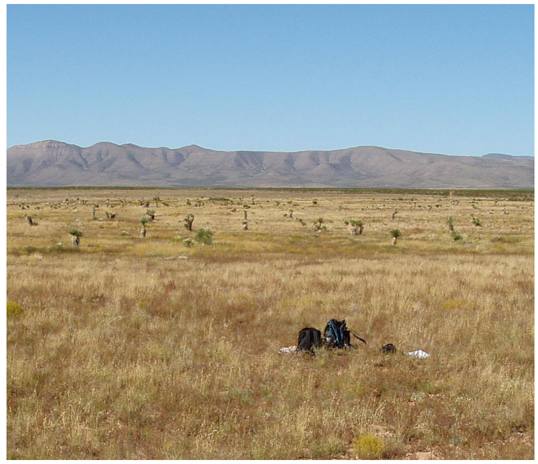
New Mexico
Rangeland Ecological Assessment

findings & application



A new assessment of ecological condition & restoration opportunity on Bureau of Land Management & other lands in southern New Mexico.

Provides guidance for restoration & priority-setting, & an interactive, updateable geodatabase.

Based on expert-mapping & USDA Natural Resource Conservation Service Ecological Site Descriptions.

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Final Report, March 2008

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New Mexico Rangeland Ecological Assessment

Final Report, February 2008

Prepared by The Nature Conservancy, New Mexico Chapter

Steven Yanoff, Patrick McCarthy, Joanna Bate, Lara Wood Miller, Anne Bradley, Dave Gori

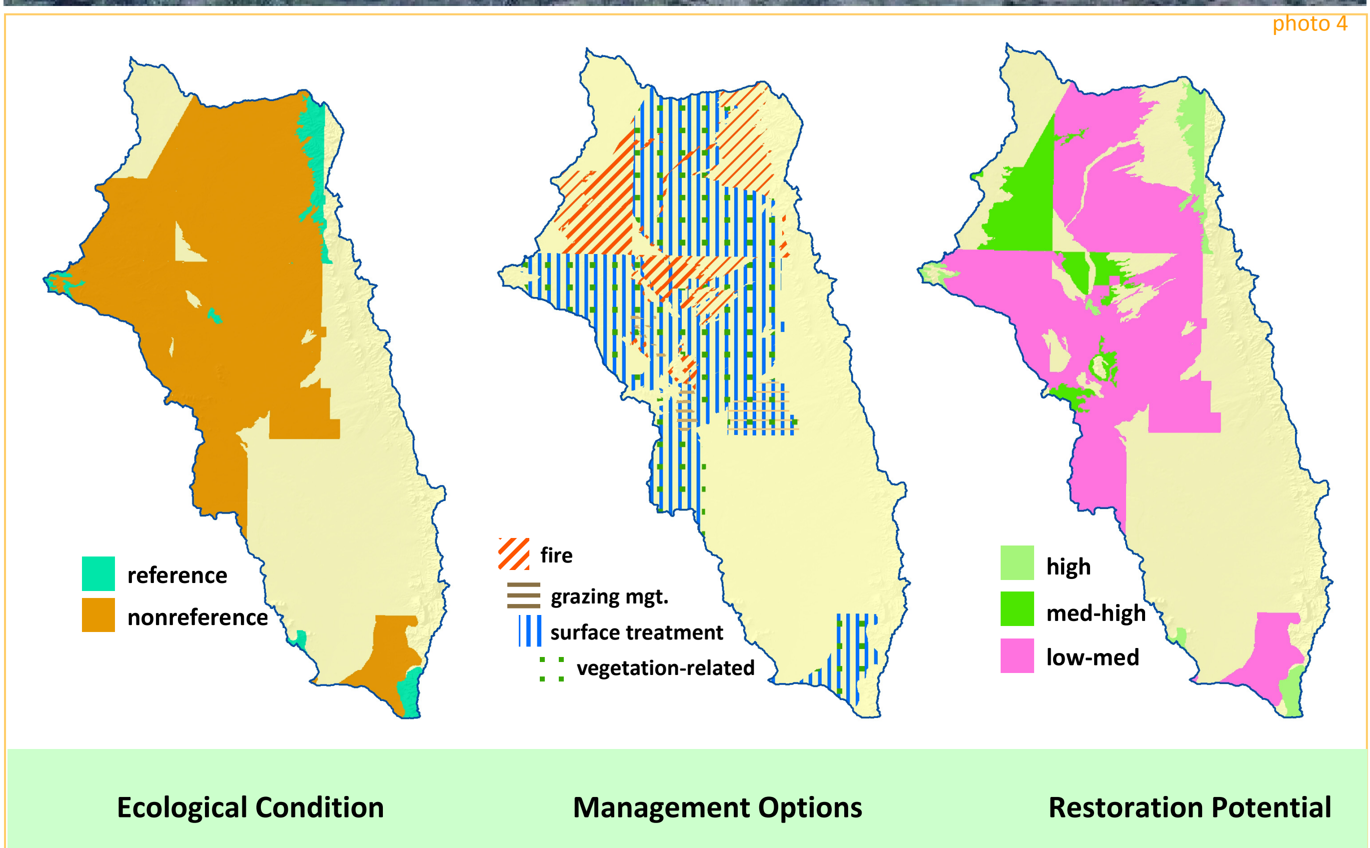

Fig. 1. Example of categories mapped by the REA in a USGS 8-digit watershed in southern New Mexico. Such information can help determine restoration priorities and methods.

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Contents

Appendices 1 and 2 are electronic files only.
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FIGURES (Including maps & tabular results)

TABLES

BOXES (special topics)

A. Executive Summary

I. Goals of the REA

The New Mexico Rangeland Ecological Assessment ("REA") is a regional assessment of ecological condition and restoration opportunity on over 14 million acres in southern New Mexico. It is the first assessment of its kind to span this area in nearly 30 years.

The REA has three primary goals. The first is to provide data to policy-makers, land managers and the public that broadly identify rangeland ecological conditions and restoration opportunities. This will help REA users to identify candidate landscapes for restoration, which in turn will allow them to target and apply limited resources more effectively to areas and ecosystems in need of restoration, and will deliver the greatest return on investment.

The second goal of the REA is to provide information in a dynamic, updateable information format. To achieve this goal, a geodatabase has been created which will allow managers to create and update maps and analyses over time.

The third goal of the REA is to suggest an approach for applying and integrating regional scale data, like the REA, along with other tools as part of a comprehensive restoration strategy.

REA results can support priority-setting for restoration by identifying areas and ecosystems that are in the expected, or "reference" condition, as well as those in altered or "non-reference condition", and those at risk of major alteration (type conversion). Information in the REA can be integrated into agency planning processes, resource management plans, other documents and public review. For example, the REA maps, data and analyses can be combined with information already available to the BLM from Land Health Assessments, field monitoring (BLM Vegetation and Monitoring and Analysis Program or VMAP), public comments and other sources such as LANDFIRE Fire Regime Condition Class maps (FRCC).

In addition, the REA can be used by land use planners and others to characterize current conditions, better understand reference conditions, and to describe desired conditions and evaluate how to achieve them. Such objectives support agency goals of ecological sustainability and the restoration of natural fire regimes, as articulated in the BLM Land Health Standards, the National Fire Plan, resource management plans and other institutional documents.

They also support widespread commitments to land health held by other land management agencies, rural communities, ranchers, conservation organizations and the public.

II. Status of Southern New Mexico's Native Grasslands

The expansive grasslands of New Mexico – although they are perhaps less visited, less studied and less appreciated than our mountains and rivers – represent one of the state's great natural treasures. Our grasslands, including savannas, provide irreplaceable habitat for wildlife; they have great scenic beauty; they support rural economies and livelihoods; and they supply clean water to communities. Recent global analyses (e.g. Niemeijer et al. 2005) have shown that grasslands are one of the Earth's fastest disappearing, least effectively protected major habitat types – and that many of North America's largest, most intact expanses of semi-desert grassland and short-grass prairie lie within New Mexico.

But New Mexico's grasslands are at risk. They have declined considerably over the past 100-200 years (e.g. Bogan et al., 1998, Dick-Peddie, 1993, Gibbens et al., 2005). Threats to our grasslands include fragmentation by road-building for oil and gas development, non-adaptive grazing regimes, high levels of soil erosion, loss of their natural fire regimes, and the spread of invasive plants. Grasslands on private land are vulnerable to permanent crop-agricultural conversion. A changing climate will further challenge the adaptive capacity of all our native systems. Consequently, we are at risk of losing much of this signature habitat type of New Mexico's southern deserts and eastern plains, along with the plants and animals that they support, and the economic benefits that they bring. Over the course of three years, the Bureau of Land Management (BLM) and The Nature Conservancy (TNC), with the assistance and support of other public agencies and numerous rangeland professionals, conducted a region-wide analysis to improve information on grassland status, and to identify restoration opportunities for this important ecosystem. The results of this extensive analysis are contained within this Rangeland Ecological Assessment (REA).

III. What the REA Provides

The REA estimates the condition of 14.2 million acres of land in southern New Mexico, including extensive public lands in BLM's Carlsbad, Las Cruces, Roswell and Socorro field offices. The REA maps the current condition of grasslands, shrublands and savanna based on states described in so-called "ecological site descriptions" (ESDs) and expert knowledge. ESDs have been developed by the Natural Resource Conservation Service, and they are a consistent, science and expert-based resource increasingly used by land managers. The REA compares current condition to the expected or "reference" condition, and summarizes the vegetation, ecological processes and restorative management options of these states. Depending on these management options the REA interprets restoration potential, or the effort needed to restore states towards or to reference condition. To provide a wide-ranging view of southern New Mexico's rangelands, the REA's scope is public land managed by BLM as well as other areas familiar to rangeland experts.

The products of the REA include:

- This **narrative report**, which documents and interprets the project's findings with respect to ecological condition and restoration opportunity.
- An **interactive, dynamic geodatabase in ArcGIS format** that provides tools and data for regional and landscape-scale natural resource management planning to BLM, other public agencies and the public.
- Two **supplementary reports**. One describes a new method for estimating departure from reference condition based on ESDs, and complementary to Fire Regime Condition Class (FRCC), and the other summarizes a method using remote sensing and satellite imagery for rapid ecological assessment.

These products, which have been provided to the BLM New Mexico state office and field offices, are available to the public at http://www.nmconservation.org.

Ecological Site Descriptions and Manager Experience are the Basis of the REA

The REA, by using Natural Resource Conservation Service ecological site descriptions (ESDs), provides a window into not only *how much* grassland and savanna have been transformed, but *how and why* they have changed by describing the transition drivers that move grassland and savanna ecosystems away from reference condition. Employing these ecological models built by managers, land users and scientists, the REA draws preliminary conclusions about the key agents of transformation of New Mexico rangelands. Perhaps most important, the REA, together with ESDs and local knowledge, suggests ways managers can improve or maintain the health of the land.

IV. Key Findings

A summary of the acres analyzed and the relative proportion of acres in different categories can be found in Table 1 below**.** Of all lands analyzed in the REA and resolved to either a reference or non-reference state, **35% is still in reference condition and 65% is in non-reference condition.** On BLM lands, the percentages are similar; 34% are in reference condition and 66% are in non-reference condition.

When these acres are broken out into the grassland and savanna vegetation that would have occurred under reference condition (according to ESDs), savanna appears to have more area still in reference condition – 41% of all land and 40% of BLM managed land. Historic grasslands have a lower percentage of their analyzed area in reference condition (35% for all land and 31% for BLM managed land). For both grassland and savanna the largest shift from reference condition is associated with woody plant invasion, dominance or alteration.

Within the landscapes not currently in reference condition, 21% of all land and 23% of BLM land would benefit from relatively moderate effort to improve their condition; in other words, no extensive structures, other inputs to maintain or restore soil function, or cultivation are necessary. When added to the areas already in reference condition, **60% of all lands and 59% of BLM lands are good candidates for further restoration evaluation and action by relatively moderate investments.** This leaves 40% of all land and 41% of BLM managed land in a condition that may require higher management effort to either reestablish reference condition or to move the land to a healthier state.

Areas currently in reference condition will require ongoing management attention to keep them in this condition. Reestablishing a more natural fire regime, managing grazing, limiting new disturbances such as road building, and adjusting management in response to regular resource monitoring will help assure their continued persistence.

The potential shifts in condition resulting from a changing climate should also be kept in mind. Arid plant communities are already living at physiological limits, as illustrated by their often dramatic response to drought documented in the ESDs. Greater climatic variability is now predicted for the Southwest (Seager et al. 2007). Land managers will have to assess whether historic management strategies are sufficient to maintain or improve land health over time.

Finally, an additional potential use of the REA is to identify areas that may be vulnerable to future alteration. The likelihood of ecosystems to shift to non-reference condition is suggested by summarizing the proportions of the ecological sites mapped by the REA that are now in non-reference condition. Results highlight landscapes (ecological sites) that have undergone the largest departure (by area) from reference condition, and therefore, may represent sites that may be less resilient. The authors hope that the REA provides useful, timely information that will help managers and the public work towards land health and sustainability now and in the future.

V. Some important concepts for reviewing Table 1 below:

1. Reference condition

The NRCS ESDs identify ecosystems in "reference" condition. Reference conditions refer to presettlement conditions before intensified land use began in the mid to late 1800s in New Mexico, and are our best estimate of how healthy systems look and respond to their environment. Reference conditions are maintained within an historic range of variation by climate, fire or other natural disturbances. In southern New Mexico, many grasslands and savannas that departed from their original reference state are today invaded or dominated by woody vegetation, and reflect altered ecological processes. The REA maps this major shift in its calculation of acres in non-reference condition.

2. Conservation and restoration opportunities

We interpreted landscapes currently in reference condition as priorities for ongoing conservation to prevent departure. We interpreted landscapes in moderate departure – those that do not appear to require soil restoration, cultivation or major investments to halt erosion or type conversion – as having the best opportunities for restoration. There may be instances where areas requiring intensive work may also be restoration priorities. Examples are a riparian system dominated by salt cedar, or former grassland now dominated by species not native to the site. In the former case, extensive removal of the exotic species may include a follow-up flushing of the soil to remove salt. In the latter, soil erosion control and planting with native seed may be required. The overriding resource values of these systems may justify the relatively high cost per acre of treatment. In order to set priorities, a mid-scale analysis like the REA should be coupled with on-the-ground knowledge of condition and resource values at risk.

3. Transition drivers

Transition drivers are processes that individually, or combined, move areas in reference condition to or between non-reference condition states, according to ESDs. The processes themselves may occur in reference condition. For example, loss of grass cover (a vegetation-related driver) may have occurred in response to moderate variations in climate. Only if it facilitated a shift to a non-reference condition state, is it considered a driver. Transition drivers are often a complex of processes, like long term drought and non-adaptive grazing regimes, combining to change the status of a site.

4. Management tools for restoration

In the REA, we rely on the management options listed in the existing ESDs as a guide to methods managers should consider for restoration. In some cases, the ESDs provide a general objective, such as brush removal, but leave the specific methods to the manager. Often a combination of methods may be advisable to restore and maintain healthy landscapes over time. For example, an initial mechanical treatment may be followed in later years by prescribed fire and a well managed grazing regime.

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Table 1. REA Results Summary[1]

(see above and *Glossary* for field definitions, and *A Primer for Understanding Results* for essential background)

	All Land	Public Land (BLM)
1. Project Area	45 million (m) acres	10.5 million (m) acres

2. What was mapped by the REA?

A. Within the project area

acres	% all land	acres	% BLM land
14.2 m	32%	7.5 m	72%

B. State types in the REA-mapped part of the project area

	acres	% all land	acres	% BLM land
NRCS	10.7 m	79%	5.9 m	81%
Expert	2.8 m	21%	1.4 m	19%

Unresolved acres: *0.7 m* *0.2 m*

3. Ecological Condition

(3a below is for all states, 3b-5b is for NRCS states; see *Glossary*)

A. Current Reference or Non-Reference Condition

	acres	% all land	acres	% BLM land
Reference	4.5 m	35%	2.4 m	34%
Non-reference	8.3 m	65%	4.6 m	66%

Unresolved acres: *1.4 m* *0.5 m*

B. Change from Reference Condition by Generalized State

	Grassland		Savanna		Grassland		Savanna	
Bare/annuals	-	0%	0.1 m	1%	-	0%	<0.1 m	1%
Grass altered	0.2 m	8%	0.0 m	0%	0.1 m	9%	-	0%
Woody invaded	0.5 m	19%	0.0 m	0%	0.3 m	18%	-	0%
Woody dominated	-	0%	1.3 m	25%	-	0%	0.8 m	26%
Woody altered	1.0 m	38%	1.7 m	33%	0.6 m	42%	1.0 m	33%
No change	1.0 m	35%	2.2 m	41%	0.4 m	31%	1.3 m	40%
total	2.7 m		5.3 m		1.5 m		3.2 m	

Unresolved acres: *2.6 m* *1.2 m*

Generalized states under reference condition are Grassland and Savanna (column headings). Current generalized states are in rows. Bare/annuals, Grass altered and these Woody generalized states are departed from reference condition (see *Glossary*). No change = current grassland or savanna in reference condition.

Table 1. REA Results Summary continued

4. Transition Drivers

	All Land: acres	All Land: % all land	Public Land (BLM): acres	Public Land (BLM): % BLM land
Climate-related	4.3 m	48%	2.4 m	49%
Fire-related	3.3 m	37%	1.8 m	37%
Grazing-related	5.1 m	58%	2.9 m	59%
Soil-related	4.8 m	54%	2.7 m	55%
Vegetation-related	5.0 m	57%	2.8 m	58%
None	3.5 m	40%	1.9 m	39%
Unresolved acres:	*1.8 m*		*0.9 m*	

Drivers shift states to and between non-reference condition states. None = reference condition. ESDs often associate multiple drivers with states so acres overlap and summed percents exceed 100%. For example, if drought and altered fire regime both drive a transition they are tallied in Climate *and* Fire categories.

5. Restoration Opportunity

A. Management Options

	All Land: acres	All Land: % all land	Public Land (BLM): acres	Public Land (BLM): % BLM land
Fire mgt	3.7 m	45%	1.9 m	41%
Grazing mgt	1.9 m	23%	1.0 m	23%
Soil mgt	2.2 m	27%	1.3 m	26%
Vegetation mgt	4.8 m	58%	2.8 m	59%
None	1.4 m	17%	0.9 m	19%
Unresolved acres:	*2.4 m*		*1.1 m*	

B. Interpreted Management Effort for Restoration

	All Land: acres	All Land: % all land	Public Land (BLM): acres	Public Land (BLM): % BLM land
Maintenance	3.5 m	39%	1.9 m	36%
Moderate	1.9 m	21%	1.2 m	23%
Moderate-High/High	3.7 m	40%	2.2 m	41%
Unresolved acres:	*1.6 m*		*0.6 m*	

Management options shift states towards or to reference condition. None = reference condition states, except for those included in Fire mgt for maintenance. ESDs often associate multiple options with states so acres overlap and summed percents exceed 100%. For example, if Fire and Grazing mgt are cited for one state they are tallied in both options. Interpreted management effort: Maintenance = reference condition states, Moderate = soil mgt or cultivation not cited by ESDs, High = soil mgt or cultivation cited.

[1]Based on REA-mapped states (Appendix 1). Percents exclude unresolved acres (areas mapped to > 1 state that conflict): each analysis has a different size unresolved class so acres and percents may differ between analyses; see Box 3. Vegetation management includes "brush control" which may entail fire or other options not specified in ESDs (see section G, *Applying the REA*). Example how to read this table: 72% of BLM land in the project area was mapped in the REA. Of that and excluding unresolved acres, (1) 81% is NRCS states, (2) 34% is reference condition, (3) 42% of former reference condition grassland is now woody altered, (4) altered fire regime was indicated as a driver of non-reference condition on 37%, (5) 41% indicates restorative fire management, and (6) 23% may be associated with moderate restoration effort.

