6	10.2 ±2.2
North Dakota	Trace	Trace	Trace	Trace
Oklahoma	1.9 ±0.8	1.6 ±0.8	Trace	Trace
Oregon	16.7 ±5.0	8.3 ±3.6	8.7 ±3.9	4.4 ±2.7

South Dakota	1.1 ±0.5	0.8 ±0.4	1.0 ±0.5	0.7 ±0.4
Texas	11.5 ±1.9	8.8 ±1.6	3.3 ±0.9	2.1 ±0.7
Utah	51.0 ±6.3	36.9 ±6.0	18.9 ±4.1	15.0 ±3.6
Washington	Trace	Trace	Trace	Trace
Wyoming	6.8 ±3.0	2.8 ±1.4	5.3 ±2.3	2.4 ±1.3
Nation	16.2 ±0.8	11.6 ±0.7	8.1 ±0.4	5.8 ±0.4

Table 4. Non-Federal rangeland where soil aggregate stability is rated 4 or less, by state, with margins of error

State	Soil Aggregate Stability Is Rated 4 or Less
	Percent
Arizona	69.8 ±2.8
California	29.6 ±6.3
Colorado	32.9 ±2.8
Florida	28.8 ±12.3
Idaho	27.9 ±5.2
Kansas	7.2 ±1.7
Louisiana	Trace
Montana	13.6 ±2.1
Nebraska	33.9 ±3.5
Nevada	64.6 ±6.7
New Mexico	61.3 ±4.0

North Dakota	1.6 ±0.7
Oklahoma	16.2 ±2.5
Oregon	36.6 ±4.1
South Dakota	3.5 ±1.4
Texas	25.7 ±2.3
Utah	43.1 ±5.6
Washington	12.7 ±4.1
Wyoming	46.5 ±4.7
Nation	32.6 ±0.9

Table 5. Non-Federal rangeland where 1-meter inter-canopy gaps account for at least 20% of the land and the inter-canopy gaps have at least 5, 10, 15, or 20 percent lichen crust or moss cover, by state, with margins of error

State	At least 5%	At least 10%	At least 15%	At least 20%
	Percent	Percent	Percent	Percent
Arizona	2.9 ±1.5	1.5 ±1.0	0.9 ±0.8	Trace
California	Trace	0	0	0
Colorado	Trace	Trace	Trace	Trace
Florida	0	0	0	0
Idaho	Trace	Trace	0	0
Kansas	0	0	0	0
Louisiana	0	0	0	0
Montana	Trace	Trace	Trace	Trace

Nebraska	0	0	0	0
Nevada	3.0 ±2.0	2.2 ±1.6	2.0 ±1.6	Trace
New Mexico	0.5 ±0.4	Trace	Trace	Trace
North Dakota	0	0	0	0
Oklahoma	0	0	0	0
Oregon	2.9 ±1.7	2.0 ±1.6	Trace	Trace
South Dakota	Trace	0	0	0
Texas	Trace	Trace	Trace	0
Utah	3.7 ±1.7	2.2 ±1.3	1.8 ±1.3	0.9 ±0.7
Washington	0	0	0	0
Wyoming	Trace	Trace	Trace	Trace
Nation	0.6 ±0.2	0.4 ±0.1	0.2 ±0.1	Trace

About the Data

Estimates presented here are based upon rangeland data collected on-site as part of the National Resources Inventory (NRI). Rangeland is defined by the NRI as a Land cover/use category on which the climax or potential plant cover is composed principally of native grasses, grasslike plants, forbs, or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This includes areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and such practices as deferred grazing, burning, chaining, and rotational grazing are used, with little or no chemicals or fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland.

These results are based upon NRI rangeland data collected in the field on rangeland during the period 2004 to 2011. Current estimates cover non-Federal rangeland in 17 western states

(extending from North Dakota south to Texas and west) and to a limited extent in Florida and Louisiana.

