Tapping Soil Survey Information for Rapid Assessment of Sagebrush Ecosystem Resilience and Resistance

By Jeremy D. Maestas, Steven B. Campbell, Jeanne C. Chambers, Mike Pellant, and Richard F. Miller

On the Ground

- Emerging applications of ecosystem resilience and resistance concepts in sagebrush ecosystems allow managers to better predict and mitigate impacts of wildfire and invasive annual grasses.
- Widely available soil survey information can be harnessed to spatially depict and evaluate relative resilience and resistance from regional to site scales.
- New products and tools illustrate how managers can use soils data to inform rapid risk assessments, determine appropriate management strategies, and prioritize resources to maintain and restore functioning sagebrush ecosystems.

Keywords: sagebrush ecosystems, sage grouse, resilience, resistance, soils, cheatgrass.

Rangelands 38(3):120–128
doi: 10.1016/j.rala.2016.02.002

A new ecologically-based approach to risk abatement has emerged that can aid land managers in grappling with escalating impacts of large-scale wildfire and invasive annual grasses in sagebrush ecosystems, particularly in the Great Basin. Specifically, ecosystem resilience and resistance (R&R) concepts have been more fully operationalized from regional to site scales to help reduce fire and invasive species risks in priority habitats for sagebrush-dependent species, like the greater sage-grouse (*Centrocercus urophasianus*).[1–3] Resilience refers to the ability of ecosystems to reorganize after disturbances like wildfire without crossing thresholds to alternative states with different structure and function, while resistance is the capacity of an ecosystem to remain largely unchanged despite disturbances or pressure from invasive species, like cheatgrass (*Bromus tectorum*). Resilience and resistance concepts help managers better understand key drivers of ecosystem change, identify relative risks of crossing thresholds to undesired states, and design appropriate management actions to promote desired ecosystem trajectories.

Climate, soils, topography, and vegetation are the primary biophysical factors that determine the potential ecosystem R&R for any given area. Maps and other geospatial products depicting these environmental factors are invaluable for helping agency leadership and field practitioners assess relative risks, prioritize allocation of limited resources, and determine appropriate management practices to most efficiently address wildfire and invasive species. While many standalone products exist, from remote-sensing to on-the-ground inventories, one free and widely available source of relevant information integrating many biophysical factors is the National Cooperative Soil Survey.[4] In this paper, we describe new products and tools recently assembled using existing soil survey data to aid rapid assessment of potential resilience and resistance across sage-grouse habitats and sagebrush ecosystems in the western United States.

Landscape Indicators of Resilience and Resistance

Soil temperature and moisture strongly influence the kind and amount of vegetation, and consequently, are closely tied to sagebrush ecosystem R&R.[5] A recent breakthrough in the practical application of resilience and resistance concepts has been linking *soil temperature and moisture regimes* to sagebrush ecosystem responses to disturbance and cheatgrass invasion.[1,6,7] In soil taxonomy, temperature regimes reflect the mean annual soil temperature at a depth of 20 inches below the soil surface or at a restrictive feature if the soils are shallower, while moisture regimes indicate the length of time plant-available moisture is present during the growing season.[8] Soil temperature and moisture regimes are a way of classifying a continuous gradient of conditions, from hot to cold and dry to wet, that affect plant community

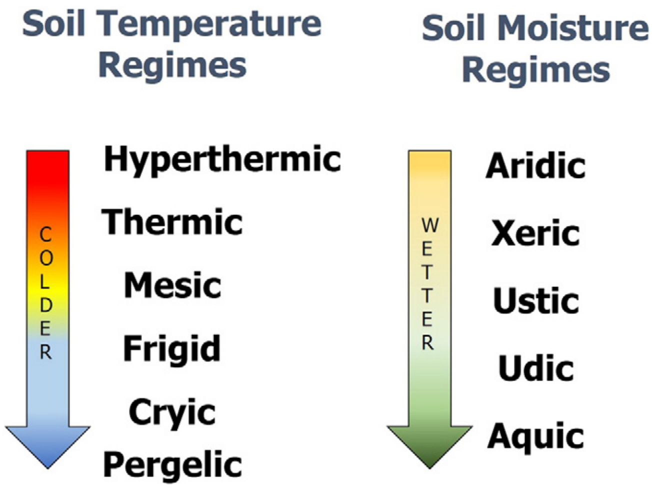

Figure 1. Soil taxonomic temperature and moisture regime terminology. Temperature regimes are defined by specific mean soil temperatures, and seasonal fluctuations from the mean, within the main root zone. Moisture regimes relate to the length of time plant-available moisture is present during the growing season. For complete definitions see the 2014 Keys to Soil Taxonomy.[8]

composition and productivity and, therefore, are commonly used in defining ecological sites. Typical sites in sagebrush ecosystems have temperature regimes that range from *mesic* to *cryic* and moisture regimes from *aridic* to *xeric* or *ustic* (Fig. 1).