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B. Glossary

Term[2]	REA Usage
Ecological Condition	**1. Reference** (ca. 1800s, natural disturbances and minimal human impacts) or **Non-reference Condition** [ESD, NS, ES]. **2. Generalized States:** (a) *reference condition grassland*, *savanna*, *shrubland/woodland, bare ground/annuals* – historic species composition and abundance at potential and ecological processes intact given natural variation in climate and disturbance, in *grassland* woody plants ≤ 5% canopy cover or described as minor, in *savanna* woody plants have variable abundance but are not minor; (b) *grass* or *woody invaded* – by species absent or minor historically, ecological processes may be impaired, (c) *woody dominated* – grass patchy, woody abundance > historical, ecological processes moderately altered, favor woody plants; (d) *grass or woody altered* – historical grass species absent or minor, ecological processes highly altered; (e) *Bare/annuals* – historical species absent or minor, ecological processes highly impaired. Generalized states interpreted from ESDs since no generalized state classification existed at the time of this report. See Methods for expanded definitions. [ESD, NS, I]
Transition Drivers	Natural and anthropogenic processes that drive transitions to non-reference condition states, standardized as *Climate* (e.g. drought), *Fire* (e.g. lack of fire), *Grazing* (e.g. overgrazing), *Soil* (e.g. erosion) and *Vegetation* related (e.g. grass cover loss, plant competition). ESDs typically cite multiple interacting drivers. For simplicity the REA highlights individual drivers. The time period of driver activity is unspecified (e.g. drought may promote shrub invasion currently and/or in the past). [ESD, NS]
Ecological Site Descriptions	ESDs are published descriptions of *ecological sites*, land units classified by NRCS to assist management. Ecological sites are defined by soils, terrain, climate, potential vegetation and states. States reflect ecological condition (above) and thresholds, and are summarized in state-transition models. Models depict natural, anthropogenic and managed pathways between states. ESDs underlie the REA.
Restoration Opportunity	**1. Management Options** maintain reference condition or shift non-reference condition states towards or to reference condition: *Fire* (e.g. prescribed), *Grazing* (e.g. modified), *Soil* (e.g. erosion control, soil amendments, dune destruction) and *Vegetation* (e.g. remove invasive woody plants, seed historical plant species) related management. The REA reports options for restoring non-reference condition states without identifying their target states (for specific pathways to return to reference condition or other states see ESDs). ESDs often cite multiple management options, sometimes as part of an integrated restoration strategy. For simplicity the REA highlights individual options. ESDs often cite "brush control" but do not specify a means. Brush control was assigned to the Vegetation option but we suppose it might also involve fire and/or grazing management, depending on the state. [ESD, NS]. **2. Restoration Potential** is the REA's interpretation of restoration effort by assuming reference condition states require *maintenance*, and distinguishing non-reference condition states that do not require *soil management or cultivation*, from those that do. We interpreted soil management and cultivation (e.g. seeding) as requiring the most effort, although this must be confirmed for specific cases. [ESD, NS, I]
States	States are described in ESDs in terms of ecological condition, transition drivers and management options as described in this table. States are fairly stable and separated by ecological thresholds. Transitions between states require significant drivers or management input. Some transitions are not reversible. The REA mapped *NRCS States* as described in ESDs, and *Expert-States* if experts disagreed with ESDs, or recent ESDs were unavailable. Original states are listed in the State Attributes Table (Appendix 1).
State Attributes	Ecological condition, transition drivers and restoration opportunity standardized as described above. State attributes were databased and linked to the REA state map. For example, an NRCS state might be attributed as currently non-reference condition, grassland under reference condition, woody-invaded currently, driven to non-reference condition by fire and grazing -related drivers (e.g. reduced fire and overgrazing), and restorable through fire and grazing management (e.g. prescribed fire and modified grazing); based on its ESD.
Unresolved Class	Spatially overlapping or single states with multiple state attributes that conflict (e.g. reference and non-reference condition states at same location). Each REA analysis (reference/non-reference condition, etc.) has a distinct unresolved class, which complicates comparisons between analyses (See Box 3).

[2]Information source codes: ESD – NRCS ecological site descriptions, NS – REA-mapped NRCS states, ES – REA-mapped expert states, I – interpreted by REA. Some terms are defined further in *Methods* and *Results*. The REA adapted some terms and concepts of the Natural Resource Conservation Service (USDA NRCS Range and Pasture Handbook, 1997).

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C. Acknowledgements

Many organizations and people contributed to the design and content of the New Mexico Rangeland Ecological Assessment (REA). Agency participants included field and administrative professionals of the USDI Bureau of Land Management (BLM), USDA Agricultural Research Service-Jornada Experimental Range, USDA Natural Resources Conservation Service (NRCS), New Mexico State University Cooperative Extension and US Department of Defense (Fort Bliss). New Mexico State University and University of Arizona faculty, field biologists and World Wildlife Fund staff also contributed. The USDA Forest Service and LANDFIRE, a national interagency ecological assessment project, supported related work that informed the REA. The Earth Data Analysis Center and Natural Heritage New Mexico at the University of New Mexico designed a preliminary method for rapid satellite image-based assessment (Appendix 4). Teri Neville of Natural Heritage New Mexico and Keith Elliot (Elliot Software) provided additional technical assistance. The New Mexico chapter of The Nature Conservancy (TNC) coordinated and implemented the REA, and various offices of TNC provided guidance and expertise. The REA is part of a cooperative assistance agreement between TNC and the BLM. Project funding was provided by the BLM New Mexico State Office and TNC.

The BLM, state and national NRCS staff and the New Mexico State University Range Improvement Task Force reviewed the interim REA report.

A special thanks to Roxanna Hannan, Pricilla Ornelas, Reese Lolley, Kate Smith, Robert Strahan, Celia Valenzuela and Amy Livingston for support and advice.

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D. Getting Started

The New Mexico Rangeland Ecological Assessment (REA) is made up of two parts. The first is this report, which presents results of a major new ecological assessment carried out by The Nature Conservancy (TNC) and Bureau of Land Management (BLM), with the help of many others. The report summarizes ecological condition, drivers of departure from reference condition, and restoration opportunity for more than 14 million acres in southern New Mexico. Results are organized by BLM field office and USGS 8-digit HUC watershed. The report includes TNC's guidance for applying the REA, alone and as part of an integrated management and restoration strategy.

The second part of the REA includes the appendices. Appendix 1 provides detailed REA results. Appendix 2 contains the actual REA data. These spatial layers and tables are stored in a geodatabase in ArcGIS (ESRI) format. The geodatabase can be updated, so the REA can serve as a dynamic long-term resource. Appendix 3 describes an "ESD-departure" metric, a calculation of departure from reference condition similar to Fire Regime Condition Class, that links to NRCS ecological site descriptions. It recommends complemetary use of both ESD-departure and FRCC. Appendix 4 outlines an approach for rapid ecological assessment using satellite imagery.

The REA conveys complex ecological information in a way that is meant to be accessible to a variety of users, from agency administrators, resource specialists and GIS technicians, to a public audience with a range of interests. To this end we include both summaries and details in the report. Many sections start with introductions that identify key points. These are followed by detailed content.

For a quick and simple rundown of the major REA findings and concepts, the reader should consult the *Executive Summary*, *Overview*, and section summaries. Maps and tables of REA results are also quite accessible. "Boxes" & "Tips" scattered thoughout the report highlight special topics and links to other information sources. For detailed information read the main text of the report and explore the appendices and geodatabase.

The section, *Understanding the REA*, provides important background for interpreting the REA. The extent of REA mapping, NRCS vs. expert states, spatial scale and other subjects are discussed.

Electronc versions (Adobe pdf) of the REA report and geodatabase are online at http://nmconservation.org (follow the REA links).

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E. Project Overview

In short: *The New Mexico Rangeland Ecological Assessment (REA) is a regional assessment of ecological condition and restoration opportunity on over 14 million acres in southern New Mexico. It is the first assessment of its kind to span this area in nearly 30 years. The REA has three purposes. The first is to provide data to policy-makers, land managers and the public that broadly identifies ecological condition and restoration opportunity. Such information can help prioritize areas, ecosystems and limited resources more effectively across large areas. It can also serve as a landscape and regional context for field-level management. The second goal is to provide this information in a dynamic, updateable information format (geodatabase). The third goal is to suggest an approach for applying the REA, along with other information, as part of a comprehensive restoration strategy.*

The REA maps the current condition of grasslands, shrublands and shrub and tree savannas based on states described in Natural Resource Conservation Service ecological site descriptions (ESDs) and expert knowledge. ESDs are a consistent, science and expert-based resource increasingly used by land managers. The REA compares current condition to reference condition, and summarizes the vegetation, ecological processes and restorative management options of these states. Depending on these management options the REA interprets restoration potential, or the effort needed to restore states towards or to reference condition. To provide a wide-ranging view of southern New Mexico's rangelands, the REA's scope is public land managed by the USDI Bureau of Land Management as well as other areas familiar to rangeland experts.

Tip: The REA can help answer critical questions at a regional scale. For example, what areas & ecosystems may be at risk, where do intact & restorable grasslands occur in southern New Mexico, & what general restoration methods are recommended for different states by ESDs?

In Detail: The REA is the first ecological assessment of its kind to cover much of southern New Mexico's rangelands since the 1970s (Soil Vegetation Inventory Method or SVIM, Wagner, 1989)[3]. It provides a regional perspective on ecological condition and restoration opportunity across millions of acres of grasslands, shrublands, and shrub and tree savannas. Results in this report and the accompanying geodatabase can help policy-makers, land managers and the public prioritize areas and ecosystems for restoration, in the face of limited resources. The USDI Bureau of Land Management (BLM), charged with managing significant areas of rangelands on behalf of the public, will gain a sweeping picture of those areas through the REA, one that can illuminate restoration needs at major planning and ecological scales. The REA is also informative locally, but only in combination with finer scale data.

For example, the REA can help identify and prioritize areas and ecosystems that reflect restoration opportunity statewide, among BLM field offices, and for resource management plans and large watersheds. It can help focus efforts on areas at risk of crossing ecological thresholds, that once crossed may be difficult or impossible to feasibly

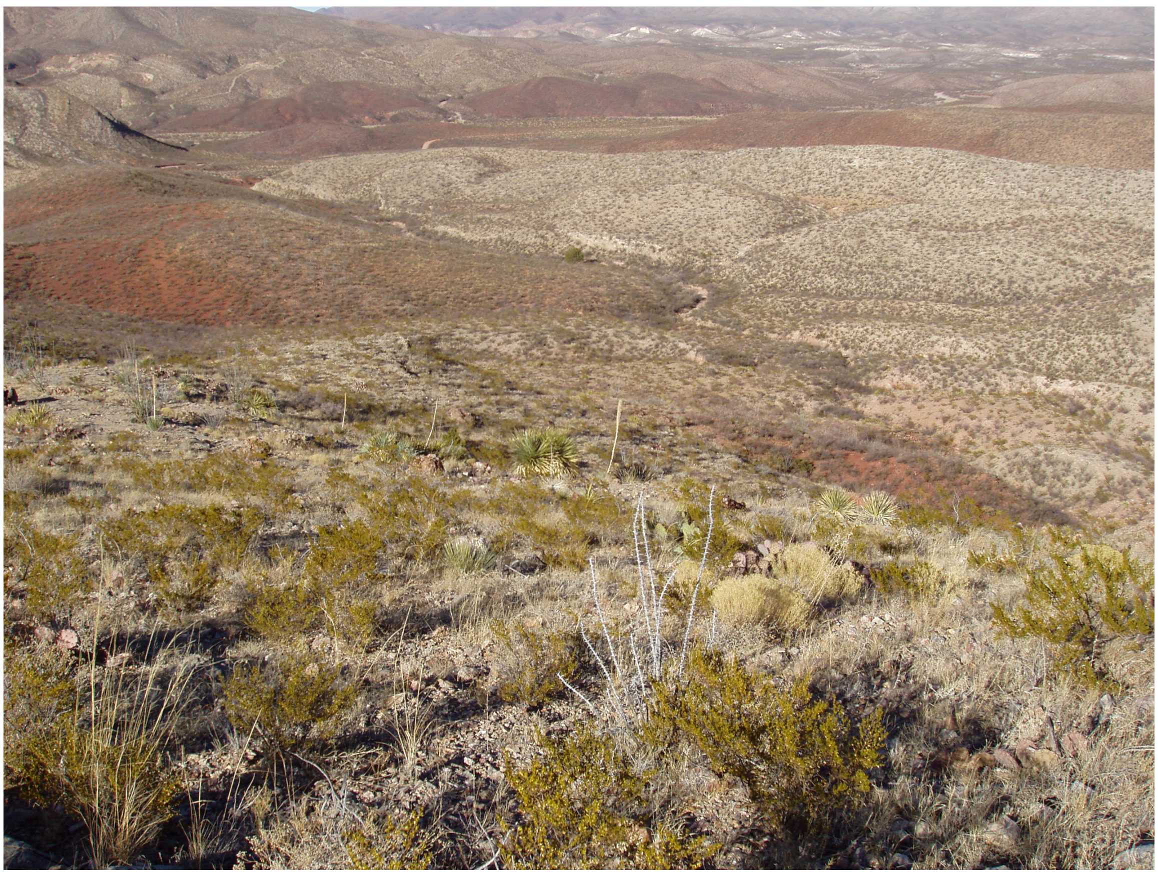


photo 6

[3]BLM's SVIM differs from the REA since it is dated, did not integrate NRCS state-transition models (which were not yet available) and did not map restoration opportunity. The NRCS National Resources Inventory and BLM land health assessments are ongoing efforts that summarize ecological condition based on ground points. In contrast, the REA is spatially comprehensive in that experts map continuous areas and, by linking to ESDs and their state-transition models, maps restoration opportunity. The USDA Agricultural Research Service-Jornada Experimental Range mapped states similar to the REA. It differed by its heavy use of remote-sensing, it did not map restoration opportunity, and it is limited to BLM land in BLM's Las Cruces Field Office.

restore. Higher resolution data, such as BLM land health assessments, can confirm and complement REA results and focus project-level planning.

The REA strives to build an extensive picture of ecological condition and restoration opportunity of southern New Mexico's rangelands. Accordingly, rangeland experts participating in the REA map BLM-managed land as well as other areas known well to them. Since the REA extends beyond BLM land it can inform restoration efforts at watershed scale and encourage involvement from diverse stakeholders.

The REA is carried out under an assistance agreement between the BLM and The Nature Conservancy (TNC). The basis for this collaboration is that TNC supports efforts to conserve, maintain and restore native ecosystems, and BLM mandates such as the National Fire Plan and Rangeland Health Standards have similar aims in terms of supporting ecologically sustainability. The REA also serves public interests by providing a well-informed, objective assessment.

The REA Framework:
Ecological Site Descriptions

To support science-based, consistent land management the REA adapted USDA Natural Resources Conservation Service ecological site descriptions (ESDs; NRCS, 1997) as its framework. ESDs are a standardized ecological and management classification that synthesizes the available scientific literature and expert knowledge. They promote integrated land management by describing multiple ecological processes and management tools. ESDs are specialized for rangelands and have been formally accepted by the US Departments of Interior and Agriculture for land assessment and management.

ESDs contain information about ecological condition, in terms of"states" that occur in different land types called ecological sites. Ecological sites are distinguished by soils, terrain, climate and potential vegetation. States are classified as reference or non-reference condition. Under reference condition a reference condition state would occupy an entire ecological site. ESDs describe the vegetation of states and pathways between them as defined by ecological dynamics (e.g. shrub-invasion), drivers of non-reference condition (e.g. altered fire regime) and restorative management options (e.g. prescribed fire). These pathways are depicted in state-transition models which separate states by ecological thresholds, and so alert managers to risks of ecological change and avenues for restoration. For example, a tree-encroached savanna state may be at risk of becoming tree dominated, but restorable through woody plant removal, and fire and grazing management. A duneland state, conversely, may require intensive surface treatments such as erosion control for restoration. ESDs emphasize descriptive indicators of states rather than fixed quantitative criteria.

REA Products and Application

In the REA, experts map states described in ESDs and in some cases assign custom states. Results are digitized in a Geographic Information System (GIS), and maps and analyses of ecological condition and restoration opportunity are produced at mid-scale (approximately 1:23,000 to 1:100,000 scale). These include reference and non-reference condition, dominant vegetation, drivers of non-reference condition, and management options to maintain reference condition or shift states towards or to reference condition. Based on the management options the REA estimates the difficulty of restoring states, which we term restoration potential. In sum, the REA mapped and analyzed 7.5 million acres of BLM land and over 14 million acres overall in southern New Mexico. This includes parts of four BLM field offices, 20 counties and 32 major watersheds (USGS 8-digit hydrologic unit code).

The REA is innovative in that it represents the information in ESDs spatially, which signifies a key step in increasing their usefulness. This can support priority setting for restoration at mid or coarser scales. Furthermore, land managers can use the information about current condition in the REA, along with information in ESDs about alternative or future states (e.g. in state-transition models), to anticipate ecological change and so enhance management decisions. Since ESDs include information about climate effects, the REA also can help managers anticipate increasing climate variability, at least generally (Box 7).

Several other state-mapping efforts exist, including that of the USDA Agricultural Research Service-Jornada Experimental Range in southern New Mexico (see *Links* in section H). Since ESDs were originally developed for fine-scale application (e.g. pasture management), their application at broader scales is a recent advance that will benefit from review and guidance by the NRCS and others. The sub-section in section F, *A Primer for Understanding Results*, provides background on the REA's mapping process to guide interpretation of REA maps and analyses.

REA data are stored in a geodatabase, which allows users to check, update and expand the REA. The REA, then, can be used to help establish a baseline of ecological condition document the success of current restoration efforts, and serve a monitoring role if periodically updated. Other information can be spatially overlaid onto the REA, ranging from national LANDFIRE maps of ecological departure (Fire Regime Condition Class, FRCC) to ground-based data. This allows the REA to be combined with diverse information resources and address management needs at multiple scales.

The REA does not recommend specific management goals, desired states, treatment methods or restoration projects. Rather, it provides all of the information gathered and encourages users to consult ESDs for state-specific details about restorative pathways and particular management options. The REA does provide suggestions, however, on how to apply this assessment as part of a comprehensive restoration strategy (see Section G., *Applying the REA*). This guidance is that of The Nature Conservancy, and does not necessarily reflect the BLM, NRCS, expert mappers or other contributors to the REA. The thrust of this guidance is that the REA's regional scope, especially if combined with other information at multiple scales, can support a cost-effective yet ecologically sound long-term prioritization and restoration approach.

F. Methods

1. Map States

- Expert Mapping
- Building the GIS and Simplifying State Maps

2. Attribute States

- Ecological Condition
- Transition Drivers
- Restoration Opportunity
- Technical Procedure

TAKE A LOOK:

- ♦ REA PROJECT AREA (FIG. 2)
- ♦ EXAMPLE REA MAPPING TEMPLATE (FIG. 3)
- ♦ MAPPING NRCS STATES & ATTRIBUTES FROM ESDS (BOX 1)
- ♦ EXTRACT FROM STATE ATTRIBUTES TABLE (FIG. 4)

Tip: Experts mapped states in the REA. States can also be mapped from remote-sensing data. To learn more see Appendix 4, *Rapid Ecological Condition Mapping Approach*, & contact the USDA Agricultural Research Service (ARS) Jornada Experimental Range (http://usda-ars.nmsu.edu/).

Step 1:
Map States

photo 7

In short: *The REA mapped states in southern New Mexico, focusing on USDI Bureau of Land Management and other rangelands known to expert mappers. States are described in Natural Resource Conservation Service ecological site descriptions (ESDs) and reflect reference or non-reference condition. They are identified by vegetation and ecological processes and depicted in state-transition models. Example states are reference condition swale grasslands and non-reference condition gullied former swale grasslands. Seventy experts with first-hand knowledge of New Mexico rangelands contributed to the REA state map. They followed a fixed mapping protocol to yield consistent and repeatable results. Topographic and soils maps were mapping templates and ESDs served as the reference for assigning states. Where ESDs were insufficient, experts assigned "expert-states" using ESDs as guides. State maps were digitized in a geographic information system (GIS) and simplified where more than one state was mapped for the same area.*

Tips:
1. Standard definitions for ecological sites & states are in the NRCS National Range & Pasture Handbook (http://www.glti.nrcs.usda.gov/technical/publications/nrph.html).
2. New Mexico ESDs are online at the NM NRCS web site (http://www.nm.nrcs.usda.gov/).
3. Bestelmeyer et al. (2003) suggest how ESDs apply to land management.