The findings presented here are obtained from three types of data:

- Bare ground - The percent of bare ground is determined from the line-point intercept at 3-foot intervals along two intersecting 150-foot transects (Herrick et al. 2005).
- Plant inter-canopy gaps - Inter-canopy gaps are measured using the line intercept transect protocol, an on-site method to record all foliar gaps of at least 1-foot in length along two intersecting 150-foot transects (Herrick et al. 2005).
- Soil aggregate stability - A rangeland soil stability test is conducted in the field. Soil (~ 1/4" or 6mm diameter) samples are exposed to rapid wetting (USDA-NRCS 2010; Herrick et al. 2001). Soil samples are rated on a scale from one to six (6 is most stable) based on a combination of ocular observations of slaking during the first 5 min following immersion in distilled water, and the percent remaining on a 1.5-mm sieve after five dipping cycles at the end of the 5-minute period.

These quantitative data may be used to support the findings in the Rangeland Health assessments, as well as form a baseline of natural resource conditions. When current Grazing Land sample sites are revisited, changes from this baseline data will be evaluated.

Quality assurance and statistical procedures are designed / implemented to ensure data are scientifically legitimate. Irrespective of the scale of analysis, margins of error must be considered. Margins of error (at the 95 percent confidence level) are presented for all NRI estimates.

About the Protocols

The findings presented here are derived using data collected for three field protocols:

Line point intercept data are utilized in summaries of non-native plant species, non-native invasive herbaceous species, native invasive woody species, and bare ground. Line point intercept data are collected along two intersecting 150-foot transects centered on each sample location. Data collectors record plant species, litter, lichen, moss, rock fragment, bedrock, and/or bare soil present at each 3-foot interval.

Line intercept for inter-canopy gaps data are used to identify areas with large foliar inter-canopy gaps which have more exposure to erosion and may provide opportunity for invasive plants to become established. Data collectors record lengths of plant inter-canopy gaps along the two intersecting 150-foot transects.

Soil aggregate stability is a recognized indicator of soil quality and rangeland health. Data collectors water immerse soil surface peds collected at the sample site and subject the soil peds to five dipping cycles. Soil stability is rated based on the outcomes of these water exposure techniques. Ratings range from 1 (very unstable) to 6 (very stable).

About the Maps

The maps are constructed with NRI rangeland data collected in the field on rangeland during the period 2004 to 2011. The regions are based on level IV ecoregion boundaries defined by the U.S. Environmental Protection Agency Western Ecology Division (http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm). In some cases level IV ecoregions were combined to include more sample sites. An additional category, referred to as "Insufficient point count (35 or less)", represents areas where there were too few data points. Regions without non-Federal rangeland are described as "No on-site rangeland samples". Areas of Federal land are depicted with cross-hatching.

Bare Ground and Foliar Canopy Gap Maps

The bare ground and canopy gap maps present by classes (none, 10% or less, 10-25%, 25-50%, over 50%): (1) overall average bare ground on non-Federal rangeland; (2) non-Federal rangelands where at least 20, 30, 40, or 50 percent is bare ground; (3) non-Federal rangelands where 1- or 2-meter inter-canopy gaps account for at least 20 percent of the area; and (4) non-Federal rangelands where 1- or 2-meter inter-canopy gaps account for at least 20 percent of the area and inter-canopy gaps are at least 50 percent bare ground.

Soil Aggregate Stability Maps

The soil aggregate stability maps present by classes (none, 25% or less, 25-50%, 50-75%, over 75%) the amount of non-Federal rangeland where soil aggregate stability ratings are 4 or less, indicating less stable soil.

More Information

Herrick, J.E., J.W. Van Zee, K.M. Havstad, and W.G. Whitford. 2005. Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems. USDA-ARS Jornada Experimental Range, Las Cruces, New Mexico

Herrick, J.E., W.G. Whitford, A.G. de Soyza, J.W. Van Zee, K.M. Havstad, C.A. Seybold, and M. Walton. 2001. Field soil aggregate stability kit for soil quality and rangeland health evaluations. Catena 44:27-35.

Related journal article: National Ecosystem Assessments Supported by Scientific and Local Knowledge, Frontiers in Ecology and the Environment, October 2010

Send comments and questions to the NRI Help Desk