Resilience to disturbance changes along environmental gradients, and typically increases as conditions become more favorable for plant growth and reproduction. Areas with warm (*mesic*) soil temperature and dry (*aridic*) soil moisture regimes typically have lower productivity and potential resilience, while those with cool (*frigid*) to moderately cold (*cryic*) soil temperature and relatively moist (*xeric*), or summer moist (*ustic*), soil moisture regimes have higher productivity and potential resilience (Fig. 2).[1,5,7] Resistance to invasion increases as the environment becomes less suitable for growth and reproduction of the invader, and is strongly influenced by climate and soil characteristics. Resilience and resistance are modified by effects of elevation, landform, slope, aspect, soil properties, vegetation composition and structure, and disturbance.[5,6]

Emerging research describing the association between soil temperature and moisture regimes and invasive annual grass risk increasingly makes possible the application of these abiotic factors as indicators of relative resilience and resistance. For the most pervasive species cheatgrass, germination, growth, and reproduction appear to be optimal under relatively warm temperature regimes (*mesic-aridic* to *xeric*), limited by low and sporadic precipitation under dry moisture regimes (dry end of *aridic*), and generally constrained by cold temperature regimes (*frigid* to *cryic*).[9] While cheatgrass can

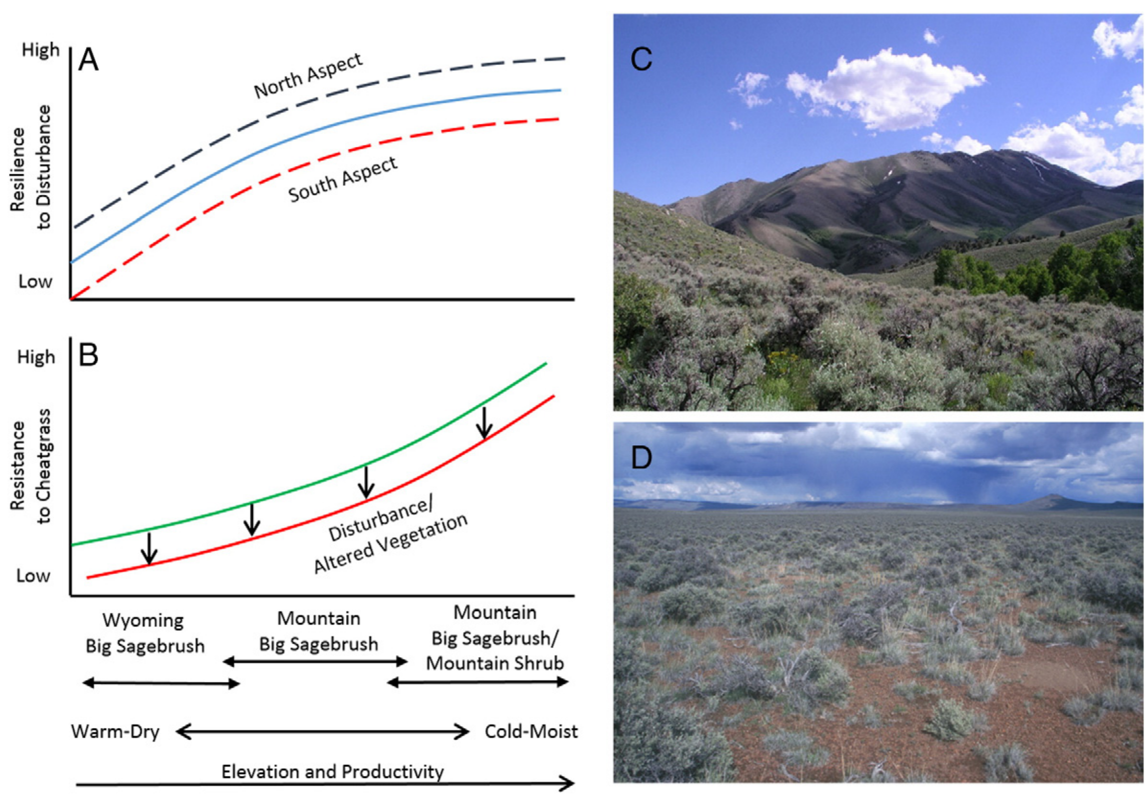

Figure 2. Conceptual models of resilience to disturbance (A) and resistance to cheatgrass (B) over a typical soil temperature and moisture gradient in sagebrush ecosystems.[1] These relationships are modified by other soil properties, such as texture and depth, and vegetation composition and abundance. Comparing a cool and moist (*frigid/xeric*) mountain big sagebrush site in Nevada (C) to a warm and dry (*mesic/aridic*) Wyoming big sagebrush site in Oregon (D) illustrates broad differences in site productivity across sagebrush ecosystems that are correlated with potential resilience and resistance (Photos: Richard F. Miller, Jeanne C. Chambers).

become established across an extremely broad range of environmental conditions, these insights help identify where the species is most likely to be problematic and compromise the ability of the ecosystem to withstand disturbance without undergoing a catastrophic state shift. For other annual grass species, such as medusahead (*Taeniatherum caput-medusae*) and ventenata (*Ventenata dubia*), detailed correlations with soil temperature and moisture regimes are currently less well understood and some variation would be expected given individual species relationships with other factors (e.g., soil texture). However, a framework that functions well for the most widespread invasive species, and has potential to work for other annual species in the same functional group with some adjustments, could serve as a broadly applicable conservation tool.