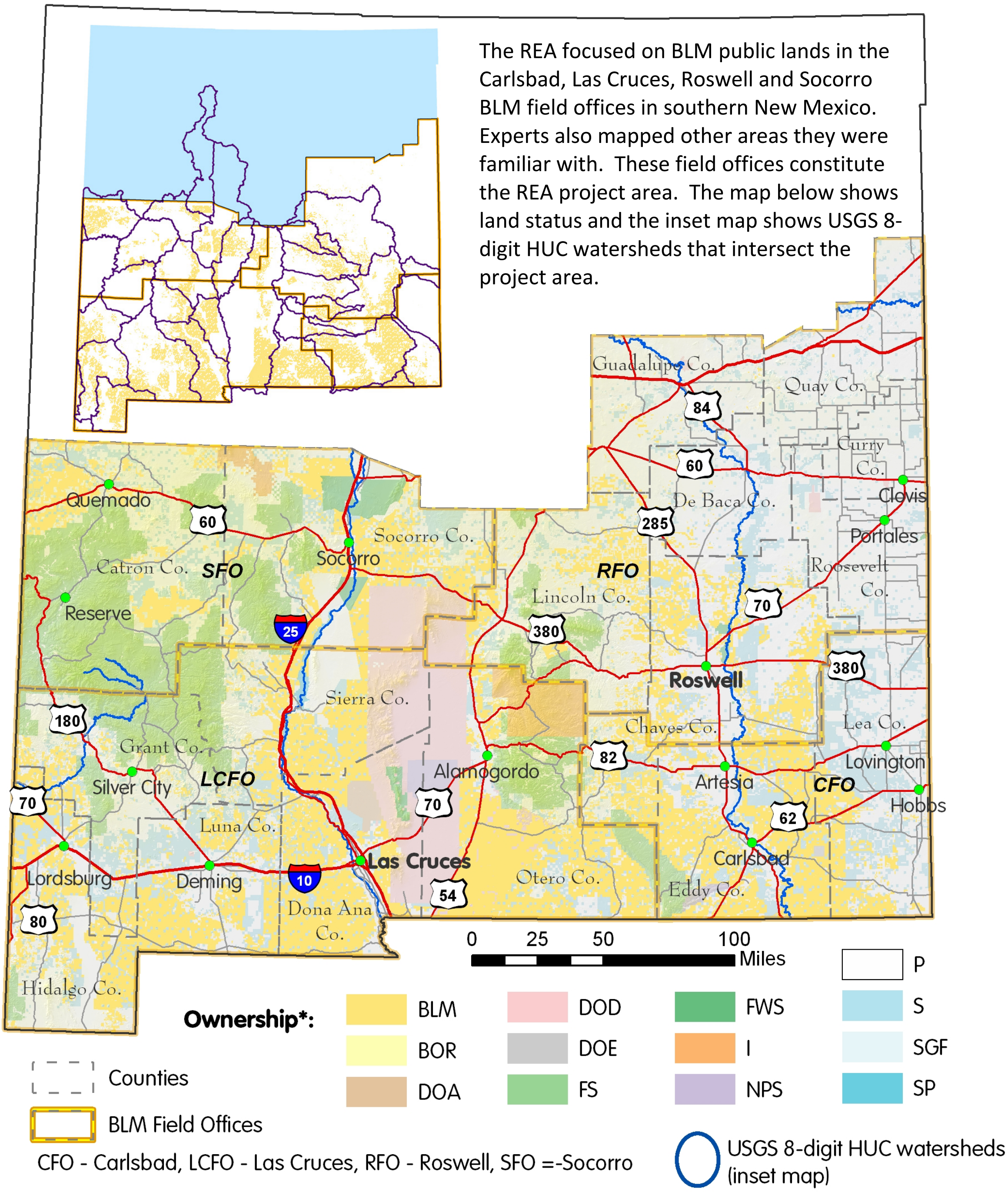
In Detail:

Expert Mapping

The REA collected information about rangeland condition in southern New Mexico. It focused on public land managed by the USDI Bureau of Land Management (BLM) in four BLM field offices (Fig. 2), and included other areas known to expert mappers. The REA worked directly with rangeland professionals. These 70 experts included resource specialists from the BLM, USDA Natural Resources Conservation Service (NRCS), USDA

Agricultural Research Service-Jornada Experimental Range, New Mexico Cooperative Extension, and US Department of Defense (Ft. Bliss). Field biologists also took part.

Figure 2. REA Project Area. (Univeral Transverse Mercator System [UTM] zone 13)



Experts mapped states described in NRCS ecological site descriptions (ESDs). ESDs were summarized in the *Terminolgy* and *Project Overview* sections and are depicted in Box 1. States are associated with land types called ecological sites, and represent reference or non-reference condition. The WP2 Deep Sand ecological site, for example, contains

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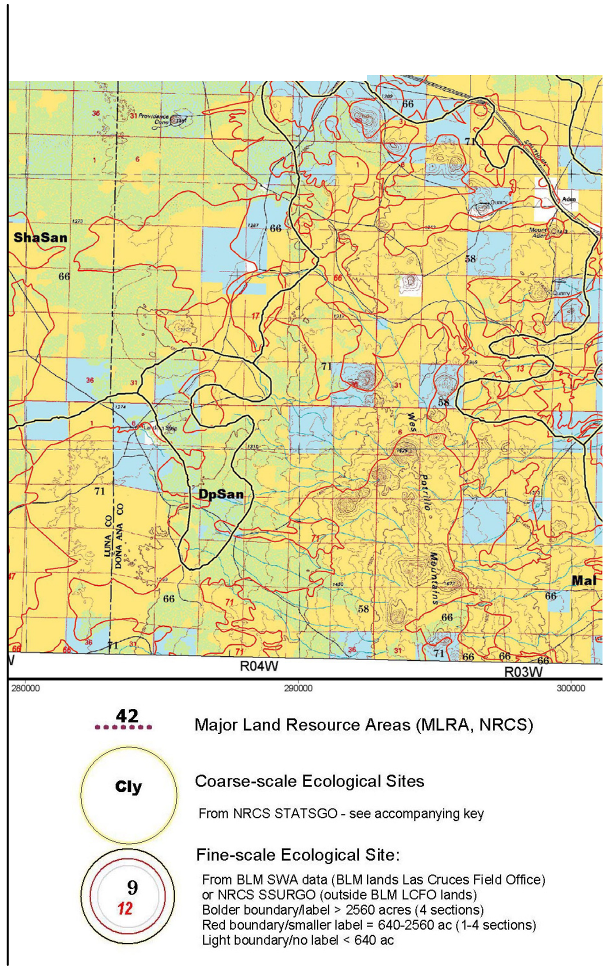
*BLM Bureau of Land Management, BOR Bur. of Reclamation, DOA Dept. of Agriculture, DOE Dept. of Energy, DOD Dept. of Defense, FS Forest Service, FWS Fish & Wildlife Service, I Indian, NPS National Park Service, P Private, S state, SGF, NM Game & Fish, SP NM parks reference condition grassland and non-reference condition tree-invaded states. Where experts disagreed with ESDs or newer ESDs were not available they mapped so-called expert-states, using ESDs as guides.

Fig. 3. Example REA Mapping Template



The REA mapping protocol was designed to produce consistent and repeatable results. Experts drew states onto clear film maps of ecological sites printed from NRCS county and area soil surveys (SSURGO, Soil Survey Staff). These, in turn, were overlaid onto 1:100,000 scale BLM topographic maps (Fig. 3). Ecological sites were correlated to soil types based on tables in the soil surveys, which ranged from roughly 1:23,000 to 1:64,000 scale. As an added reference, 1:250,000 scale ecological sites from the NRCS US General Soil Map (STATSGO, Soil Survey Staff) were also overlaid.

Experts sometimes mapped multiple states at the same location. This occurred where experts differed in their knowledge of the landscape, or in their interpretation of ESDs (since ESDs are largely descriptive and lack fixed quantitative criteria for assigning states). It also occurred where states could not be spatially distinguished because of a soil survey's map scale (e.g. some soil survey map units correlate to more than one ecological site). In sum, experts produced 194 state maps.

Building the GIS and Simplifying State Maps

Expert maps were scanned and georeferenced in ArcGIS (ESRI). These spatial layers were joined as a composite layer that included new, merged polygons where multiple states overlapped. State names and details were entered in a Microsoft Access database and spatially linked to the spatial layers. Areas with mulitple states mapped at the same location were partly resolved by having BLM nominate a lead expert. In this report we analyze this "simplified" state map and archived the original state map in the REA geodatabase (Appendix 2). Multiple states remain where BLM could not decide among experts, or where single experts mapped multiple states (e.g. due to soil survey scale). The resultant "unresolved class" is discussed in the *Glossary* and *A Primer for Understanding Results* (Box 3).

Step 2:
Attribute States

photo 8

In short: *REA-mapped NRCS states, as described in Natural Resources Conservation Service ecological site descriptions (ESDs), were attributed with ecological condition, drivers of non-reference condition and restoration opportunity. Ecological condition includes reference and non-reference condition and generalized states under reference condition and currently. Restoration opportunity includes restorative management options and restoration potential – the interpreted effort of different management options. REA-mapped expert-states were attributed with reference and non-reference condition based on expert knowledge. We attributed states by developing a table of state-specific values from ESDs and experts, then linking this table to the REA state map. The state map was then re-coded into state attribute maps. An example of a fully attributed NRCS state is an SD4 Loamy woody-invaded former grassland state. Based on its ESD, transition drivers are climate (drought), grazing (overgrazing), fire (altered fire regime) and vegetation related (reduced grass cover), and it is restorable through shrub control and prescribed grazing. Its restoration potential is moderate, since the ESD suggests woody plant removal but not soil rehabilitation.*

Tip: Expert-mapped states & their attributes - condition, drivers & restoration opportunity - can be reviewed & modified. See *Applying the REA* & Appendix 2. The State Attributes table (Appendix 1) records how state attributes were standardized for each state.

In Detail:

Ecological Condition

We attributed REA-mapped states described in Natural Resources Conservation Service ecological site descriptions (NRCS states) with ecological condition based on information contained in the ESDs. Ecological condition included reference or non-reference condition, and generalized states under reference condition and currently. Expert-states were simply attributed with reference or non-reference condition from information provided by experts. Ecological condition was standardized in the REA (illustrated in Tbl. 2, see State

Attributes Table, Appendix 1), so that each REA-mapped state was assigned one value from categories 1 and 2 below as follows:

1) Current reference or non-reference condition

(a) *Reference condition*: historic plant species at potential and ecological processes intact given natural variation in climate and disturbance processes, refers to time period of mid to late 1800s prior to intensified human land use.

(b) *Non-reference condition*: in departure from reference condition.

2) Generalized states

Both current vegetation and ecological processes, relative to reference condition, are diagnostic.

(a) *Reference condition grassland, savanna* or *shrubland/woodland*: historic grass and/or woody plant species at potential and ecological processes intact given natural variation in climate and disturbance regimes. Refers to time period of mid to late 1800s prior to intensified human land use. In *grassland* grass is dominant and woody plants have ≤ 5% canopy cover or are described as minor in ESD. In *savanna* grass and woody plant abundance are variable but both are characteristic and not described as minor in ESD. In *shrubland/woodland* woody plants are naturally dominant and grass is minor or absent. In *bare/annuals* bare ground and/or annual plants are naturally dominant.

(b) *Grass* or *woody invaded*: former grassland now with variably abundant grass (grass-invaded) or woody plant (woody invaded) species absent or minor under reference condition. Reference condition grass is dominant in both states, and in woody invaded state grass is abundant in shrub interspaces. Ecological processes may be impaired (e.g. reduced resource retention and soil erosion) but not excessively.

(c) *Woody dominated*: former grassland or savanna now dominated by woody plant species absent, minor or not dominant under reference condition. Reference condition grass species present in woody plant interspaces but patchy, low cover or otherwise altered from reference condition. Ecological processes moderately altered favoring woody plants (e.g. reduced resource retention and soil erosion in woody plant interspaces).

(d) *Grass* or *woody altered*: former grassland or savanna now dominated by grass or woody plant species absent, minor or not dominant under reference condition. Grass absent to sparse in woody plant interspaces and if present mostly restricted under woody plant canopies. Ecological processes functionally altered (e.g. high soil erosion).

(e) *Bare/annuals*: bare ground/annuals dominant and reference condition species absent to sparse. Ecological processes functionally altered (e.g. high soil erosion).

Generalized states were interpreted and standardized from the states described in ESDs because no formal generalized state classification existed at the time of this report. The

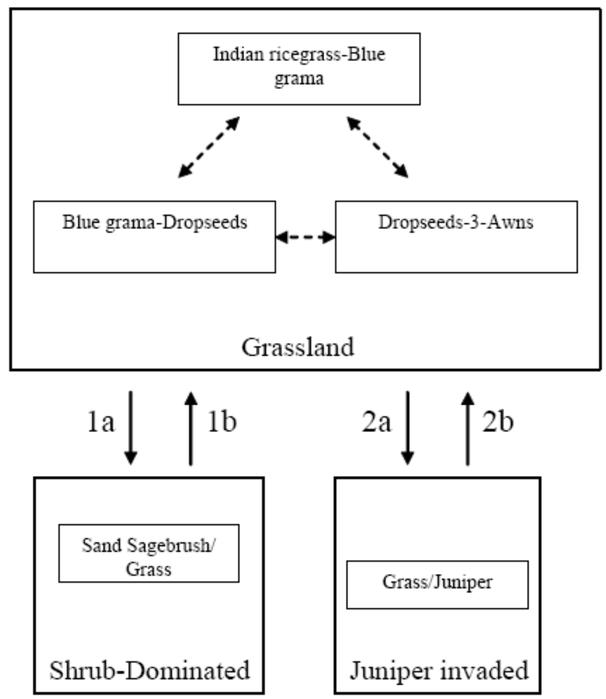
USDA Agricultural Reseach Service-Jornada Experimental and NRCS in New Mexico are currently developing descriptions and a key for generalized states. Ecological condition and other state attributes are illustrated below in Box 1.

Mapping NRCS States & Attributes from ESDs

Box 1

The REA maps states and state attributes from NRCS ecological site descriptions (ESDs). State attributes are: (1) *ecological condition* (current reference/non-reference condition, vegetation under reference condition and generalized states, (2) *transition drivers* that drive states to or between non-reference condition states (e.g. drought), and (3) *management options* that shift states towards or to reference condition (e.g. prescribed fire). Only newer ESDs have state-transition models depicting pathways between states.

The **WP2 Deep Sand** ESD state-transition model is shown on the right. States are the large boxes and arrows between them are transitions. In this model *Grassland* is the reference condition state. “Gaps” between states are ecological thresholds. “A” pathways are transition drivers and “B” pathways are management options. The REA would standardize and map the *Juniper-Invaded* state’s ecological condition as non-reference condiiton woody (tree)-invaded former grassland, transition drivers as vegetation-related, management options as vegetation and grazing management, and restoration potential as moderate.



1a. Loss of grass cover, resource competition.
1b. Brush control, prescribed grazing.

2a. Juniper seed dispersal, loss of grass cover, resource competition.
2b. Brush control, prescribed grazing.

Transition Drivers

Single or multiple transition drivers were assigned to REA-mapped NRCS states. Drivers shift an ecological site from reference to non-reference condition or from one non-reference condition state to another, as described in the ESDs. For example, the WP2 Deep Sand ESD (Box 1) proposes the Juniper-Invaded state follows grass cover loss and resource competition between grass and tree seedlings. We standardized transition drivers as *climate* (e.g. increased winter precipitation), *fire* (e.g. lack of fire), *grazing* (e.g. overgrazing), *soil* (e.g. erosion), and *vegetation* related (e.g. grass cover loss, resource competition, invasive seed supply) (illustrated inTbl. 2, see State Attributes Table in Appendix 1).

The REA identified transition drivers by their effects, not the process itself. Thus grass cover loss (Box 1) may have occurred under reference condition, for example with moderate climate variablility. Only if it facilitated a state shift, either alone or with other processes like long term drought and overgrazing, is it considered a driver. The time period that transition drivers operated is not specified in ESDs or the REA and can vary. For example, grass cover loss may have contributed to tree invasion previously and/or be having impacts in the present.

Restoration Opportunity

Restoration opportunity has two components: (1) state-specific management options for restoration, and (2) interpreting restoration potential based on these options. Management options were assigned to REA-mapped NRCS states. They specify actions for shifting a non-reference condition state towards or to reference condition. They also include options to maintain reference condition, if described in ESDs. The REA lists all options without specifying their target states (management outcomes). That information can be obtained from the ESDs. Standardized management options (illustrated in Tbl. 2, see State Attributes Table in Appendix 1) are *fire* (e.g. prescribed fire), *grazing* (e.g. prescribed grazing), *soil* (e.g. gully repair) and *vegetation* management (e.g. remove woody plants and restore grass cover).

Restoration potential is The Nature Conservancy's interpretation of the management effort needed to maintain reference condition, or shift non-reference condition states towards or to reference condition. Restoration potential was attributed for NRCS states (illustrated in Tbl. 2, see State Attributes Table in Appendix 1). Management options for reference condition states were coded *maintenance*. ESDs only indicated maintenance for some REA-mapped reference condition states, and these were for fire management (e.g. prescribed fire). Restoration potential for non-reference condition states distinguishes options that include or exclude soil management (soil or hydrological work) or plant cultivation (e.g. watering). Those that *exclude soil management/cultivation* were interpreted as requiring moderate effort; those that *include soil management/ cultivation* were interpreted as requiring high effort.

Management options for the WP2 Deep Sand Juniper-Invaded state (Box 1) are woody plant control and prescribed grazing. The type of control is unspecified, but we assume mechanical, fire and/or chemical. We interpreted any of these as requiring moderate effort, compared to soil management or cultivation. Our assignment of restoration potential is generalized, and at project level would require an evaluation of specific factors, such as exact treatment methods and costs.

Technical Procedure

The technical procedure for attributing states starts with the State Attributes Table (illustrated in Tbl. 2, complete table is in Appendix 1) that crosswalks NRCS states to ecological condition, transition drivers and restoration opportunity, and expert-states to reference or non-reference condition. This involved interpreting and databasing state-specific attributes from ESDs and experts. The table was linked to the REA state map, which was re-coded to produce several maps. The main REA maps are: (1) NRCS and expert-states, (2) reference/non-reference condition, (3) generalized states under reference condition, (4) current generalized states overlaid onto those under reference condition, (5) transition drivers, (6) management options, and (7) restoration potential.

Table 2. Extract from State Attributes Table

REA-mapped NRCS and expert-states were attributed with ecological condition, transition drivers and restoration opportunity based on ESDs and expert information. Results were entered in the State Attributes table, which was linked to the REA state map. This table extracts a small portion of the State Attributes table for illustration, and only NRCS states are shown. See Appendix 1 for the complete table.

Key (in order of columns left to right):
1. Y yes, **N** no; **2. RG** or **RGS** reference condition grassland or savanna**;**
3. I invaded, **D** dominated, **GA** grass- altered, **GW** woody- altered; **4-5.** related to **C** climate, **F** fire, **Gr** grazing, **S** soil or **V** vegetation drivers (4) or management (5);
6. M maintenance, **NSC** no soil mgt/cultivation, **SC** soil mgt/cultivation

State (NRCS name)	1. Reference Condition	2. Ref Cond Generalized State	3. Current Generalized State	4. Transition Drivers	5. Management Options	6. Restoration Potential: Interpreted Effort
SD2--Shallow Sandy--Black Grama-Dominated Grassland (R)	Y	RG	RG	na	F	M
SD2--Shallow Sandy--Black Grama-Limited Grassland	N	RG	GI GA	F--V--G--S--C	F--S	SC
SD2--Shallow Sandy--Bunchgrasses/Mesquite	N	RG	WI	F--V--G--C	F--V	SC
SD2--Shallow Sandy--Mesquite Shrubland	N	RG	WA	V--G--S	V--S	SC
SD2--Shallow Sandy--Shrub-Invaded Grasslands	N	RG	WI	F--V--G--C	F--V	SC
SD3--Bottomland-Grassland (R)	Y	RG	RG	na	F	M
SD3--Bottomland--Mesquite-Dominated	N	RG	WA	V--G--S	V--G--S	SC
SD3--Bottomland--Saltcedar	N	RG	WI WA	F--V--G--S	F--V--S	SC
SD3--Deep Sand--Grassland (R)	Y	RGW	RGW	na	F	M
SD3--Deep Sand--Shinnery Oak-Dominated	N	RGW	WD	F--V--G--S--C	F--V--G	NSC
SD3--Gravelly--Shrub-Dominated	N	RGW	WD	F--V--G--S--C	F--V--G	NSC
SD3--Gravelly--Shrubland	N	RGW	WA	V--S	V--G--S	SC
SD3--Limy--Shrub-Dominated	N	RGW	WD	F--V--G-S--C	F--V--G	NSC
SD3--Limy--Shrubland	N	RGW	WA	V--G--S--C	V--G--S	SC

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G. Results

1. A Primer for Understanding Results
2. Ecological Condition
   - States
   - Current Reference and Non-Reference Condition
   - Generalized States under Reference Condition
   - Generalized States: comparing current to those under reference condition
   - Finer-scale REA Analyses
3. Transition drivers
4. Restoration Opportunity
   - Management Options
   - Restoration Potential

TAKE A LOOK:

- CONSIDERING SCALE (BOX 2)
- WHAT THE REA MAPPED (FIG. 4)
- THE UNRESOLVED CLASS (BOX 3)
- CURRENT REFERENCE & NON-REFERENCE CONDITION (FIG. 5)
- GENERALIZED STATES UNDER REFERENCE CONDITIION (FIG. 6)
- GENERALIZED STATES: COMPARING CURRENT TO REFERENCE CONDITION (FIG. 7)
- FINER-SCALE REA ANALYSES (BOX 4)
- MULTIPLE TRANSITION DRIVERS (BOX 5)
- DRIVERS OF DEPARTURE FROM REFERENCE CONDITION (FIG. 8)
- MULTIPLE MANAGEMENT OPTIONS (BOX 6)
- RESTORATIVE MANAGEMENT OPTIONS (FIG. 9)
- INTERPRETED RESTORATION POTENTIIAL (FIG. 10)

Tip: The REA is a dynamic & updateable resource. Current & future states can be checked & updated from field reconnaissance & remote sensing. The unresolved class can be further resolved, new areas mapped, & REA state attributes revised. New information from ESDs or elsewhere can be integrated. The REA geodatabase is update-ready. See *Applying the REA* & Appendix 2.

1. A Primer for Understanding Results


photo 9

In short: *The REA mapped 7.5 million acres of BLM public land and 14.2 million acres overall in southern New Mexico. REA maps identify broad patterns in ecological condition and restoration opportunity across this area. Using the REA with other data that span multiple scales would provide the most complete picture of ecological condition and restoration opportunity.*

REA results should also be viewed with the following in mind:

1. The spatial accuracy of the REA was not assessed, so REA maps and reported acres are estimates. Accuracy for specific locations is not known.

2. The REA is mid-scale but map scale varied across the assessment area. Mapping intensity also varied (some areas are completely mapped, some partly). Likewise, the REA's two "state types" – Natural Resources Conservation Service (NRCS) and expert-states – were mapped to different extent and attributed differently. Comparing REA results between areas, then, must account for this variability.

3. Areas mapped to more than one state were largely resolved by "lead experts", but that excluded alternative opinion. Some areas with multiple states remain, resulting in an unresolved class that complicates the interpretation of REA results and comparisons.

4. NRCS ecological site descriptions (ESDs) are a significant resource for ecological assessment, but like any classification have limitations. ESDs: (a) generalize over large areas, (b) are largely descriptive and not quantitative, (c) can vary in nomenclature, underlying data and specificity, and (d) may lack information about ecological function in terms of the size and spatial configuration of states, and cross-scale dynamics (discussed below). The REA limited interpretation of ESDs, but some interpretation was necessary.

6. The REA is based on expert knowledge, which offers different advantages than remote sensing-based maps.

Tip: Use the REA alongside multi-scale data, like national LANDFIRE maps (www.landfire.gov), ARS-Jornada Experimental Range state maps (http://usda-ars.nmsu.edu) & BLM land health assessments.

In Detail: To better understand REA results it is necessary to consider the following points. The REA was mapped at roughly 1:23,000-1:100,000 scale (Box 2). This is appropriate for assessing major ecological trends, general planning and land management. It is best applied to large areas, such as the REA project area and BLM field offices. The REA can be informative for smaller areas, like resource planning units and watersheds. But accuracy may decline at higher resolution, so REA results should be interpreted carefully and corroborated with finer scale data. Maps and results given in acres are approximations that have not been assessed for accuracy. As with any regional map, the REA may be too coarse to apply to specific locations.

Considering Scale

Box 2

1. Mapping Scale

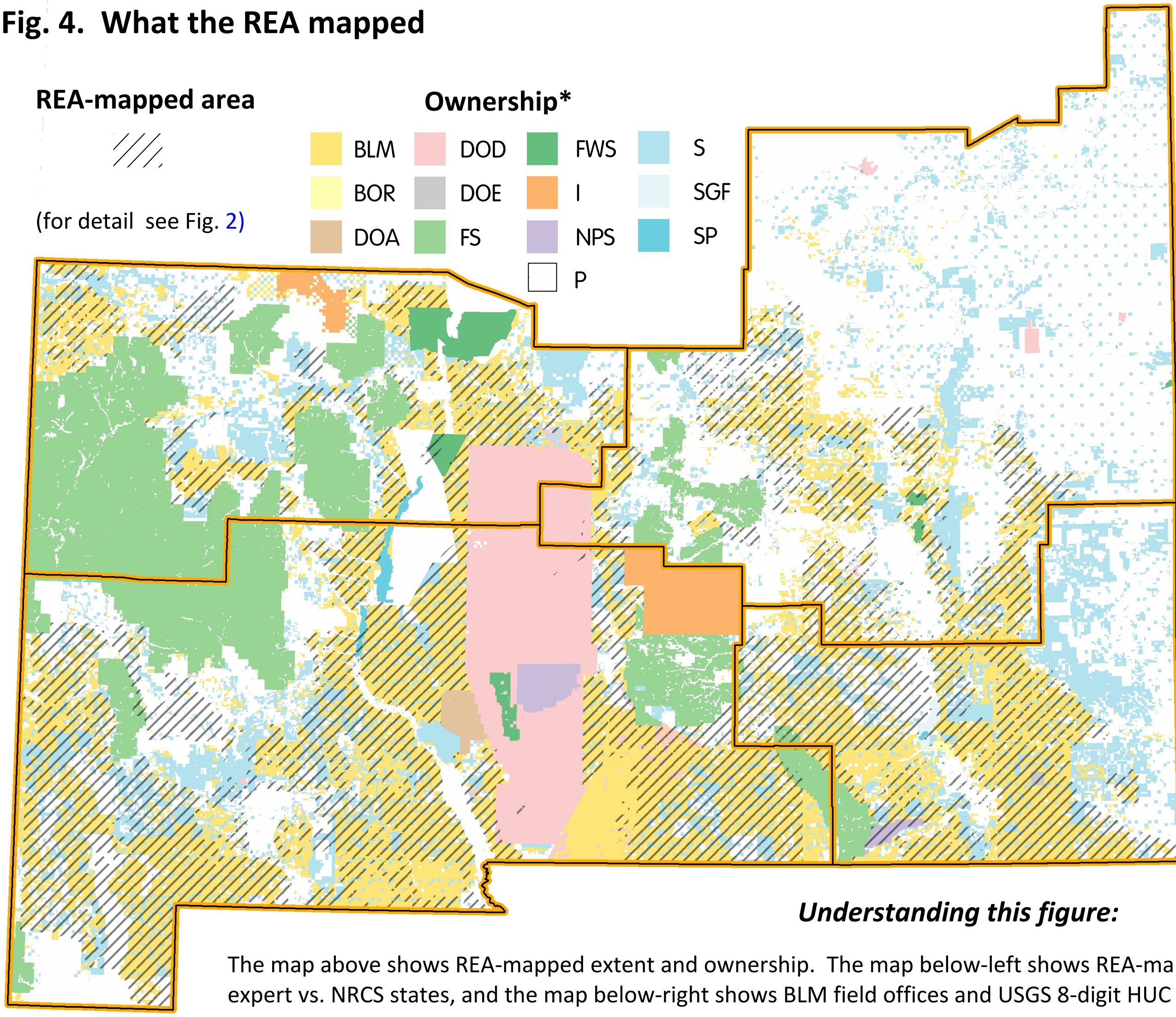
The REA is approximately mid-scale but varied due to its mapping templates – BLM topographic maps and NRCS soil surveys. The BLM maps are 1:100,000 scale and county and area soil surveys in New Mexico are about 1:23,000 to 1:63,000 scale (Soil Survey Staff, SSURGO). Since experts used both for mapping, REA maps can reflect this scale range. A third template, the NRCS US General Soil Map, was occasionally used by experts and is 1:250,000 scale (Soil Survey Staff, STATSGO). Scale also varied when experts "lumped or split" ecological sites, based on field experience. Another way of looking at this is that the REA, at its coarsest, is about 1:250,000 scale, it is typically 1:23,000-1:100,000 scale, but in some places it is finer-scale.

2. Ecological Scale

This report summarizes ecological condition and restoration opportunity mapped across a large area. Such wide-ranging information is critical for providing a comprehensive picture to policy makers, land managers and the public. However, generalized information can oversimplify the underlying ecology and management of these ecosystems. In particular, some issues of "ecological scale" are not typically addressed by ESDs, and so not reflected in the REA. These include: (1) ecological dynamics can proliferate across spatial scales (e.g. woody invasion can accelerate from patch to landscape scales), (2) the spatial configuration of ecological sites and states is a factor (e.g. erosional runoff or lack of fire in one state can affect others), and (3) different size reference condition areas may have different abilities to support sustaining processes (e.g. viability may increase with size but it also depends on 1 and 2). Underlying these ideas is emerging evidence that cross-scale dynamics exert a major influence on ecosystems, including some found in southern New Mexico (Peters et al. 2006, Strange, 2007). REA-mapped reference condition states (Fig. 5), for example, lack information about such issues. Some of these areas may be at risk by their small size, processes occurring in adjacent states, and whether ecological dynamics are operating at patch or landscape scale. As information accumulates through research and monitoring the ability to assess the viability of reference condition states and other issues related to ecological scale will advance.

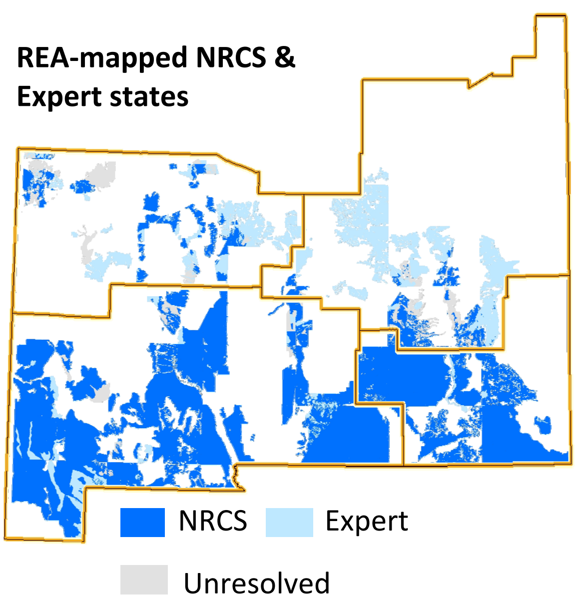
The REA mapped 7.5 million acres (72%) of BLM land and 14.2 million acres (32%) overall (Fig. 4). The extent of the REA map varied across this area. For example, over 80% of BLM land was mapped in ten HUC-8 digit watersheds, and less than 50% in seven. The REA mapped both Natural Resource Conservation Service (NRCS) and expert-states. Since we attributed expert-states with reference and non-reference

Fig. 4. What the REA mapped



Understanding this figure:

The map above shows REA-mapped extent and ownership. The map below-left shows REA-mapped expert vs. NRCS states, and the map below-right shows BLM field offices and USGS 8-digit HUC watersheds that include REA-mapped areas. The table (next page) reports: (1) acres of all land and BLM land in the REA project area, and (2) acres of all REA-mapped land and BLM land, and percent REA-mapped of all land and BLM land in the project area. Expert and NRCS states, as a percent of all REA-mapped land and REA-mapped BLM land, are shown. Results are for the project area, BLM field offices and HUC-8 watersheds. For example, the Carlsbad field office (CFO) contains 2.1 million acres of BLM land of which 1.6 million, or 77%, was mapped by the REA. One percent of REA-mapped CFO BLM land was mapped to expert-states, 98% to NRCS states and <1% was unresolved (both expert and NRCS states).

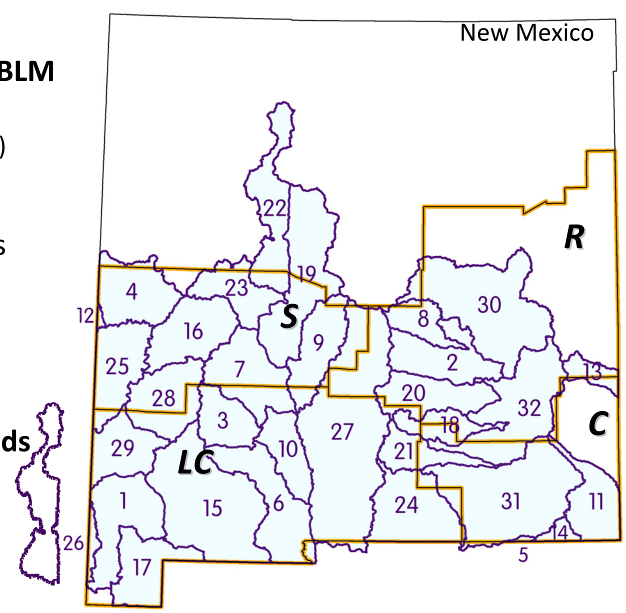


Southern NM BLM field offices
(REA project area)

C – Carlsbad
LC – Las Cruces
R – Roswell
S – Socorro

USGS 8-digit HUC watersheds

(names on next page)



*BLM Bureau of Land Management, BOR Bur. of Reclamation, DOA Dept. of Agriculture, DOE Dept. of Energy, DOD Dept. of Defense, FS Forest Service, FWS Fish & Wildlife Service, I Indian, NPS National Park Service, P Private, S state, SGF, NM Game & Fish, SP NM parks

Fig. 4 continued:

What the REA mapped

	Project Area: acres (millions)		REA Map: acres (millions) and % mapped of all land	state types			REA Map: acres (millions) and % mapped of BLM land	state types		
	all land	BLM land		expert-states*	NRCS-states*	unresolved*		expert-states+	NRCS-states+	unresolved+
REA Project Area: (BLM field offices)	*45.0*	*10.5*	14.2 (32%)	20%	75%	5%	7.5 (72%)	19%	78%	3%
Carlsbad	6.3	2.1	3 (48%)	2%	98%	<1%	1.6 (77%)	1%	98%	<1%
Las Cruces	16.0	5.4	7.4 (46%)	7%	90%	2%	4.1 (76%)	8%	91%	2%
Roswell	14.0	1.5	2.2 (16%)	67%	23%	10%	0.9 (62%)	65%	26%	8%
Socorro	8.7	1.5	1.6 (19%)	47%	35%	18%	0.9 (59%)	54%	35%	12%
USGS 8-digit HUC watersheds:										
1 Animas Valley	1.4	0.5	1.1 (79%)	6%	94%	<1%	0.5 (92%)	8%	92%	0%
2 Arroyo Del Macho	1.2	0.4	0.4 (35%)	87%	6%	7%	0.2 (56%)	84%	6%	10%
3 Caballo	0.8	0.2	0.2 (27%)	10%	74%	15%	0.1 (70%)	12%	73%	15%
4 Carrizo Wash	1.2	0.4	0.3 (29%)	17%	45%	38%	0.2 (49%)	19%	54%	27%
5 Delaware	0.03	0.02	0.02 (75%)	6%	94%	0%	0.01 (76%)	2%	98%	0%
6 El Paso-Las Cruces	1.5	0.9	1 (64%)	<1%	100%	0%	0.7 (79%)	<1%	100%	0%
7 Elephant Butte Reservoir	1.4	0.2	0.3 (23%)	25%	64%	11%	0.2 (77%)	22%	64%	14%
8 Gallo Arroyo	0.6	0.1	0.4 (58%)	100%	0%	0%	0.1 (82%)	100%	0%	0%
9 Jornada Del Muerto	1.1	0.3	0.3 (28%)	73%	24%	3%	0.2 (74%)	70%	28%	3%
10 Jornada Draw	0.8	0.4	0.5 (56%)	<1%	100%	0%	0.4 (95%)	<1%	100%	0%
11 Landreth-Monument Draws	1.0	0.2	0.3 (31%)	1%	99%	0%	0.2 (77%)	<1%	100%	0%
12 Little Headwaters	0.03	0.01	<0.01 (0.1%)	0%	0%	100%	<0.01 (0.4%)	0%	0%	100%
13 Lost Draw	0.3	0.01	0.01 (5%)	100%	0%	0%	<0.01 (0.63%)	100%	0%	0%
14 Lower Pecos-Red Bluff Reservoir	0.2	0.1	0.2 (98%)	0%	100%	0%	0.1 (99%)	0%	100%	0%
15 Mimbres	2.9	1.0	1.3 (45%)	2%	92%	6%	0.6 (62%)	3%	94%	3%
16 Plains of San Agustin	1.3	0.1	0.2 (15%)	23%	52%	25%	0.04 (41%)	42%	39%	20%
17 Playas Lake	1.1	0.5	0.9 (82%)	33%	66%	1%	0.5 (97%)	31%	68%	1%
18 Rio Felix	0.6	0.2	0.2 (39%)	1%	79%	20%	0.1 (70%)	2%	87%	12%
19 Rio Grande-Albuquerque	2.1	0.2	0.2 (11%)	44%	56%	<1%	0.1 (62%)	51%	49%	<1%
20 Rio Hondo	1.1	0.1	0.2 (15%)	47%	31%	22%	0.1 (53%)	35%	54%	11%
21 Rio Penasco	0.7	0.1	0.3 (41%)	0%	100%	0%	0.1 (97%)	0%	100%	0%
22 Rio Puerco	1.4	0.3	0.1 (5%)	36%	35%	29%	0.1 (20%)	32%	37%	31%
23 Rio Salado	0.9	0.1	0.1 (6%)	24%	71%	5%	0 (28%)	36%	64%	0%
24 Salt Basin	1.5	0.9	1.3 (84%)	4%	96%	<1%	0.8 (90%)	6%	94%	<1%
25 San Francisco	1.2	<0.1	<0.01 (<0.1%)	100%	0%	0%	<0.01 (0.25%)	100%	0%	0%
26 San Simon	0.1	0.1	0.04 (37%)	<1%	100%	0%	0.1 (53%)	0%	100%	0%
27 Tularosa Valley	4.2	0.9	0.8 (19%)	28%	66%	6%	0.5 (51%)	30%	67%	3%
28 Upper Gila	1.3	0.1	0.1 (9%)	100%	0%	0%	0.1 (93%)	100%	0%	0%
29 Upper Gila-Mangas	1.0	0.3	0.4 (45%)	5%	91%	4%	0.2 (67%)	6%	94%	<1%
30 Upper Pecos	2.7	0.2	0.3 (10%)	92%	8%	1%	0.1 (37%)	84%	16%	1%
31 Upper Pecos-Black	2.8	1.5	1.8 (63%)	2%	98%	<1%	1.1 (73%)	2%	98%	<1%
32 Upper Pecos-Long Arroyo	2.0	0.6	1.1 (53%)	36%	54%	11%	0.5 (78%)	44%	48%	9%

*% of REA-mapped all land, +% of REA-mapped BLM land. The unresolved class, and so the area mapped to each attribute (e.g. reference/non-reference condition etc.), will differ for each analysis. See *A Primer for Understanding Results* for background.

condition, but not the other ecological condition components, transition drivers or restoration opportunity, as we did for NRCS states, a portion of the REA map is fully attributed (NRCS states), and a portion is partly attributed (expert-states). Expert-states are common in the BLM Roswell and Socorro field offices, since those areas lack newer NRCS ecological site descriptions (ESDs). Comparisons of REA results between BLM field offices, watersheds or other units must consider such variability in the REA map.