Soil climate data (temperature and moisture regimes) and other soil properties are fundamental to classifying and mapping soils, and as such, are widely available in soil surveys. Because soil temperature and moisture regimes reflect a combination of key climate and soil factors, they can be used as indicators of potential R&R across broad geographies. Several other soil properties, such as texture at various depths and depth-to-restrictive features which influence water capture and storage, can also be harvested from soil surveys further facilitating site assessments.

Assembling Soils Data

We compiled available soil survey data to facilitate broad scale analyses of R&R across ecoregionally-based sage-grouse management zones in the western United States.[10] Soils data were derived from two primary sources: 1) completed and interim soil surveys available through the Soil Survey Geographic Database (SSURGO), and 2) the State Soils Geographic Database (STATSGO2).[4]

SSURGO represents the most detailed soil survey product produced by the National Cooperative Soil Survey. Data are collected through field inventory and interpreted at scales ranging from 1:12,000 to 1:63,360, with 1:24,000 being the most common. SSURGO products represent mostly 2nd and 3rd order soil surveys.[11] In 2nd order soil surveys, the soils in each delineation are identified by field observations and by remotely sensed data. Boundaries are verified at closely spaced intervals. Minimum delineation size is 1.5 to 10 acres. In 3rd order soil surveys, soil boundaries are plotted by observation and interpretation of remotely sensed data. Soil boundaries are verified by traversing representative areas and by some transects. Minimum delineation size is 4 to 40 acres. Spatial and tabular data are linked in the database to information about the component soils and properties for each soil map unit. The soils product we assembled for the range of sage-grouse used Gridded Soil Survey Geographic (gSSURGO) data to display a 10-meter raster dataset.

In 17% of our project area, SSURGO data were not available so we used coarser general soil map data from STATSGO2 to fill gaps. STATSGO2 is a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and can be cartographically shown at a scale of 1:250,000. It was created by generalizing more detailed soil survey maps and using data on geology, topography, vegetation, and climate in combination with Landsat images. Map unit composition was determined by transecting or sampling areas on the more detailed soil maps and then expanding the data to characterize the whole map unit.

Soil surveys represent an attempt to depict complex environmental patterns using representative sampling and extrapolation based upon professional judgment and, as such, have some limitations that should be considered. Soil scientists delineate unique soil map units based on known relationships between soils and landforms, but are often unable to verify every single soil polygon in the field especially in large rangeland settings. Also, virtually every delineation of a map unit includes areas of soil components or miscellaneous areas (inclusions) that are not identified in the name of the map unit. Many inclusions are too small to be delineated separately without excessive map detail and may not even be possible to identify with practical field methods. Users are encouraged to field verify soils when planning onsite projects.

Our outputs included geodatabases that combine key soils data across sage-grouse management zones, which have been made available online for conservation planning.[10] Data fields harvested include soil map units, taxonomic information, soil temperature and moisture regimes, moisture subclasses, mean annual air temperature and precipitation, and ecological sites. Because soil map units can consist of multiple components, tables in the geodatabases allow users to represent either the dominant soil condition (i.e., an aggregation of similar components) or the dominant component (i.e., the single component representing the largest proportion of the unit) depending upon the questions being evaluated. Numerous applications are possible with the aggregated datasets, but included in this paper are just a few examples already being applied for sage-grouse conservation at multiple scales.

Depicting the R&R Gradient

Aggregating soil survey data allows, for the first time, a visual representation of the potential R&R gradient underlying planning areas such as sage-grouse management zones using soil temperature and moisture regime classes as indicators (Fig. 3). This regional (multi-state) perspective reveals coarse-scale biophysical patterns and differences, such as, a preponderance of warm and dry regimes in the Great Basin compared to the relatively cooler areas with ustic moisture regimes that receive summer precipitation in the Great Plains region. Maps at this scale can be useful for communicating basic ecosystem attributes when comparing sites across broad geographies. For example, one practical application would be for scientists and practitioners to preface research and management discussions by describing the type of site they are working with (e.g., mesic/aridic or frigid/aridic Wyoming big sagebrush) to help compare "apples to apples" when interpreting observations. These maps can also assist with rapid regional planning to determine where more detailed step down assessments are warranted.

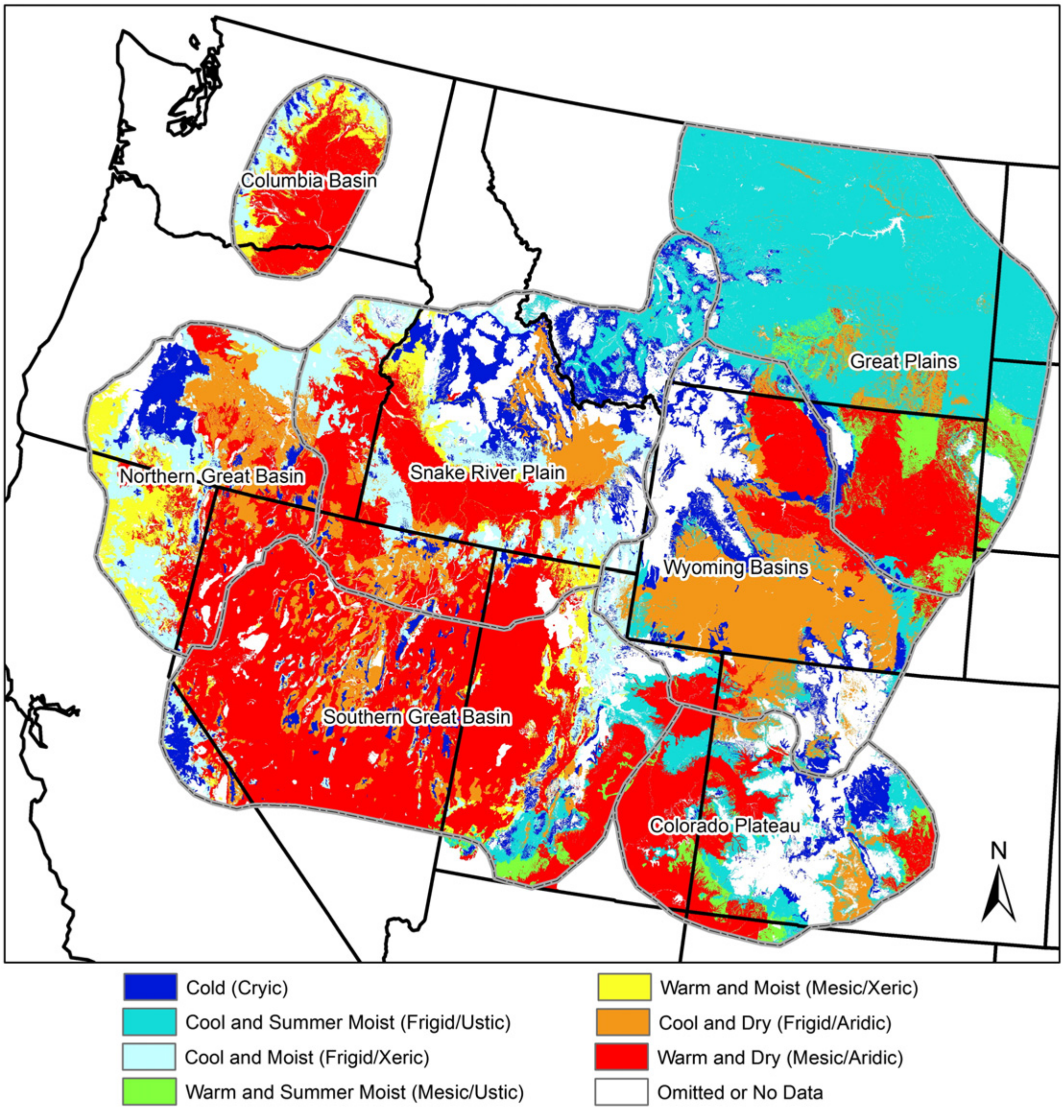

Figure 3. Soil temperature and moisture regime classes that can be used to indicate relative ecosystem resilience and resistance across sage-grouse management zones in the western United States.

At more local (ranch or allotment) scales, the environmental gradient can be further discerned by using soil moisture subclasses to better display nuances in the inherent variability. Soil moisture regimes are divided into moisture subclasses to depict soils that are relatively wetter or dryer than described by the central moisture regime concept (i.e., *typic*). For example, a soil that is slightly wetter than an aridic-typic site would be assigned a xeric moisture subclass and described as "aridic bordering on xeric". Managers will find that the moisture subclass maps more accurately depict observable gradients on the ground than the broader moisture regime level data, but they must still be combined with other abiotic and biotic information to make informed decisions (Fig. 4). Aspect, slope, soil textures and depth, and vegetation composition and abundance are particularly influential in producing differences in R&R within a site.[2,3] For example, even within the same soil temperature and moisture regime, sites with deeper or finer textured soils, a high percentage of deep-rooted perennial grasses, or little-to-no invasive plants would be expected to have higher R&R than sites with shallower or coarser textured soils, few deep-rooted perennial grasses, or an abundance of invasives.

A Simplified Tool for Landscape Triage

The aggregated soils data products can also be used to build custom prioritization tools based on land manager needs and expertise. For example, in the western portion of the sage-grouse range where impacts of wildfire and invasive annual grasses have been most pronounced, we built a simplified index of R&R to aid landscape planning for the Bureau of Land Management and Forest Service interagency Fire and Invasive Assessment Tool.[12] Using best available information and expert input, we placed each soil temperature and moisture regime/

moisture subclass into one of three categories of relative R&R: high, moderate, and low (Table 1). Soils with high water tables, wetlands, or frequent ponding that would not typically support sagebrush were not rated. The resulting product provides a map illustrating an index of relative R&R across the western management zones (Fig. 5) Interactive map available at: http://map.sagegrouseinitiative.com/.