Selecting lead experts to resolve multiple states had advantages and disadvantages. It simplified REA results but excluded other opinion. Some multiple states remain, yielding an “unresolved class” with values that conflict, like overlapping reference and non-reference condition states. Until this class is resolved REA results may be under or over-estimated. For example, once resolved, overlapping reference and non-reference condition states would be re-assigned to one or the other, changing both acres and percentages. Another point is that the size of the unresolved class varied by analysis (Box 3). An area mapped to both reference condition grassland and savanna, for example, is resolved in terms of reference/non-reference condition but unresolved for current generalized states. *Different size unresolved classes mean that acres and percentages may not agree between analyses, and related categories of different analyses, such as management options and restoration potential, may not match-up.*

ESDs are an important resource for ecological assessment but like any classification they have limitations. ESDs are generalized across large areas. Thus, similar to limitations of mapping scale, a state may not be tailored to a specific location. Since states are: (1) largely defined by descriptive, rather than quantitative criteria, (2) state nomenclature can be inconsistent, and (3) there was no formal classification of generalized states in ESDs at the time of this report, their standardization into generalized states in the REA required some interpretation. For example, it was sometimes difficult to distinguish woody-dominated from woody-altered states, and experts proposed some grass-invaded states not recognized in ESDs. Research to support ESDs varies by ecosystem; in particular the historical role of fire is not well understood in desert grasslands of southern New Mexico. ESDs vary in specificity. Some specify management options like prescribed fire and modified grazing to reduce woody plants; others cite woody plant control but do specify treatments. Likewise, transition drivers can be ambiguous in ESDs. Since we attributed these cateogries from ESDs, such unspecified drivers and options may be under-estimated in REA results. This is expanded upon in Section G., *Applying the REA*.

ESDs may not address the ecological functionality of states in terms of size or spatial configuration. For example, the viability of an REA-mapped reference condition state may decline if it has decreased relative to its reference condition size (that of its associated ecological site), or due to proximity to non-reference condition states. ESDs also may lack data about spatial and temporal rates of change across scales. Recent literature (e.g. Peters et. al, 2006) suggests ecological processes accelerate from finer to broader scales (e.g. bare soil patches coalesce to amplify erosion rates). Such information could alert managers to state shifts that incur more risk than others. Size, spatial configuration and cross-scale change are discussed further in Box 2.

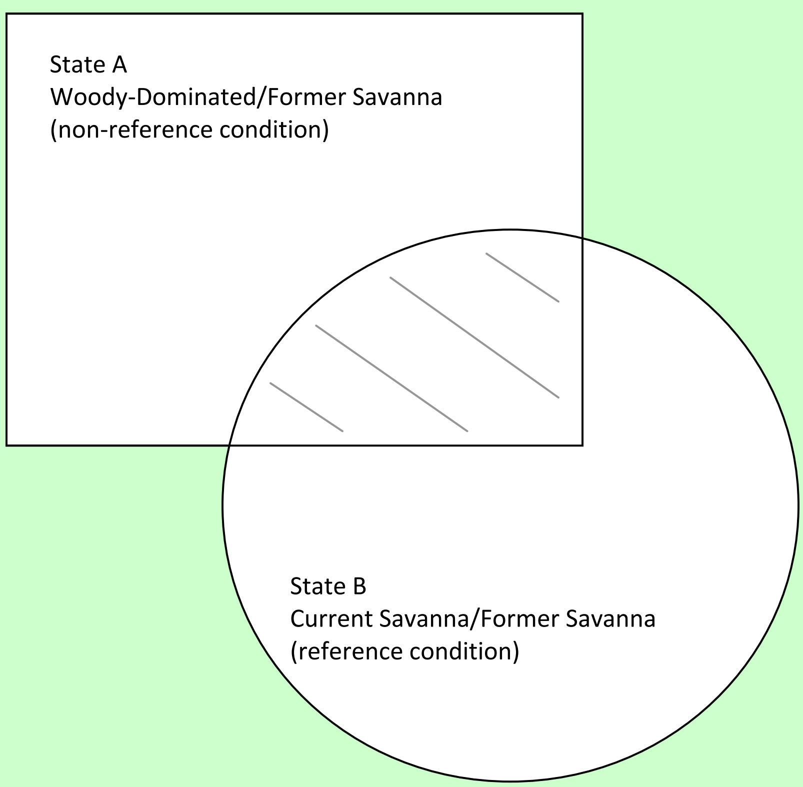
As an expert assessment, the REA profits from individual field experience. Yet it lacks the relative objectivity possible from remote sensing-based maps. Remote sensing, in contrast, can suffer from a lack of expert input, and often achieves only fair accuracy.

The Unresolved Class

Box 3

The REA unresolved class includes areas mapped to more than one state where state attribute values that conflict. This occurred where experts disagreed with each other based on field experience and mapped the same location to different states, or where ecological sites could not be spatially distinguished due to mapping scale (e.g. where a soil survey used as a mapping template correlated several ecological sites to one soil map unit). The unresolved class was partly resolved by asking BLM staff to designate a “lead expert” where states conflict, but some unresolved areas remain.

In this example, State A is a non-reference condition woody-dominated former reference condition savanna, and State B is a current reference condition savanna. The overlapping area (gray) is a state conflict. This includes three analyses: reference/non-reference condition generalized states under reference condition and generalized states currently. Reference/non-reference condition and current generalized states are unresolved in the overlapping area. In contrast, the generalized states under reference condition would be for both states, so there is no unresolved area. This illustrates how the unresolved class can differ in size between REA analyses – the unresolved class is smallest for the analysis of generalized states under reference condition. When analyses are combined (e.g. generalized states under reference condition vs. current) the unresolved class is that of both input analyses. The unresolved class is reported at the end of each figure in the results that follow (Fig.’s 5 and 7-10), but is excluded from the figures themselves for simplicity. Thus total arces in these figures differ between analyses (since the unresolved class is not shown) and some categories (e.g reference condition) may not match between analyses. Comparisons of acres and percentages, then, between analyses should take this into account.



2. Ecological Condition

photo 10

In short: *Ecological condition is reflected by REA-mapped states and their aggregation into current reference or non-reference condition and generalized states under reference condition and currently. The REA mapped over 400 different states based on NRCS ecological site descriptions and expert knowledge. Thirty-four percent of REA-mapped BLM land, excluding the unresolved class, was mapped in reference condition and nearly twice that area, 66%, is in non-reference condition. Under reference condition, 32% would be grassland and 68% savanna states (<1% would be woodland). Fifty-nine percent of former reference condition grassland is now woody-invaded or woody-altered. Another 9% is grass-altered (dominated by non-historic species) and is altered by 3% bare ground and annual plants. Twenty-nine percent of grassland remains in reference condition. Of former reference condition savanna, 59% is woody-dominated or woody-altered. One percent is bare/annuals, and the remaining 40% was mapped as still in reference condition.*[4]

Tip: Other resources for reference/non-reference condition are Fire Regime Condition Class (http://frames.nbii.gov) & Indicators of Rangeland Health (http://www.blm.gov/nstc/pubs.html)

In Detail[2]:

States

The REA mapped 405 states in the project area, including 146 NRCS and 259 expert-states. These range from reference condition grassland and savanna (e.g. Black grama-Tobosa and Grass/Shrub Mix) to former grasslands now dominated by bare ground or woody plants (e.g. Gullied, Sandsage-Dominated). REA-mapped states fall within 134 ecological sites which span four NRCS Major Land Resource Areas (MLRAs) – Arizona and New Mexico Mountains, Pecos-Canadian Plains and

[4]Percentages exclude areas not mapped by the REA and exclude the unresolved class. The unresolved class differs in size for each analysis and is reported at the end of most figures in the Results section. Comparisons, then, between analyses as well as between BLM field offices and watersheds (since REA mapping extent varied), should account for this. See *A Primer for Understanding Results* for more information.

Valleys, Southern Desertic Basins, Plains and Mountains, and New Mexico and Arizona Plateaus and Mesas (see http://www.nm.nrcs.usda.gov/technical/fotg/section-2/esd.html for a general distribution map). While the individual REA-mapped states provide the most specific information about ecological condition and other state attributes, they were too numerous to review in this report. Instead, we report results for current reference/non-reference condition and generalized states under reference condition and currently, which provide summary measures of ecological condition. The actual REA state map can be examined in the accompanying geodatabase (Appendix 2) and states and their attributes are documented in Appendix 1, *REA Details*.

Current Reference and Non-Reference Condition

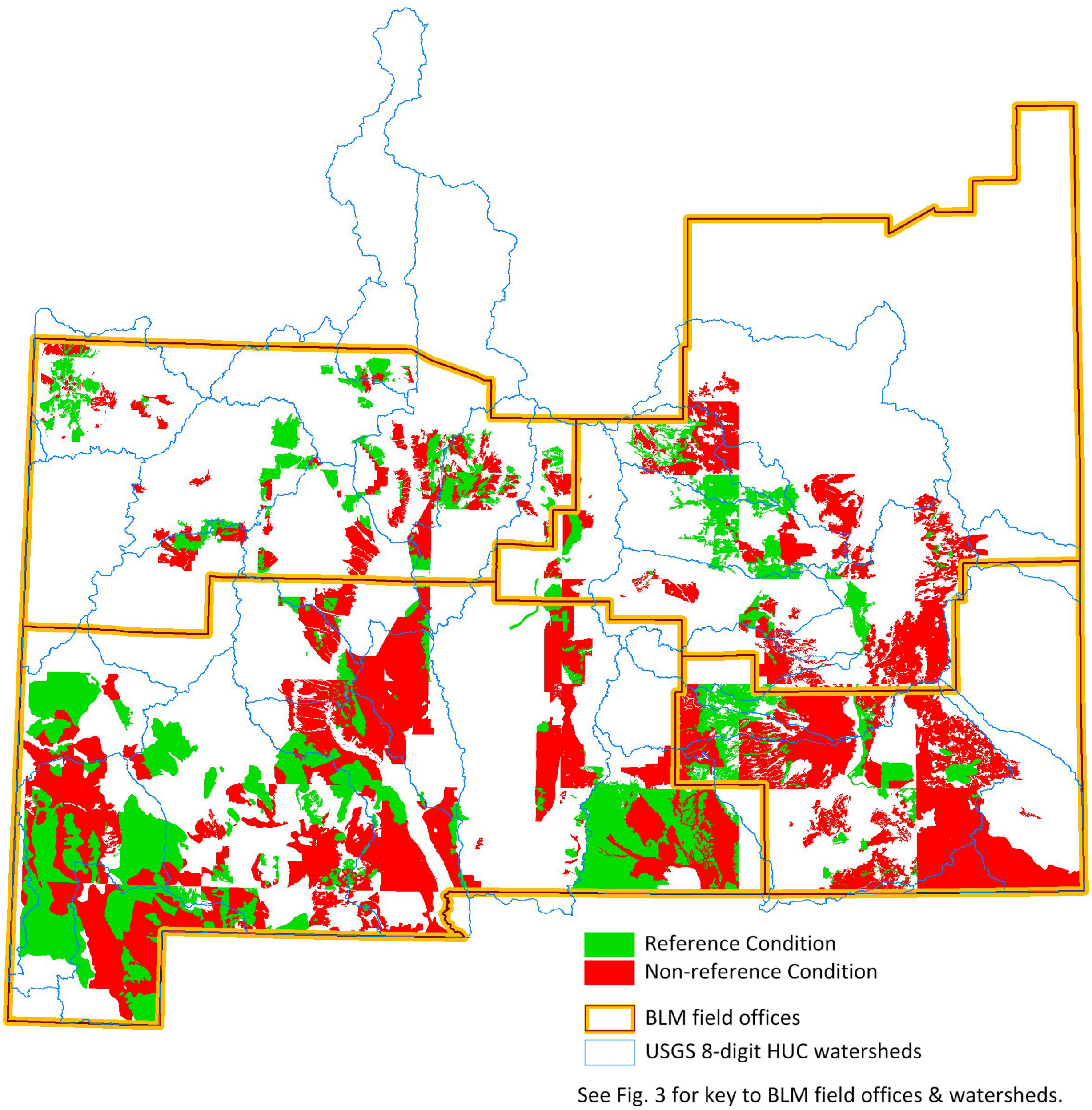
Just over one-third (34%) of the 7 million acres of REA-mapped BLM land, excluding the unresolved class, was mapped as reference condition and 66% was mapped as non-reference condition (Tbl. 1, Fig. 5). Reference condition ranged from 16% to 45%, and non-reference condition from 55% to 84%, among the four BLM field offices. Reference condition covered considerably smaller proportions than non-reference condition, except in the Socorro field office where results were more similar (45% reference vs. 55% non-reference condition area). Reference and non-reference condition varied widely among HUC-8 digit watersheds. For example, while extensive non-reference condition area characterized many watersheds, it was substantially lower in several, such as Salt Basin. The trend, though, was for higher non-reference condition area. On average, 63% of REA-mapped BLM land in these watersheds was mapped as non-reference condition and 34% as reference condition.

Results for all land in the REA project area had a similar pattern of higher non-reference condition area. Reference condition accounted for 35% of the 12.8 million acres mapped by the REA (excludes the unresolved class), and non-reference condition 65%. This trend generally held across field offices and HUC-8 digit watersheds, as did the variability of results seen for BLM land.

Generalized States under Reference Condition

Generalized states that would occur under reference condition were estimated by summing areas of current REA-mapped reference condition states and those reference condition states that correspond to current REA-mapped non-reference condition states, according to ESDs. For REA-mapped BLM land, excluding the unresolved class, this was 32% grassland and 68% savanna generalized states (Fig. 6). Savanna includes grass/shrub and grass/tree states. The greater extent of savanna is likely due to the predominance of physical environments (soils and terrain) that ESDs describe as supporting mixed grass and woody plant states under reference condition. For example, 46% of this area was mapped as gravelly or hills ecological sites in the REA. Woodland was not mapped, possibly because most REA-mapped areas were lower elevation. Results for all land in the REA project area were similar – grassland would cover 36% and savanna 64% We do not present results for BLM field offices or watersheds because we compared generalized states currently vs. those under reference condition in the next analysis.

Fig. 5. Current Reference and Non-reference Condition



Understanding this figure:

Current reference/non-reference condition applies to REA-mapped NRCS and expert-states. The first two columns of the table (next page) show the acres of the project area and BLM land mapped to reference and non-reference condition by the REA. The middle columns show reference and non-reference condition as a percent of REA-mapped all land. The last two columns show the same but as a percent of REA-mapped BLM land. Results are reported for the project area, BLM field offices and USGS 8-digit HUC watersheds, and exclude the unresolved class. For example, 400,000 acres (rounded) of BLM land in the Animas Valley watershed (Fig. 4) was mapped to NRCS and expert-states by the REA, and of that, 52% was mapped as reference condition.

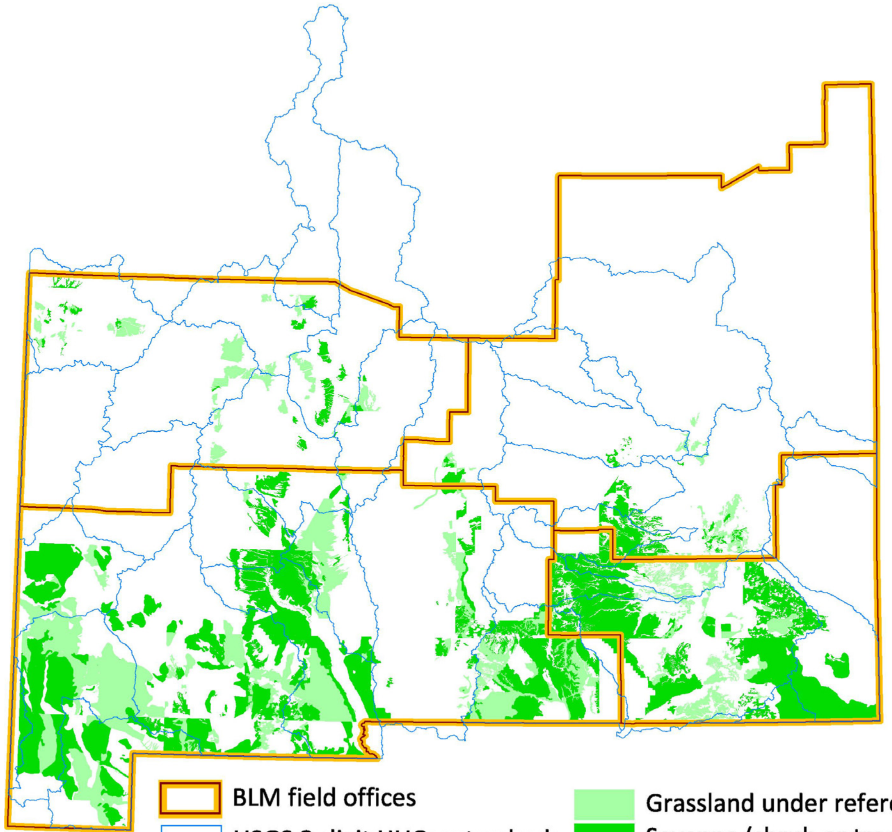
Fig. 5 continued:

Current Reference and Non-reference Condition

	REA-mapped acres (millions)		% of REA-Mapped: all land		% of REA-Mapped: BLM land	
	all land	BLM land	Reference	Non-Reference	Reference	Non-Reference
REA Project Area: (BLM field offices)	*12.8*	*7.0*	*35%*	*65%*	*34%*	*66%*
Carlsbad	2.5	1.4	18%	82%	16%	84%
Las Cruces	7.1	4.0	41%	59%	39%	61%
Roswell	1.9	0.8	31%	69%	31%	69%
Socorro	1.3	0.8	48%	52%	45%	55%
average:	*3.2*	*1.8*	*34%*	*66%*	*33%*	*67%*
USGS 8-digit HUC watersheds:						
1 Animas Valley	1.1	0.4	58%	42%	52%	48%
2 Arroyo Del Macho	0.4	0.2	63%	37%	53%	47%
3 Caballo	0.2	0.1	18%	82%	22%	78%
4 Carrizo Wash	0.2	0.1	58%	42%	57%	43%
5 Delaware	0.0	0.0	5%	95%	5%	95%
6 El Paso-Las Cruces	0.9	0.7	20%	80%	21%	79%
7 Elephant Butte Reservoir	0.3	0.2	29%	71%	25%	75%
8 Gallo Arroyo	0.3	0.1	49%	51%	52%	48%
9 Jornada Del Muerto	0.3	0.2	45%	55%	46%	54%
10 Jornada Draw	0.5	0.3	5%	95%	5%	95%
11 Landreth-Monument Draws	0.3	0.1	0.1%	100%	0.2%	100%
12 Little Headwaters	0.0	0.0	0%	0%	0%	0%
13 Lost Draw	<0.1	<0.1	0%	100%	0%	100%
14 Lower Pecos-Red Bluff Reservoir	0.2	0.1	0%	100%	0%	100%
15 Mimbres	1.2	0.6	48%	52%	42%	58%
16 Plains of San Agustin	0.2	0.1	74%	26%	64%	36%
17 Playas Lake	0.9	0.5	38%	62%	43%	57%
18 Rio Felix	0.1	0.1	37%	63%	33%	67%
19 Rio Grande-Albuquerque	0.2	0.1	29%	71%	25%	75%
20 Rio Hondo	0.1	0.1	37%	63%	39%	61%
21 Rio Penasco	0.2	0.1	30%	70%	36%	64%
22 Rio Puerco	0.1	0.04	77%	23%	72%	28%
23 Rio Salado	<0.1	<0.1	81%	19%	78%	22%
24 Salt Basin	1.2	0.7	55%	45%	65%	35%
25 San Francisco	<0.1	<0.1	0%	100%	0%	100%
26 San Simon	0.1	<0.1	82%	18%	85%	15%
27 Tularosa Valley	0.8	0.4	25%	75%	30%	70%
28 Upper Gila	0.1	0.1	37%	63%	50%	50%
29 Upper Gila-Mangas	0.4	0.2	63%	37%	55%	45%
30 Upper Pecos	0.3	0.1	5%	95%	11%	89%
31 Upper Pecos-Black	1.4	0.9	16%	84%	14%	86%
32 Upper Pecos-Long Arroyo	0.9	0.4	19%	81%	19%	81%
average:	*0.4*	*0.2*	*35%*	*62%*	*34%*	*63%*

Excludes the unresolved class, which for this analysis was 1.4 million acres (ma) of REA-mapped all land and 0.5 ma of REA-mapped BLM land. See Fig. 4 and *A Primer for Understanding Results* for background.