When combined with other data layers, such as the sage-grouse priority habitat areas and existing sagebrush land cover, the data on R&R provided the teams with a crucial tool for assessing relative risks to important habitats across large areas and rapidly targeting appropriate management strategies for potential project areas. Local planning teams used this tool to inform where strategic actions may need to be taken before, during, and after wildfire to best conserve sagebrush habitats and prevent conversion to annual grasslands. For example, sites with relatively low R&R located in and around important sage-grouse habitats were a top priority for proactive installation of strategic fuel breaks, pre-positioning of firefighting resources during fire, and aggressive post-fire rehabilitation, because these sites were most likely to suffer severe impacts from fire and invasive annuals. In contrast, areas with moderate-to-high R&R were prioritized for targeted conifer removal to prevent loss of understory perennial vegetation due to woodland encroachment and maintain resilient landscapes.

Increasingly, land managers in the Great Basin face the daunting task of rehabilitating rangelands affected by mega-fires covering hundreds of thousands of acres. The R&R index provides a useful post-fire planning tool, especially when combined with local information that can be applied quickly to triage large areas and determine where to invest limited time and resources to prevent the most detrimental resource impacts. The product is scalable and customizable so users can adjust the ranking of individual soil types to R&R categories within local planning areas based on expert judgment of the relative risks.

Information for Site-Scale Planning

Depicting soil temperature and moisture regimes is just a first step in prioritization at larger scales that is followed by more detailed assessments at the site scale. Additional factors must be incorporated when developing local management prescriptions. A variety of soil survey products can be helpful when used in conjunction with site evaluations of R&R, ranging from ecological site descriptions (ESDs) to interpretive soils reports providing relevant soils, climate, and vegetation information.

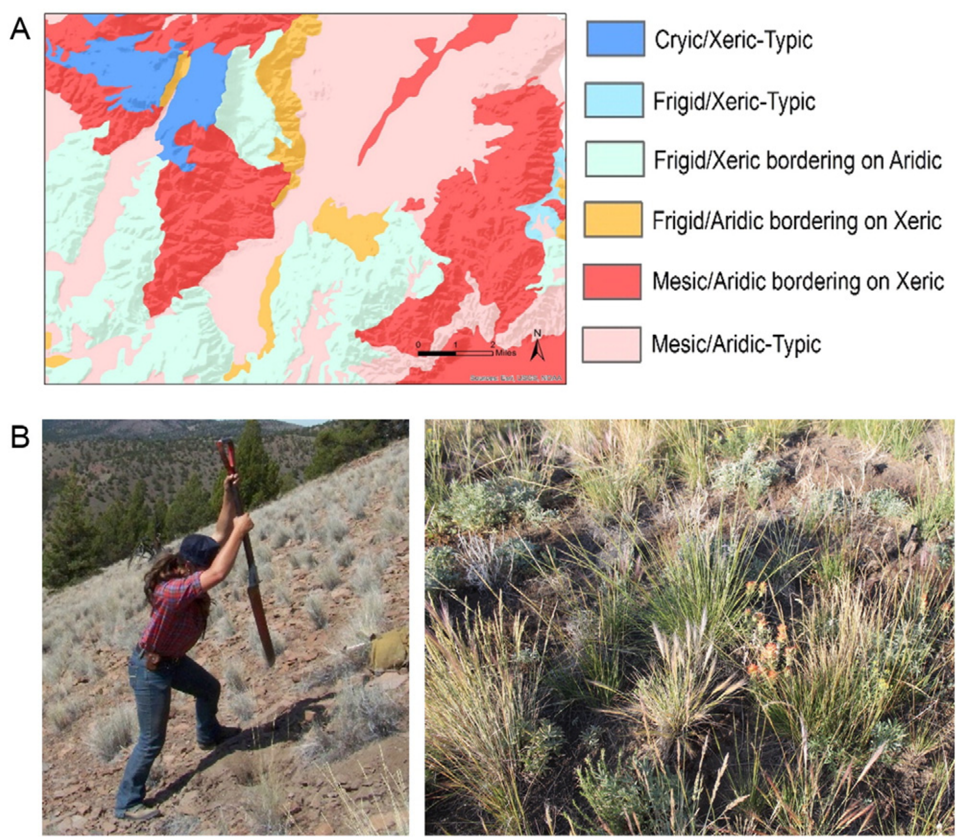

Figure 4. Displaying soil temperature and moisture regimes down to moisture subclass (A) provides necessary refinement of the environmental gradient when evaluating potential disturbance and treatment outcomes at local scales. Maps must be combined with field verification and assessment of other site attributes that heavily influence R&R, such as, aspect, soil properties, and current vegetation (B). (Photos: NRCS).

Table 1. Rating of relative resilience and resistance across predominant rangeland ecosystems in the western sage-grouse range

Soil temperature and moisture regime, moisture subclass	Common name	Typical shrub type	R&R rating
Cryic/Xeric-Typic	Cold/moist	Mountain big sagebrush, mountain brush	High
Cryic/Xeric bordering on Aridic	Cold/moist bordering on dry	Mountain big sagebrush	High
Frigid/Xeric-Typic	Cool/moist	Mountain big sagebrush, mountain brush	High
Cryic/Aridic bordering on Xeric	Cold/dry bordering on moist	Mountain big sagebrush, low sagebrush	High
Cryic/Aridic-Typic	Cold/dry	Low sagebrush	Moderate
Frigid/Xeric bordering on Aridic	Cool/moist bordering on dry	Mountain big sagebrush	Moderate
Frigid/Aridic-Typic	Cool/dry	Mountain/Wyoming big sagebrush, low sagebrush	Moderate
Frigid/Aridic bordering on Xeric	Cool/dry bordering on moist	Mountain/Wyoming big sagebrush, low sagebrush	Moderate
Mesic/Xeric-Typic	Warm/moist	Wyoming big sagebrush, basin big sagebrush	Moderate
Mesic/Xeric bordering on Aridic	Warm/moist bordering on dry	Wyoming big sagebrush, black sagebrush	Low
Mesic/Aridic bordering on Xeric	Warm/dry bordering on moist	Wyoming big sagebrush, basin big sagebrush	Low
Mesic/Aridic-Typic	Warm/dry	Salt desert shrub	Low

Any good site assessment begins with gathering the best available information to characterize site conditions and potential issues. ESDs are a well-known decision support tool providing much of the baseline information necessary to evaluate expected soil and climate characteristics and vegetation attributes. ESDs provide information not only on soil temperature and moisture regimes, but also information on other soil characteristics and potential composition and relative abundance of native plant species, which help determine the relative R&R of a site. State-and-transition models are a central component of ESDs that contain the core elements of resilience-based management including concepts of alternative states and thresholds between states.[13,14] ESDs are informed by science and management experience and are published regularly online in the Ecological Site Information System.[i] Where published ESDs are not yet available, a generalized set of state-and-transition models have been developed for R&R assessments in common sagebrush types in the Great Basin.[2,3,6]

Additional soil survey information can be used to inform site inventory protocols that help managers rate R&R at the site scale. Recently, two new field guides have been developed that provide decision support tools for rapidly assessing R&R and predicting vegetation response to management treatments and post-wildfire recovery in sagebrush ecosystems of the Great Basin.[2,3] These guide step practitioners through a series of questions related to primary drivers of R&R, including soil temperature and effective moisture, current or potential vegetation, and wildfire severity or treatment impacts, which allow them to score a site's relative R&R and determine appropriate management actions. Many of the factors used in the field guide score sheet can be initially approximated using soil survey information.

To facilitate site assessments, we created a new soils report feature in Web Soil Survey[ii] that can be used to rapidly extract information for potential project areas where published surveys are available in the Great Basin.[15] The feature allows end users to delineate an area of interest using a web-based interactive soils map and generate a custom *Resilience and Resistance Score Sheet Soils Report* with pertinent information for each soil map unit in the area (Fig. 6).

The R&R soils report, ESDs, and other soils data are intended to be used as part of the initial background data

[i] For more on the Ecological Site Information System see https://esis.sc.egov.usda.gov/.

[ii] For more on the Web Soil Survey see http://websoilsurvey.sc.egov.usda.gov/.