Fig. 6. Generalized States under Reference Condition



BLM field offices
USGS 8-digit HUC watersheds
Grassland under reference condition
Savanna (shrub or tree) under reference condition

See Fig. 3 for key to BLM field offices & watersheds.

Understanding this figure:

Generalized states under reference condition applies to REA-mapped NRCS states. This map shows the major vegetation types that would occur under reference condition based on the REA-mapped reference condition states and the reference condition states that correspond to REA-mapped non-reference condiiton states as described in ESDs. Vegetation under reference condition is analyzed further below in combination with generalized states.

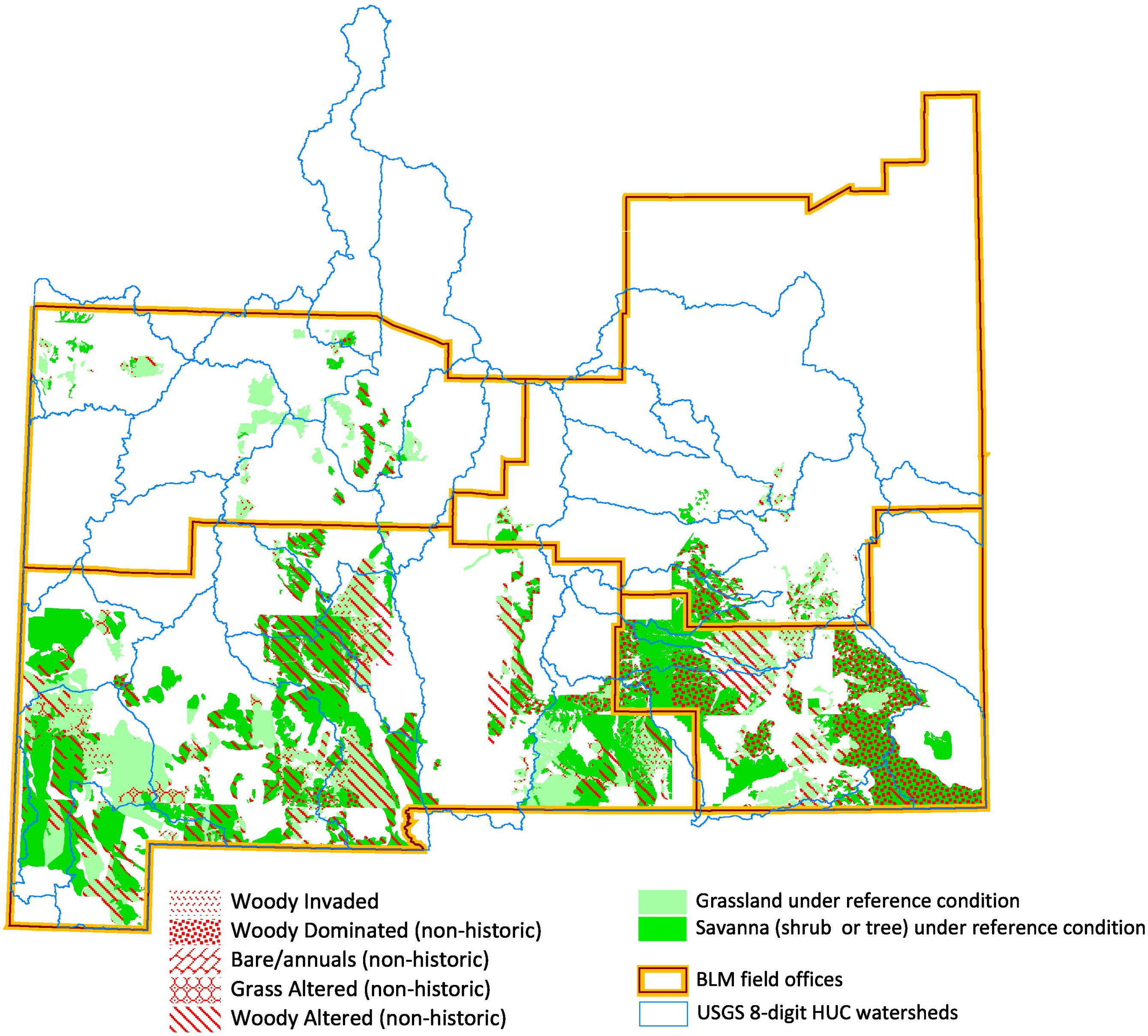
Generalized States – comparing current to those under reference condition

The most prominent transition among non-reference condition states was the establishment or proliferation of woody plant species in former reference condiiton grassland or savanna (grass/woody vegetation; Tbl. 1, Fig. 7). Such states covered 60% of REA-mapped BLM lands, excluding the unresolved class. They included woody-invaded states on 6% of this area, woody-dominated states on 18% and woody-altered states on 36%. Grass-altered (grasslands dominated by non-historic species) and bare/annuals states covered 3%. The remaining 37% was reference condition grassland and savanna.

Generalized states varied in extent among field offices and HUC-8 watersheds, but non-reference condition woody plant invaded, dominated or altered states were again generally most common. This pattern was fairly consistent for all land mapped in the REA project area as well.

Results can be further stratified by the two major reference condition generalized states, grassland and savanna, by normalizing the percentages in the table in Fig. 7. For REA-mapped BLM land and excluding the unresolved class, 60% of both former reference condition grassland and savanna was woody-invaded, dominated or altered.

Fig. 7. Generalized States: comparing current to reference condition



See Fig. 3 for key to BLM field offices & watersheds.

Understanding this figure:

Generalized states apply to REA-mapped NRCS states. NRCS states were most widely mapped in the Carlsbad and Las CrucesBLM field offices (Fig. 4). Current generalized states are shown overlaid onto those that would occur under reference condition, according to ESDs. The first two columns of the table (next page) show the acres of the project area and BLM land mapped by the REA to these two attributes. Other columns show generalized states as a percent of REA-mapped all land and BLM land. Results are reported for the project area, BLM field offices and USGS 8-digit HUC watersheds, and exclude the unresolved class. For example, of the 600,000 acres (rounded) of BLM land mapped to NRCS states in the El Paso-Las Cruces watershed (Fig. 4) for this analysis, 25% was mapped as woody-altered former reference condition grassland, and 45% as woody- altered former reference condition savanna. Twenty percent was mapped as current reference condition savanna, and no area was mapped as current reference condition grassland. To view these map units in more detail examine the spatial data in the geodatabase (Appendix 2).

Fig. 7 continued: Current Generalized States compared to those under Reference Condition

	REA-mapped acres (millions)		% of REA-Mapped: all land								% of REA-Mapped: BLM land							
	all land	BLM land	grassland (ref cond)	savanna (ref cond)	bare grd/annuals - former savanna	grass altered - former grassland	woody altered - former grassland	woody altered - former savanna	woody-dominated - former savanna	woody invaded - former grassland	grassland (ref cond)	savanna (ref cond)	bare grd/annuals - former savanna	grass altered - former grassland	woody altered - former grassland	woody altered - former savanna	woody-dominated - former savanna	woody invaded - former grassland
REA Project Area: (BLM field offices)	*8.0*	*4.7*	12%	27%	1%	3%	13%	22%	17%	7%	10%	27%	0.4%	3%	13%	23%	18%	6%
Carlsbad	1.7	1.1	2%	15%	0%	0.1%	11%	6%	64%	2%	3%	11%	0%	0.1%	9%	6%	67%	3%
Las Cruces	5.5	3.2	13%	32%	1%	4%	15%	26%	3%	7%	10%	34%	1%	4%	15%	28%	2%	5%
Roswell	0.4	0.2	2%	16%	1%	0%	7%	33%	20%	22%	1%	20%	0%	0%	6%	31%	26%	16%
Socorro	0.4	0.2	51%	16%	0%	1%	4%	18%	1%	9%	39%	19%	0%	1%	6%	21%	2%	13%
average:	*2.0*	*1.2*	*17%*	*20%*	*0.4%*	*1%*	*9%*	*21%*	*22%*	*10%*	*13%*	*21%*	*0.2%*	*1%*	*9%*	*22%*	*25%*	*9%*
USGS 8-digit HUC watersheds:																		
1 Animas Valley	1.0	0.4	31%	33%	2%	6%	8%	13%	0.0%	9%	20%	35%	3%	11%	7%	19%	<0.1%	6%
2 Arroyo Del Macho	<0.1	<0.1	0%	61%	0%	0%	37%	0%	0.4%	2%	0%	71%	0%	0%	28%	0%	1%	0.3%
3 Caballo	0.2	0.1	1%	11%	0%	0%	0%	84%	0.1%	4%	0.3%	15%	0%	0%	0%	82%	0.1%	2%
4 Carrizo Wash	0.1	0.1	28%	44%	0%	0%	8%	0%	0%	21%	30%	35%	0%	0%	9%	0%	0%	26%
5 Delaware	<0.1	<0.1	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
6 El Paso-Las Cruces	0.9	0.6	0%	18%	0%	0.3%	22%	49%	4%	6%	0%	20%	0%	0.1%	25%	45%	4%	6%
7 Elephant Butte Reservoir	0.2	0.1	20%	18%	0%	1%	13%	36%	1%	10%	11%	20%	0%	1%	7%	50%	1%	10%
8 Gallo Arroyo	0.0	0.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
9 Jornada Del Muerto	0.1	<0.1	58%	30%	0%	0%	9%	1%	0%	2%	59%	29%	0%	0%	9%	1%	0%	2%
10 Jornada Draw	0.3	0.2	0%	7%	0%	4%	49%	24%	1%	15%	0%	8%	0%	3%	54%	24%	1%	9%
11 Landreth-Monument Draws	0.3	0.1	0%	0%	0%	0%	0%	4%	96%	0%	0%	0.2%	0%	0%	0%	2%	98%	0%
12 Little Headwaters	0.0	0.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13 Lost Draw	0.0	0.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14 Lower Pecos-Red Bluff Reservoir	0.1	0.1	0%	0%	0%	0%	0.3%	32%	68%	0%	0%	0%	0%	0%	0.2%	29%	71%	0%
15 Mimbres	1.0	0.5	9%	33%	5%	5%	9%	29%	2%	7%	5%	37%	1%	8%	11%	30%	3%	5%
16 Plains of San Agustin	0.1	0.0	97%	2%	0%	1%	0%	0%	0%	0%	94%	6%	0%	0%	0%	0%	0%	0%
17 Playas Lake	0.5	0.3	11%	43%	0%	2%	23%	20%	0.5%	2%	11%	51%	0%	2%	16%	19%	1%	0.2%
18 Rio Felix	0.1	0.1	0%	33%	2%	0%	0%	25%	39%	1%	0%	32%	0.3%	0%	0%	24%	43%	1%
19 Rio Grande-Albuquerque	0.1	0.1	19%	5%	0%	0%	9%	63%	0%	4%	9%	8%	0%	0%	14%	66%	0%	3%
20 Rio Hondo	0.1	<0.1	0%	32%	0%	0%	0%	26%	42%	0%	0%	32%	0%	0%	0%	21%	47%	0%
21 Rio Penasco	0.2	0.1	0%	34%	0%	0%	0%	0%	66%	0%	0%	36%	0%	0%	0%	0%	64%	0%
22 Rio Puerco	<0.1	<0.1	45%	28%	0%	1%	0%	0%	20%	5%	45%	26%	0%	1%	0%	0%	22%	6%
23 Rio Salado	<0.1	<0.1	37%	35%	0%	4%	0%	0%	5%	19%	28%	37%	0%	5%	0%	0%	7%	24%
24 Salt Basin	0.9	0.6	24%	38%	0%	5%	1%	14%	8%	10%	29%	41%	0%	3%	1%	14%	2%	10%
25 San Francisco	0.0	0.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26 San Simon	0.1	0.0	0%	82%	8%	0%	0%	10%	0%	0%	0%	86%	10%	0%	0%	5%	0%	0%
27 Tularosa Valley	0.3	0.2	6%	22%	0%	2%	32%	29%	5%	3%	5%	31%	0%	3%	20%	31%	8%	2%
28 Upper Gila	0.0	0.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Upper Gila-Mangas	0.3	0.1	4%	70%	0%	8%	8%	7%	3%	0.1%	1%	83%	0%	3%	0%	13%	0.4%	0.2%
30 Upper Pecos	<0.1	<0.1	0%	0%	0%	0%	26%	0%	0%	74%	0%	0%	0%	0%	29%	0%	0%	71%
31 Upper Pecos-Black	1.0	0.7	4%	9%	0%	0.1%	16%	5%	65%	0.3%	4%	7%	0%	0.1%	11%	5%	72%	0.4%
32 Upper Pecos-Long Arroyo	0.3	0.1	1%	26%	0%	0.2%	7%	25%	3%	37%	1%	23%	0%	0.2%	7%	25%	3%	41%
average:	*0.3*	*0.2*	*12%*	*22%*	*1%*	*1%*	*12%*	*16%*	*13%*	*7%*	*11%*	*24%*	*0.4%*	*1%*	*11%*	*16%*	*14%*	*7%*

Excludes the unresolved class, which for this analysis was 2.6 million acres (ma) of REA-mapped all land and 1.2 ma of REA-mapped BLM land. See Fig. 4 and *A Primer for Understanding Results* for background.

Nine percent of former reference condition grassland was grass-altered and bare/annuals states covered 1%. Grasslands currently in reference condition accounted for 31%. Bare/annuals occured on 1% of former reference condition savanna, and 40% remained in reference condition. Results for all REA-mappped land in the project area were similar.

Finer-scale REA Analyses

This report summarizes fairly general ecological categories, such as the distribution of reference and non-reference condition states and generalized states. At its core, however, the REA mapped states, which are finer-scale and, among other things, specify dominant plant species, soil types and pathways between states. Thus the REA can help illuminate finer-scale ecological patterns than those presented in this report.

Some potential analyses include: (1) identifying the plant species that dominate ecological sites under reference condition and comparing them to current species dominants, (2) determining which ecological sites may be more vulnerable to alteration to non-reference condition based on which have higher proportions of REA-mapped non-reference condition areas, (3) estimating risks to increasing climate variability based on ESD-modeled climate drivers, (4) mapping restoration trajectories by noting the "target states" any one state might be restored to according to its ESD (e.g. Juniper-Invaded to Grassland in Box 1), and (5) assessing risk by mapping current states that ESDs depict as possibly transitioning across thresholds that may be especially severe (e.g. those that involve soil or hydrological alteration).

Some of these analyses would require adding information about state pathways to the REA geodatabase (Appendix 2), but others can be implemented using existing data. Boxes 4 and 7 provide examples generated from the REA state map.

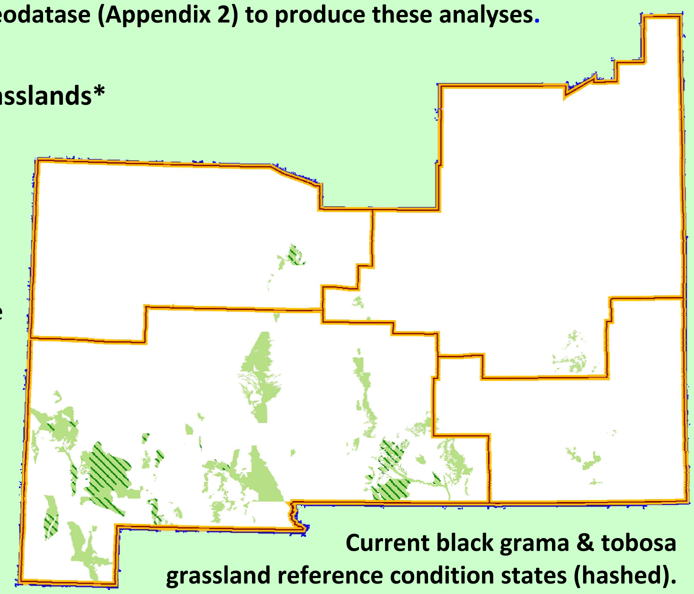
Finer-scale REA Analyses

Box 4

To highlight obvious ecological patterns yet keep things simple, the REA standardized individual states to coarse ecological categories in this report. Examples are grassland and grass/woody vegetation, and grass or woody-invaded generalized states. But the states that underlie REA maps often specify dominant plant species, soils, landforms, climate and other details. As such, the REA maps can be queried at finer-scale. Where, for example, are reference condition black grama grasslands mapped, and what shrub and tree species have invaded, dominated or fully altered former grasslands and savannas? Here we illustrate two REA-generated results at the state level, excluding the unresolved class. **We used ESDs along with the REA geodatase (Appendix 2) to produce these analyses.**

1. Black Grama & Tobosa Grasslands*

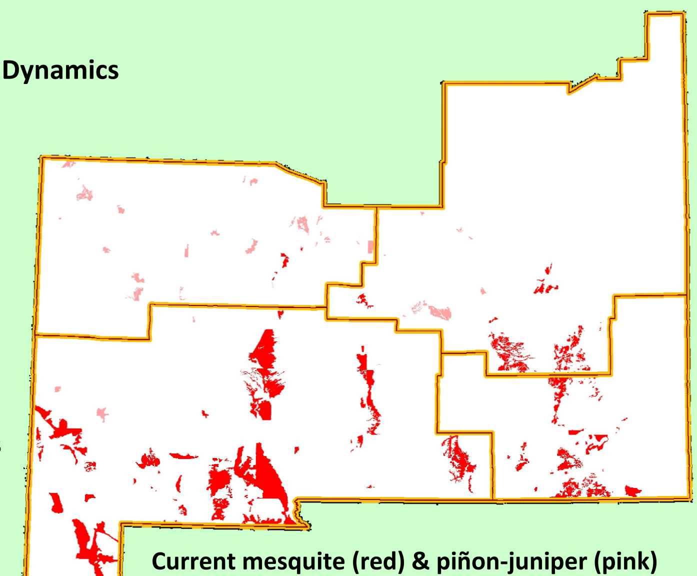
Black grama (*Bouteloua eripoda*) and tobosa (*Pleuraphis mutica*) grasslands are major southern New Mexico grassland states that, based on various sources, have declined substantially compared to reference condition. The REA mapped these grasslands on about 674,000 acres as shown at right. Under reference condition these grasslands covered 2.2 million acres of the REA-mapped area, based on REA mapped states and ESDs, a decrease of 68%.



Current black grama & tobosa grassland reference condition states (hashed). Solid green shows the REA-mapped extent of these grasslands under reference condition.

2. Mesquite & Piñon-Juniper Dynamics

According to the REA, states with mesquite (*Prosopis glandulosa*) or piñon-juniper (*Pinus edulis* and *Juniperus sp.*, "PJ") increased on 1.8 million and 215,000 acres, respectively, of former grasslands and savannas. This is shown at right. The REA state map, together with ESDs, can also provide details such as the dominant plant species of these areas under reference condition, and ecological sites and soils most prone to increasing mesquite or PJ (see Box 7 for an exmaple).



Current mesquite (red) & piñon-juniper (pink) non-reference condition states. ESDs & experts indicate these were absent under reference condition.