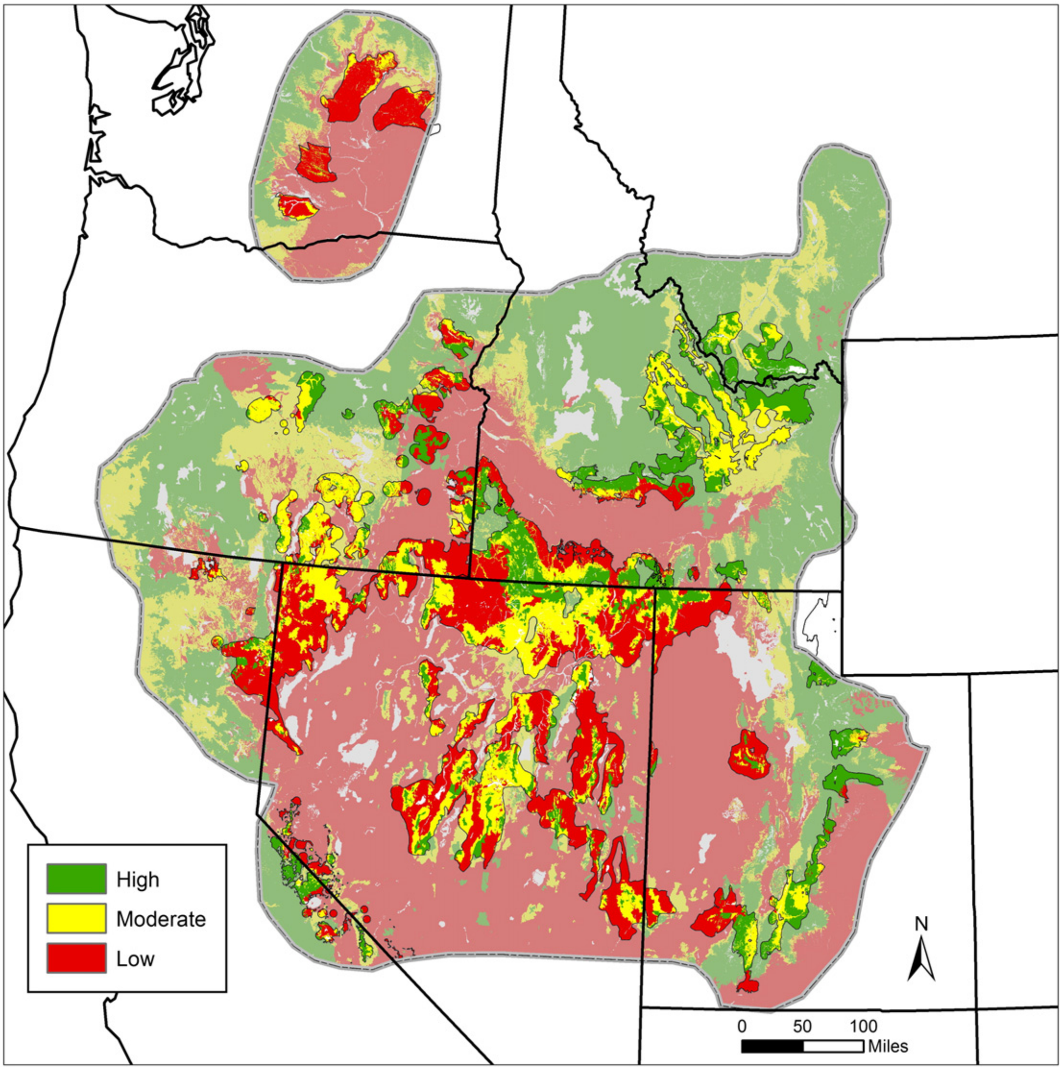

Figure 5. Placing soil temperature and moisture regimes into simplified categories of relative R&R (high, moderate, low) provides a tool for rapid risk assessment across priority areas for sage-grouse conservation in the western range (shown here in bright colors).

gathering process and must still be coupled with onsite inventories. Field verification of soil properties and assessment of the current vegetation are crucial. While we have focused primarily on approximating R&R using abiotic factors using widely available data, biotic factors including vegetation composition and abundance are extremely influential within sites. For example, a sagebrush community with a depleted perennial herbaceous understory has lower potential R&R than a comparable plant community with an understory fully occupied with desired perennial plants.[2,3] Advances in remote sensing technology allowing accurate estimation of existing vegetation at fine scales may soon make it possible to integrate biotic and abiotic factors for more informed mapping of relative R&R.

Summary

Emerging applications of resilience and resistance concepts in sagebrush ecosystems provide a powerful, ecologically-based framework for managing risks in the face of growing challenges related to invasive species and changing wildfire regimes. Tapping into the extensive information available through the soil survey program helps managers more rapidly put concepts into practice. Here we presented just a few examples of products and tools generated using existing data to aid planning for sage-grouse conservation and sagebrush ecosystems, primarily in the Great Basin. Additional applications are abundant and managers are encouraged to collaborate with local soil scientists to explore the utility of soil survey information further and seek their expertise when site planning. Incorporating soils data into planning can help land managers of sagebrush ecosystems better prioritize management strategies from landscape to site scales and maintain or restore resilient sagebrush states capable of supporting desired ecosystem services.

Acknowledgements

We thank the many Natural Resources Conservation Service specialists and others who contributed to the

Report — Resilience and Resistance Score Sheet Soils Report - Great Basin

Harney County Area, Oregon

1—Actem cobbly loam, 2 to 20 percent slopes

Map Unit Setting

Elevation: 4,200 to 6,000 feet
Mean annual precipitation: 10 to 12 inches
Mean annual air temperature: 43 to 45 degrees F
Frost-free period: 50 to 80 days
Major Land Resource Area: 23 - Malheur High Plateau

Map Unit Composition

Actem and similar soils: 85 percent
Minor components: 5 percent

Description of Actem

Taxonomic classification

Temperature regime: Frigid
Moisture regime: Aridic
Moisture subclass: Xeric
Taxonomic class: Clayey, montmorillonitic, frigid, shallow Xeric Argidurids

Typical profile

H1 - 0 to 2 inches: cobbly loam
H2 - 2 to 7 inches: clay
H3 - 7 to 15 inches: clay loam
H4 - 15 to 20 inches: cemented material
H5 - 20 to 30 inches: unweathered bedrock

Properties and interpretative groups

Parent material: Old alluvium and/or colluvium derived from igneous rock
Depth to restrictive feature: 12 to 20 inches to duripan; 20 to 30 inches to lithic bedrock
Natural drainage class: Well drained
Depth to water table: More than 80 inches
Ecological site: CLAYEY 10-12 PZ (R023XY220OR)
Common sagebrush species: Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis)

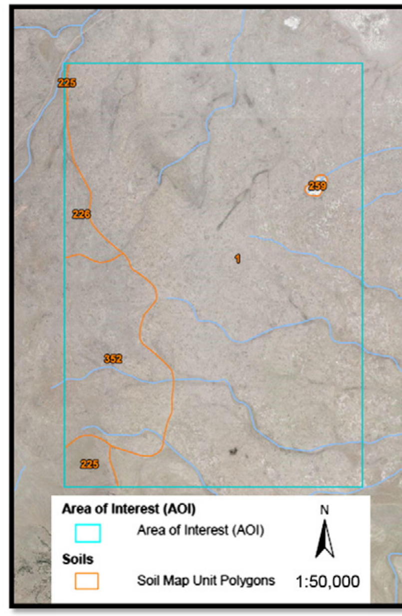

Figure 6. Example of the custom soils report that can be generated in the Web Soil Survey for an area of interest that provides relevant information for site assessments of resilience and resistance. Shown here are only the details for soil map unit 1-Actem cobbly loam.

cooperative soil survey data collection. Kurt and Jennifer Moffitt also participated in helpful discussions regarding potential applications of soil survey information and reviewed this manuscript.