* reference condition black grama &/or tobosa dominated grasslands with absent to minor shrubs; based on interpretation of ESDs

3. *Transition Drivers*

photo 11

In short: *Transition drivers cause shifts to or between non-reference condition states and multiple drivers often are cited by ESDs. For simplicity we analyzed drivers separately, thus acreages overlap and area-percentages exceed 100%. Transition drivers were grazing-related on 59% of REA-mapped BLM land, vegetation-related on 58%, soil-related on 55%, climate- related on 49% and fire-related on 37%. Some drivers may be underestimated (see below). An example of a grazing-related driver is overgrazing and of vegetation-related is loss of grass cover or resource competition from invasive plants. Examples of soil, climate and fire-related drivers are, respectively, erosion, sustained drought or increased winter precipitation, and lack of fire (compared to reference condition). In this analysis, reference condition states comprised 39% of the area.*[5]

Tip: The REA's assignment of transition drivers & other attributes of mapped states can be reviewed in the State Attributes table of Appendix 1.

In Detail[3]:

Fifty-nine percent of REA-mapped BLM land, excluding the unresolved class, was mapped to states for which Natural Resources Conservation Service ecological site descriptions (ESDs) indicate grazing-related processes contributed to transitions to or between non-reference condition states (Tbl. 1, Fig. 8). Vegetation-related drivers comprised 58%, soil- related 55%, climate-related 49%, and fire-realated 37%. Thirty-nine percent of this area was mapped as reference condition in this analysis. Results for all land in the REA project area were similar with grazing, vegetation, soil and fire-related drivers highest, respectively. This pattern differed somewhat among BLM field offices and HUC 8-digit watersheds. For example, each of these five drivers covered over 70% of REA-mapped BLM land, excluding the unresolved class, in

[5]Percentages exclude areas not mapped by the REA and exclude the unresolved class. The unresolved class differs in size for each analysis and is reported at the end of most figures in the Results section. Comparisons, then, between analyses as well as between BLM field offices and watersheds (since REA mapping extent varied), should account for this. See *A Primer for Understanding Results* for more information. ESDs do not cite grazing as a sole driver; it is always cited with other drivers.

the BLM Carlsbad field office, and over 90% in the Delaware watershed.

As noted, ESDs often associate multiple drivers with individual states, so when singled out, as we do in this report, driver acreages overlap and their percentages exceed 100%. For example, all states in the 37% fire-related driver class include fire (e.g. reduced) as a driver, but many of these have additional drivers such as grazing and soil-related drivers. Thus the 37% tallies states with fire-related plus any other driver, the 59% grazing-related driver class tallies states with grazing-related plus any other driver, etc. The multiple drivers associated with states that the REA mapped are depicted in the map in Fig. 8 and summarized in Box 5.

Multiple Transition Drivers

Box 5

ESDş often associate multiple drivers with state shifts. It seems useful, then, to assess departure from reference condition in terms of multiple possibly interacting drivers. For example, both grass cover loss and resource competition denote pathway 1a of the WP2 Deep Sand ESD (Box 1). The 146 REA-mapped NRCS states are associated with 17 single or combined transition drivers. Only soil-related drivers are cited alone and for just one state. Sixteen driver combinations are cited for 86 states. The map in Fig. 8 shows how multiple transition drivers can overlap.

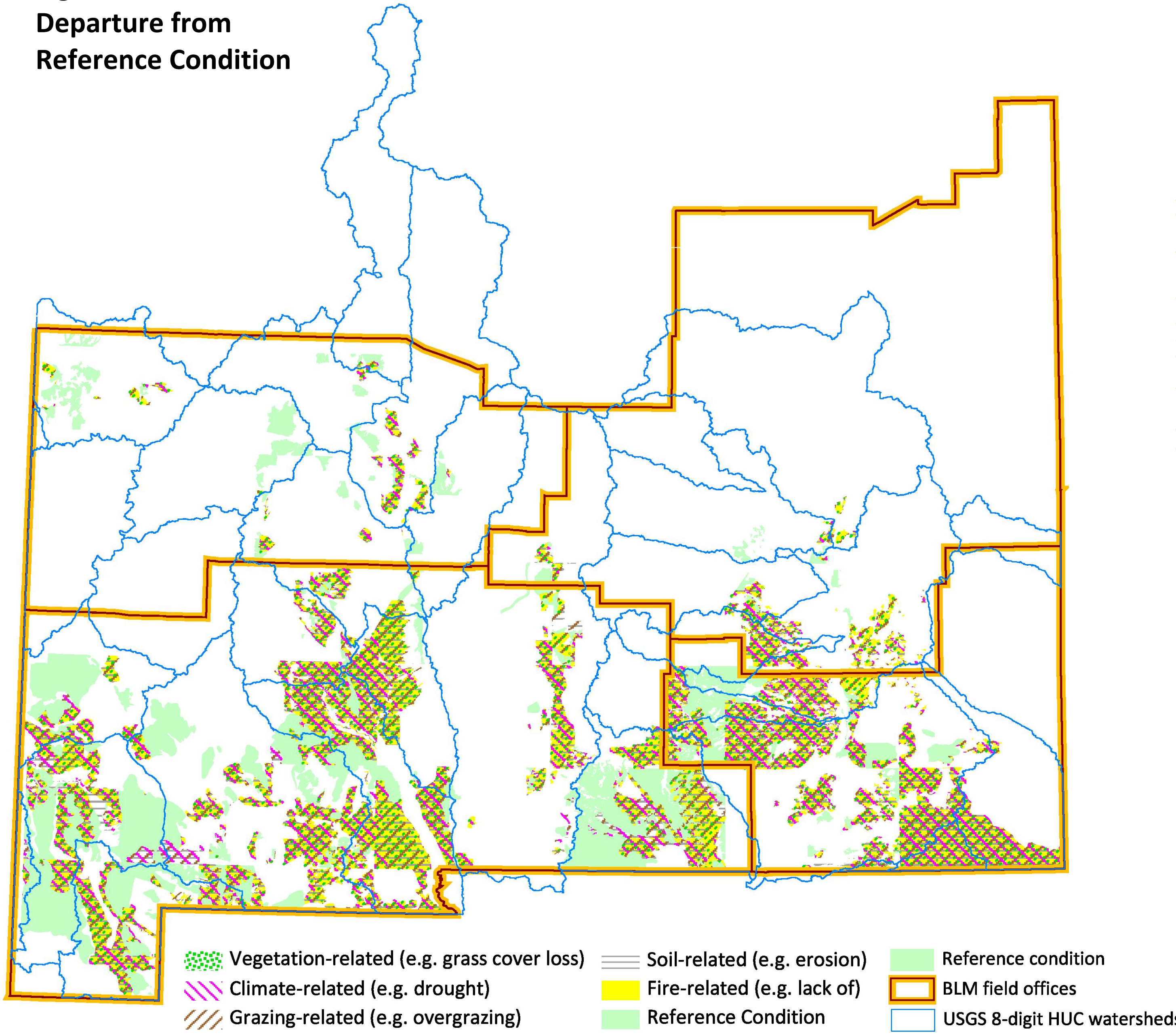
Key: D driver; **C** climate, **F** fire, **G** grazing, **S** soil & **V** vegetation related drivers

Count of States by Single or Combinations of Transition Drivers

Single Driver/State #:					
DS	1	DC DF DG DS DV	26		
subtotal	1	DF DV DS	2	subtotal	86
		DG DS	2	Reference condition	59
Multiple Drivers/State#		DC-DG-DS	5	total	146
DC DF DG	1	DC-DV	1		
DF DG DS DV	1	DC DG-DV	2		
DF DS	1	DG DS DV	7		
DF DG DV	4	DC DG DS DV	14		
DC DF DG DV	10	DS DV	5		
DF DG-DS DV	2	DC DS DV	2		

Grazing-related drivers include, for example, grazing intensity or seasonality that combined with other drivers shifts states to or between non-reference condition states. In ESDs grazing is always associated with at least one other driver. ESDs cite diverse vegetation-related drivers ranging from low grass cover (exposing soil to erosion) to plant resource competition and increased seed availability from invasive plant species. Example soil-related drivers are soil erosion and gullying. Climate-related drivers include sustained drought s, seasonal droughts and increased winter precipitation (which may favor woody plants). Fire-related drivers include both reduced and increased fire, relative to reference condition (e.g. reduced fire may favor woody plants, and increased fire may encourage certain fire-adapted shrubs). The fire-related driver class and perhaps others may be underestimated in ESDs and thus REA results, due to information gaps or other factors. This is discussed in section G., *Applying the REA*.

Fig. 8. Drivers of Departure from Reference Condition



See Fig. 3 for key to BLM field offices & watersheds.

Understanding this figure:

Transition drivers apply to REA-mapped NRCS states and are those, according to ESDs, that drive departure to or between non -reference condition states. NRCS states were most widely mapped in the Carlsbad and Las CrucesBLM field offices (Fig. 4). The REA does not identify the time period of drivers – they may be active currently and/or have been active in the past. The first two columns of the table (next page) show the acres of the project area and BLM land mapped by the REA in the drivers analysis. Other columns show drivers as a percent of REA-mapped all land and BLM land. Results are reported for the project area, BLM field offices and USGS 8-digit HUC watersheds, and exclude the unresolved class. For example, of the 500,000 acres (rounded) of BLM land mapped to NRCS states in the Mimbres watershed (Fig. 4) for this analysis, fire-related processes (e.g. altered fire regime such as fire suppression) were mapped as a driver of departure on 20% of this area, and grazing-related processes (e.g. overgrazing) on 57%. As shown in the map above, results for drivers overlap since ESDs typically associated states with more than one driver, so area-percentages may exceed 100%. To view drivers in more detail examine the spatial data in the geodatabase (Appendix 2).

Fig. 8 continued:

Drivers of Departure from Reference Condition

	REA-mapped acres (millions)		% of REA-Mapped: all land					% of REA-Mapped: BLM land				
	all land	BLM land	climate-related	fire-related	grazing-related	soil-related	vegetation-related	climate-related	fire-related	grazing-related	soil-related	vegetation-related
REA Project Area: (BLM field offices)	*8.9*	*4.9*	48%	37%	58%	54%	57%	49%	37%	59%	55%	58%
Carlsbad	2.0	1.1	75%	76%	76%	76%	78%	76%	77%	76%	77%	79%
Las Cruces	6.0	3.4	41%	24%	53%	49%	51%	41%	23%	55%	50%	52%
Roswell	0.4	0.2	58%	71%	74%	61%	76%	59%	70%	72%	62%	73%
Socorro	0.5	0.3	23%	22%	28%	24%	29%	28%	25%	32%	28%	35%
average:	*2.2*	*1.2*	*0.5*	*0.5*	*0.6*	*0.5*	*0.6*	*0.5*	*0.5*	*0.6*	*0.5*	*0.6*
USGS 8-digit HUC watersheds:												
1 Animas Valley	1.0	0.4	31%	22%	35%	35%	30%	42%	25%	45%	42%	34%
2 Arroyo Del Macho	<0.1	<0.1	34%	36%	36%	34%	36%	26%	27%	27%	26%	27%
3 Caballo	0.2	0.1	88%	58%	88%	88%	88%	85%	52%	85%	84%	85%
4 Carrizo Wash	0.1	0.1	7%	14%	19%	7%	19%	8%	16%	22%	8%	22%
5 Delaware	<0.1	<0.1	96%	96%	96%	96%	96%	97%	97%	97%	97%	97%
6 El Paso-Las Cruces	0.9	0.7	56%	32%	77%	70%	78%	53%	32%	77%	70%	78%
7 Elephant Butte Reservoir	0.2	0.1	45%	24%	59%	58%	59%	55%	26%	63%	61%	63%
8 Gallo Arroyo	0	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
9 Jornada Del Muerto	0.1	<0.1	3%	2%	9%	7%	10%	2%	1%	9%	8%	10%
10 Jornada Draw	0.3	0.2	44%	19%	93%	82%	88%	40%	14%	93%	84%	88%
11 Landreth-Monument Draws	0.3	0.1	100%	100%	100%	98%	100%	100%	100%	100%	99%	100%
12 Little Headwaters	0	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13 Lost Draw	0	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14 Lower Pecos-Red Bluff Reservoir	0.2	0.1	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
15 Mimbres	1.1	0.5	46%	21%	51%	43%	46%	49%	20%	57%	50%	49%
16 Plains of San Agustin	0.1	<0.1	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%
17 Playas Lake	0.6	0.3	41%	19%	49%	49%	49%	35%	15%	39%	38%	39%
18 Rio Felix	0.1	0.1	63%	61%	63%	62%	62%	66%	66%	66%	65%	65%
19 Rio Grande-Albuquerque	0.1	0.1	67%	60%	68%	68%	76%	69%	58%	71%	71%	83%
20 Rio Hondo	0.1	<0.1	70%	70%	70%	70%	70%	69%	69%	69%	69%	69%
21 Rio Penasco	0.2	0.1	65%	65%	65%	65%	65%	61%	61%	61%	61%	61%
22 Rio Puerco	<0.1	<0.1	26%	26%	27%	27%	27%	28%	28%	29%	29%	29%
23 Rio Salado	<0.1	<0.1	24%	24%	27%	27%	27%	30%	30%	35%	35%	35%
24 Salt Basin	1.1	0.7	26%	26%	40%	40%	37%	18%	21%	33%	30%	27%
25 San Francisco	0	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26 San Simon	<0.1	<0.1	18%	0%	18%	18%	10%	14%	0%	14%	14%	5%
27 Tularosa Valley	<0.1	<0.1	51%	20%	60%	54%	63%	46%	21%	49%	43%	58%
28 Upper Gila	0	0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Upper Gila-Mangas	0.4	0.2	28%	20%	34%	29%	32%	42%	29%	42%	36%	40%
30 Upper Pecos	<0.1	<0.1	23%	92%	100%	30%	100%	29%	96%	100%	33%	100%
31 Upper Pecos-Black	1.0	0.6	78%	75%	74%	78%	78%	77%	74%	74%	79%	78%
32 Upper Pecos-Long Arroyo	0.4	0.2	49%	70%	70%	50%	72%	40%	67%	67%	41%	69%
average:	*0.3*	*0.2*	*0.4*	*0.4*	*0.5*	*0.4*	*0.5*	*0.4*	*0.4*	*0.5*	*0.4*	*0.5*

Excludes the unresolved class, which for this analysis was 1.8 million acres (ma) of REA-mapped all land and 0.9 ma of REA-mapped BLM land. See Fig. 4 and *A Primer for Understanding Results* for background.

4. Restoration Opportunity

photo 12

In short: *REA restoration opportunity includes management options for shifting states towards or to reference condition, and intepreted restoration potential. Reference condition states were interpreted as requiring maintenance, high restoration effort was interpreted for states needing soil management or cultivation, and moderate effort was interpreted for other non-reference condition states. Individual management options are reported here but multiple options are often cited in ESDs, thus percentages exceed 100%. Vegetation options (e.g. shrub removal) covered 59% of REA-mapped BLM public land, excluding the unresolved class. Fire management options (e.g. prescribed fire for restoration or maintenance) covered 41%, soil management (e.g. erosion control) 26%, and grazing management (e.g. modified grazing) 23%. Reference condition states in this analysis occurred on 19% of this area. Some options may be underestimated (see below). In the restoration potential analysis, reference condition states for which maintenance was interpreted covered 36% of REA-mapped BLM land, excluding the unresolved class, states requiring moderate effort covered 23%, and those with moderate/high and high effort covered 41%.*[6]

Tip: The next section, *Applying the REA*, promotes the REA as part of a general restoration strategy

In Detail[4]:

Management Options

Vegetation management options (e.g. woody plant removal, seeding) were associated with 59% of REA-mapped BLM land, excluding the unresolved class. Fire management options (e.g. prescribed fire) covered 41% if this area,soil management (e.g. dune destruction, flushing soil salts) 26% and grazing management (e.g. modified

[6] Percentages exclude areas not mapped by the REA and exclude the unresolved class. The unresolved class differs in size for each analysis and is reported at the end of most figures in the Results section. Comparisons, then, between analyses as well as between BLM field offices and watersheds (since REA mapping extent varied), should account for this. See *A Primer for Understanding Results* for more information. ESDs do not cite grazing as a sole driver; it is always cited with other drivers. ESDs always cite grazing management with other options.

grazing) 23% (Tbl. 1, Fig. 9). In ESDs grazing management options are always combined with at least one other option. Fire management options include both those for shifting non-reference condition states towards or to reference condition, and for maintaining some reference condition states, as specified by Natural Resources Conservation Service ecological site descriptions (ESDs).

The pattern of vegetation and fire management options being most common characterized the BLM field offices and grazing management was also quite high in the Carlsbad BLM field office (74%). Results varied among USGS 8-digit HUC watersheds. For example, four of the five management options applied to 100% of of BLM land mapped by the REA in the Landreth-Monument Draws watershed, excluding the unresolved class. In contrast, soil management was indicated on 83% of the corresponding area in the Jornada Draw watershed. For REA-mapped all land area vegetation and fire options had the highest area proportions overall and for field offices, but again this varied by watershed.

Multiple Management Options

Box 6

As with transition drivers, ESDs often provide multiple options for restorative management. This suggests the importance of integrated restoration approaches, discussed further in section G. *Applying the REA*. For example, each WP2 Deep Sand non-reference condition state (Box 1) is associated with a vegetation-related option ("brush control") and prescribed grazing. The 146 NRCS states mapped by the REA are associated with 13 unique individual or combinations of management options (table to right). The three that are sometimes cited alone – fire, soil and vegetation management – are associated with restoration of 47 states. The other 10 are combinations of options associated with restoration of 76 states.

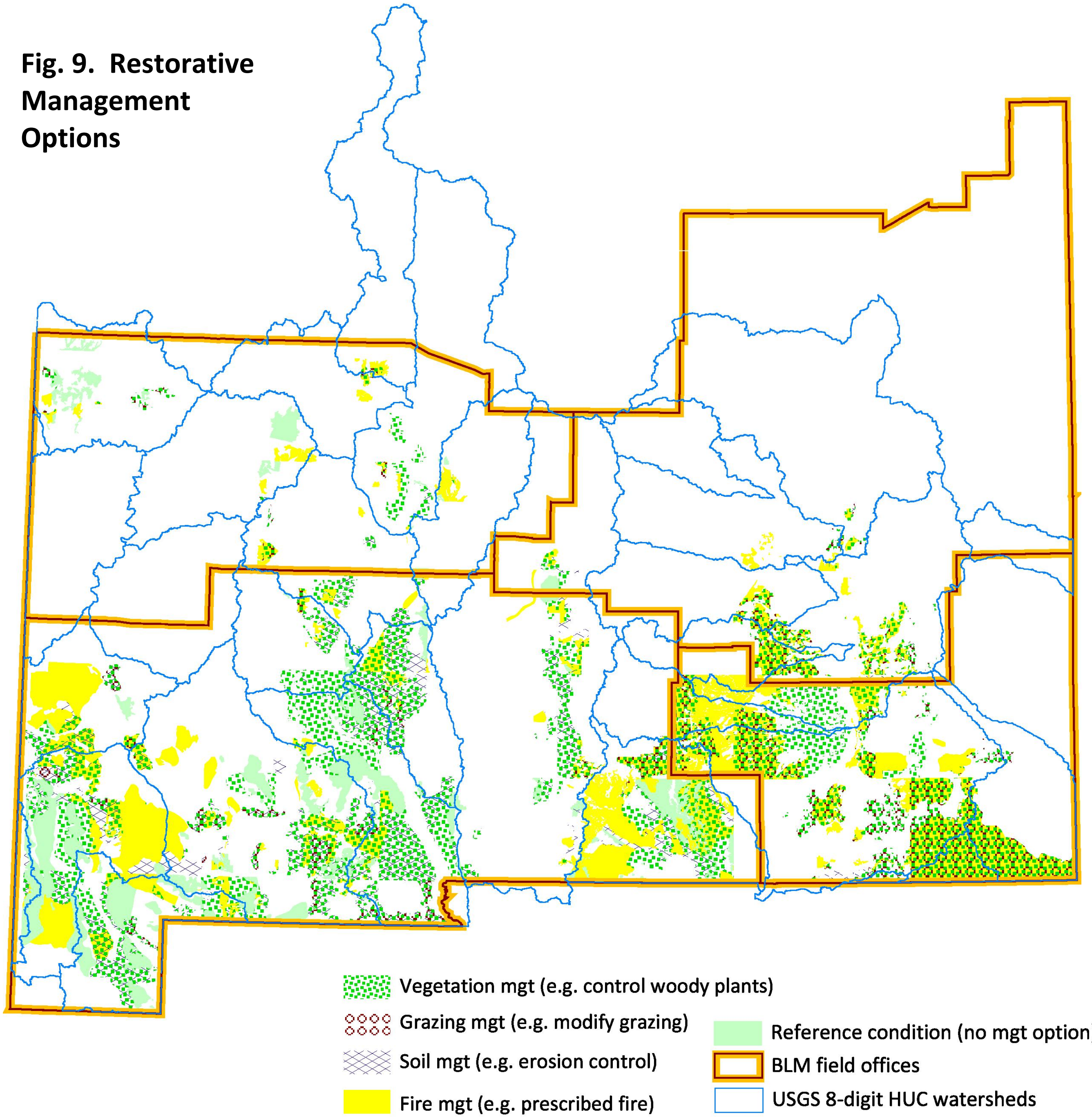
Key: **M** manage, **F** fire, **G** grazing, **S** soil, **V** vegetation

Count of States by Single or Combinations of Management Options

MF	37
MS	4
MV	6
subtotal	47
MF MG MV	3
MF MS	2
MF MV	9
MF MG MV	17
MF MG MS MV	1
MF MS MV	4
MG MS	4
MG MV	6
MG MS MV	11
MS MV	19
subtotal	76
Reference condition states with no indicated mgt option (for maintenance)	23
Total	146

Tip: Management options attributed for individual states are documented in Appendix 1, *REA Details.* Details about management options are in the ESDs themselves at http://www.nm.nrcs.usda.gov/technical/fotg/section-2/esd.html

Fig. 9. Restorative Management Options



See Fig. 3 for key to BLM field offices & watersheds.