References

1. Chambers, J.C., D.A. Pyke, J.D. Maestas, M. Pellant, C.S. Boyd, S.B. Campbell, S. Espinosa, D. Havlina, K. Mayer, and A. Wuenschel. 2014. Using resistance and resilience concepts to reduce impacts of annual grasses and altered fire regimes on the sagebrush ecosystem and sage-grouse–A strategic multi-scale approach. Fort Collins, CO, USA: U.S. Department of Agriculture, Forest Service, RMRS-GTR-326.
2. Miller, R.F., J.C. Chambers, and M. Pellant. 2014. A field guide to selecting the most appropriate treatments in sagebrush and pinyon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses and predicting vegetation response. Gen. Tech. Rep. RMRS-GTR-322-rev. Fort Collins, CO, USA: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
3. Miller, R.F., J.C. Chambers, and M. Pellant. 2015. A field guide for rapid assessment of post-wildfire recovery potential in sagebrush and pinon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses and predicting vegetation response. Gen. Tech. Rep. RMRS-GTR-338. Fort Collins, CO, USA: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
4. Soil Survey Staff, 2015. Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available at: http://websoilsurvey.nrcs.usda.gov/. Accessed 16 October 2015.
5. Chambers, J.C., B.A. Bradley, C.A. Brown, C. D'Antonio, M.J. Germino, S.P. Hardegree, J.B. Grace, R.F. Miller, and D.A. Pyke. 2013. Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in the cold desert shrublands of western North America. *Ecosystems* 17:360-375.
6. Chambers, J.C., R.F. Miller, D.I. Board, J.B. Grace, D.A. Pyke, B.A. Roundy, E.W. Schupp, and R.J. Tausch. 2014. Resilience and resistance of sagebrush ecosystems: implications for state and transition models and management treatments. *Rangeland Ecol Manage* 67:440-454.
7. Miller, R.F., J.C. Chambers, D.A. Pyke, F.B. Pierson, and C.J. Williams. 2013. A review of fire effects on vegetation and soils in the Great Basin Region: response and ecological site characteristics. Gen. Tech. Rep. RMRS-GTR-308. Fort Collins, CO, USA: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
8. Soil Survey Staff, 2014. Keys to soil taxonomy. 12th edition. Natural Resources Conservation Service.
9. Chambers, J.C., B.A. Roundy, R.R. Blank, S.E. Meyer, and A. Whittaker. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*? *Ecol Monogr* 77:117-145.
10. Maestas, J.D., and S.B. Campbell. 2014. Mapping potential ecosystem resilience and resistance across sage grouse range using soil temperature and moisture regimes. Fact Sheet. Sage Grouse Initiative. Available at: https://www.sciencebase.gov/catalog/folder/538e5aa9e4b09202b547e56c. Accessed 16 October 2015.
11. Survey Division Staff, Soil 1993. Soil survey manual. Soil Conservation Service. U.S. Department of Agriculture Handbook18.

12. U.S. Department of Interior [USDI], 2015. An integrated rangeland wildfire management strategy. http://www.forestsandrangelands.gov/rangeland/documents/IntegratedRangelandFireManagementStrategy_FinalReportMay2015.pdf 2015 (Accessed October, 16, 2015).
13. Briske, D.D., B.T. Bestelmeyer, T.K. Stringham, and P.L. Shaver. 2008. Recommendations for development of resilience-based state-and-transition models. *Rangeland Ecol Manage* 61:359-367.
14. Stringham, T.K., W.C. Krueger, and P.L. Shaver. 2003. State and transition modeling: an ecological process approach. *J Range Manag* 56:106-113.
15. Natural Resources Conservation Service [NRCS], 2015. Using the Web Soil Survey Resilience and Resistance Score Sheet Soils Report. Available at http://www.sagegrouseinitiative.com/wp-content/uploads/2013/07/WSS_RR_Report-Instructions.pdf 2015 Accessed 16 October 2015.

Authors are Sagebrush Ecosystem Specialist, USDA Natural Resources Conservation Service, West National Technology Support Center, Portland, OR 97232, USA (Maestas, jeremy.maestas@por.usda.gov); Soil Scientist, USDA Natural Resources Conservation Service, West National Technology Support Center, Portland, OR 97232, USA (Campbell); Research Ecologist, USDA Forest Service, Rocky Mountain Research Station, Reno, NV 89512, USA (Chambers); Ecologist, USDI Bureau of Land Management, Boise, ID 83709, USA (Pellant); and Professor Emeritus of Range Science, Oregon State University, Corvallis, OR 97331, USA (Miller).