Understanding this figure:

Restorative management options apply to REA-mapped NRCS states. NRCS states were most widely mapped in the Carlsbad and Las CrucesBLM field offices (Fig. 4). These state-specific management options are providedin ESDs as a means to manage non-reference condition states towards or to reference condition. All options are reported here, not just those for restoring states to reference condition. Additionally, fire management options in ESDs for maintaining reference condition states are tallied within the fire management class. The first two columns of the table (next page) show the acres of the project area and BLM land mapped by the REA in the management options analysis. Other columns show options as a percent of REA-mapped all land and BLM land. Results are reported for the project area, BLM field offices and USGS 8-digit HUC watersheds, and exclude the unresolved class. For example, of the 600,000 acres (rounded) of BLM land mapped to NRCS states in the Salt Basin watershed (Fig. 4) for this analysis, firemanagement (e.g. prescribed fire) was mapped on 54% of this area, and vegetation management (e.g. removing woody plants) on 32%. As shown in the map above, results for options overlap since ESDs typically associated states with mulitple options, so area-percentages may exceed 100%. To view options in more detail examine the spatial data in the geodatabase (Appendix 2).

Fig. 9 continued:

Restorative Management Options

	REA-mapped acres (millions)		% of REA-Mapped: all land				% of REA-Mapped: BLM land			
REA Project Area: (BLM field offices)	of project area	of BLM lands	Fire Mgt	Grazing Mgt	Soil Mgt	Vegetation Mgt	Fire Mgt	Grazing Mgt	Soil Mgt	Vegetation Mgt
	8.2	*4.7*	45%	23%	27%	58%	41%	23%	26%	59%
Carlsbad	1.7	1.0	86%	73%	1%	76%	88%	74%	1%	78%
Las Cruces	5.8	3.3	31%	7%	36%	53%	24%	6%	36%	54%
Roswell	0.4	0.2	82%	54%	5%	77%	83%	57%	4%	73%
Socorro	0.4	0.2	35%	14%	5%	37%	40%	19%	7%	45%
average:	*2.1*	*1.2*	*59%*	*37%*	*12%*	*61%*	*59%*	*39%*	*12%*	*62%*
USGS 8-digit HUC watersheds:										
1 Animas Valley	1.0	0.4	43%	3%	23%	31%	30%	4%	24%	37%
2 Arroyo Del Macho	<0.1	<0.1	66%	34%	0%	36%	74%	26%	0%	27%
3 Caballo	0.2	0.1	9%	4%	30%	88%	9%	2%	32%	85%
4 Carrizo Wash	0.1	0.1	15%	22%	0%	22%	14%	26%	0%	26%
5 Delaware	<0.1	<0.1	4%	96%	0%	96%	3%	97%	0%	97%
6 El Paso-Las Cruces	0.9	0.7	6%	9%	50%	80%	7%	8%	48%	78%
7 Elephant Butte Reservoir	0.1	0.1	34%	11%	43%	70%	27%	10%	45%	74%
8 Gallo Arroyo	0	0	0%	0%	0%	0%	0%	0%	0%	0%
9 Jornada Del Muerto	0.1	<0.1	60%	0%	9%	12%	61%	0%	9%	12%
10 Jornada Draw	0.4	0.3	14%	3%	79%	92%	9%	2%	83%	92%
11 Landreth-Monument Draws	0.3	0.1	98%	100%	0%	100%	100%	100%	0%	100%
12 Little Headwaters	0	0	0%	0%	0%	0%	0%	0%	0%	0%
13 Lost Draw	0	0	0%	0%	0%	0%	0%	0%	0%	0%
14 Lower Pecos-Red Bluff Reservoir	0.2	0.1	100%	100%	0%	100%	100%	100%	0%	100%
15 Mimbres	1.0	0.5	27%	14%	37%	52%	14%	15%	39%	50%
16 Plains of San Agustin	0.1	<0.1	30%	2%	2%	2%	56%	0%	0%	0%
17 Playas Lake	0.6	0.3	18%	3%	36%	49%	13%	2%	26%	38%
18 Rio Felix	0.1	0.1	99%	67%	1%	65%	100%	68%	0%	68%
19 Rio Grande-Albuquerque	0.1	0.1	11%	7%	11%	92%	12%	8%	14%	89%
20 Rio Hondo	0.1	<0.1	100%	67%	0%	67%	100%	66%	0%	66%
21 Rio Penasco	0.2	0.1	99%	64%	1%	64%	100%	62%	0%	62%
22 Rio Puerco	<0.1	<0.1	98%	34%	2%	34%	98%	37%	2%	37%
23 Rio Salado	<0.1	<0.1	94%	44%	6%	44%	93%	49%	7%	49%
24 Salt Basin	1.0	0.6	54%	11%	20%	40%	54%	2%	14%	32%
25 San Francisco	0	0	0%	0%	0%	0%	0%	0%	0%	0%
26 San Simon	0.1	0.0	2%	0%	18%	18%	1%	0%	14%	14%
27 Tularosa Valley	0.4	0.2	21%	5%	44%	68%	22%	8%	31%	60%
28 Upper Gila	0	0	0%	0%	0%	0%	0%	0%	0%	0%
29 Upper Gila-Mangas	0.4	0.2	79%	8%	28%	21%	78%	0%	36%	22%
30 Upper Pecos	<0.1	<0.1	70%	30%	8%	100%	67%	33%	4%	100%
31 Upper Pecos-Black	0.8	0.6	77%	74%	2%	76%	83%	75%	2%	77%
32 Upper Pecos-Long Arroyo	0.3	0.1	92%	32%	2%	64%	91%	31%	2%	64%
average:	*0.3*	*0.2*	*44%*	*26%*	*14%*	*49%*	*44%*	*26%*	*14%*	*49%*

Excludes the unresolved class, which for this analysis was 2.4 million acres (ma) of REA-mapped all land and 1.1 ma of REA-mapped BLM land. See Fig. 4 and *A Primer for Understanding Results* for background.

As for results for transition drivers, we highlighted individual management options. However, ESDs typically associate more than one management option with each state, so acreages of individual options overlap and their area-percentages exceed 100%. For example, the acreages of states for which ESDs cite both fire and vegetation management options were tallied in the 41% fire option *and* the 59% vegetation option. This is shown in Fig. 9 and multiple options are summarized in Box 6. All restorative options were included in REA results, not just those that target reference condition, and the states that particular options target are not specified.

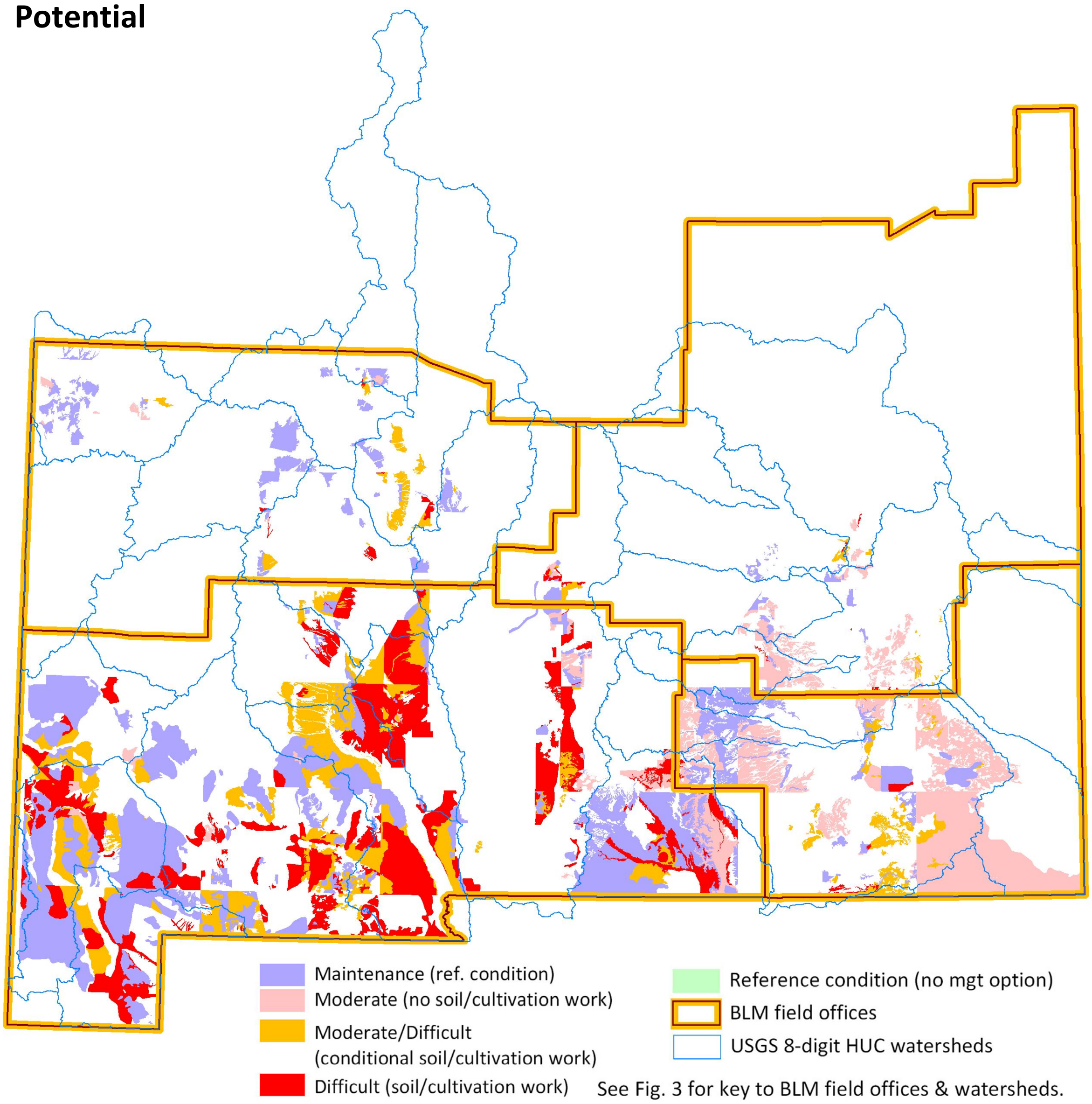
As previously stated, a particular consideration is that ESDs often cite "brush control" as an option for restoration, but may not specify the exact treatment approach. Conceivably it might be fire, chemical and/or mechanical and require follow-up such as fire and grazing management. Since brush control was aggregated in the REA's vegetation management option, fire (and perhaps other options) may be underestimated. See section G., *Applying the REA*, for more discussion of this topic.

Restoration Potential

Reference condition states, which we interpreted as requiring management for maintenance, covered 36% of REA-mapped BLM land, excluding the unresolved class (Tbl. 1, Fig. 10). States associated with management options interpreted as requiring moderate restoration effort (not soil management or cultivation) covered 23% of this area. States associated with management options that include soil management or cultivation, interpreted as requiring high restoration effort, were associated with 23% of this area. ESDs described some states as conditionally restorable with or without soil management or cultivation, depending on site-specific details. These were interpreted as requiring moderate to high management effort and covered 18% of this area.

Restoration potential varied among BLM field offices and watersheds. For example, the maintenance class covered just 17% of mapped BLM lands in the Carlsbad field office, excluding the unresolved class. This same class covered 41% in the Las Cruces field office. The high effort class dominated the Jornada Draw watershed (74%) but covered just 6% of the Jornad del Muerto watershed. Patterns for REA-mapped all land were similar to those for BLM lands.

Fig. 10. Interpreted Restoration Potential



Understanding this figure:

Restoration potential was interpreted for REA-mapped NRCS states. NRCS states were most widely mapped in the Carlsbad and Las CrucesBLM field offices (Fig. 4). Reference condition states were interpreted as requiring maintenance, non-reference condition states for which ESDs indicated soil management or cultivation would be restorative were interpreted as requiring high management effort, and other non-reference condition states were interpreted as requiring moderate management effort. States described by ESDs as conditionally restorative with soil management or cultivation (e.g. in some but not all cases a regenerative seedpool may be absent) were combined as requiring moderate/high effort. The first two columns of the table (next page) show the acres of the project area and BLM land mapped by the REA in the restoration potential analysis. Other columns show restoration potential as a percent of REA-mapped all land and BLM land. Results are reported for the project area, BLM field offices and USGS 8-digit HUC watersheds, and exclude the unresolved class. For example, of the 300,000 acres (rounded) of BLM land mapped to NRCS states in the Playas Lake watershed (Fig. 4) for this analysis, 16% was mapped to states with management options interpreted as requiring moderate/high management effort.

Fig. 10 continued:

Interpreted Restoration Potential

	REA-mapped acres (millions)		% of REA-Mapped: all land				• BLM land			
	of project area	of BLM lands	Maintain ref. cond	Moderate effort	Moderate/High effort	High effort	Maintain ref. cond	Moderate effort	Moderate/High effort	High effort
REA Project Area: (BLM field offices)	*9.1*	*5.2*	39%	21%	17%	23%	36%	23%	18%	23%
Carlsbad	2.0	1.2	21%	68%	9%	2%	17%	73%	7%	2%
Las Cruces	6.2	3.5	43%	4%	20%	32%	41%	4%	22%	33%
Roswell	0.4	0.2	22%	65%	9%	4%	25%	66%	6%	4%
Socorro	0.5	0.3	70%	5%	20%	4%	64%	7%	23%	6%
average:	*2.3*	*1.3*	*0.4*	*0.4*	*0.1*	*0.1*	*0.4*	*0.4*	*0.1*	*0.1*
USGS 8-digit HUC watersheds:										
1 Animas Valley	1.0	0.4	60%	2%	17%	21%	53%	1%	23%	23%
2 Arroyo Del Macho	<0.1	<0.1	62%	2%	33%	4%	69%	1%	24%	6%
3 Caballo	0.2	0.1	12%	0	58%	30%	15%	0	52%	32%
4 Carrizo Wash	0.1	0.1	81%	14%	5%	0	78%	16%	6%	0
5 Delaware	<0.1	<0.1	4%	0	96%	0	3%	0	97%	0
6 El Paso-Las Cruces	0.9	0.7	20%	0.3%	35%	44%	21%	0.4%	35%	44%
7 Elephant Butte Reservoir	0.2	0.1	34%	0.1%	35%	30%	30%	0.3%	38%	32%
8 Gallo Arroyo	0.0	0.0	0%	0	0%	0	0%	0	0%	0
9 Jornada Del Muerto	0.1	0.1	77%	0	17%	6%	76%	0	17%	6%
10 Jornada Draw	0.4	0.3	5%	1%	23%	71%	6%	1%	20%	74%
11 Landreth-Monument Draws	0.3	0.1	0.1%	100%	0%	0	0.2%	100%	0%	0
12 Little Headwaters	0	0	0%	0	0%	0	0%	0%	0%	0
13 Lost Draw	0	0	0%	0	0%	0	0%	0%	0%	0
14 Lower Pecos-Red Bluff Reservoir	0.2	0.1	0%	100%	0.2%	0	0%	100%	0.1%	0
15 Mimbres	1.1	0.5	49%	1%	21%	29%	42%	0.2%	23%	35%
16 Plains of San Agustin	0.1	<0.1	99%	0	0%	0	100%	0	0%	0
17 Playas Lake	0.6	0.3	51%	<0.1	20%	30%	61%	<0.1	16%	23%
18 Rio Felix	0.1	0.1	37%	61%	0%	1%	34%	66%	0%	0.3%
19 Rio Grande-Albuquerque	0.1	0.1	24%	0	67%	9%	17%	0	69%	14%
20 Rio Hondo	0.1	<0.1	32%	68%	0%	0	32%	68%	0%	0
21 Rio Penasco	0.2	0.1	40%	60%	0%	<0.1	41%	59%	0%	<0.1
22 Rio Puerco	<0.1	<0.1	73%	20%	5%	1%	71%	22%	6%	1%
23 Rio Salado	<0.1	<0.1	73%	5%	19%	4%	65%	7%	24%	5%
24 Salt Basin	1.0	0.7	58%	19%	5%	18%	68%	14%	5%	13%
25 San Francisco	0.0	0.0	0%	0	0%	0	0%	0	0%	0
26 San Simon	0.1	0.0	82%	0	0%	18%	86%	0	0%	14%
27 Tularosa Valley	0.5	0.3	25%	12%	11%	51%	29%	13%	13%	45%
28 Upper Gila	0.0	0.0	0%	0	0%	0	0%	0	0%	0
29 Upper Gila-Mangas	0.4	0.2	66%	3%	18%	13%	58%	0%	28%	13%
30 Upper Pecos	<0.1	<0.1	0%	74%	20%	7%	0%	71%	26%	3%
31 Upper Pecos-Black	1.1	0.8	18%	67%	13%	2%	16%	73%	9%	3%
32 Upper Pecos-Long Arroyo	0.3	0.1	35%	57%	6%	1%	34%	58%	6%	2%
average:	*0.3*	*0.2*	*0.3*	*0.2*	*0.2*	*0.1*	*0.3*	*0.2*	*0.2*	*0.1*

Excludes the unresolved class, which for this analysis was 1.6 million acres (ma) of REA-mapped all land and 0.6 ma of REA-mapped BLM land. See Fig. 4 and *A Primer for Understanding Results* for background.

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H. Applying the REA

Our suggestions how to use the REA for restoration

1. Setting Restoration Priorities
   - What, Where and How to Restore
2. Integrating the REA in a Comprehensive Restoration Strategy
   - Five Components
3. Updating the REA
   - The Geodatabase
   - The REA Data Exploration Tool

TAKE A LOOK:

- IDENTIFYING ECOSYSTEMS AT RISK (BOX 7)
- REA & LANDFIRE FRCC (BOX 8)

Tip: Some resources for restoration in New Mexico are the ARS-Jornada Experimental Range, NRCS, New Mexico Cooperative Extension, New Mexico Range Improvement Task Force, & New Mexico Forest & Watershed Restoration Institute. See section H., *Links*.

In this section we suggest how to apply the REA for restoration. These ideas reflect those of The Nature Conservancy and not necessarily BLM or others. The REA can help answer questions like: *What areas and ecosystems are at-risk, where do restorable grasslands occur, which management options do ESDs provide, and how are these factors spatially distributed across landscapes, such as major watersheds?* This information can assist agencies and the public prioritize restoration opportunity and appropriate management methods, using a consistent, science-based approach. While the REA offers important new information, it is one tool in a toolbox of resources. Combining the REA with other information at different scales enhances its utility and addresses some limitations (see *A Primer for Understanding Results*). Accordingly, we suggest integrating the REA as part of comprehensive restoration strategy. We describe how the REA can be a dynamic, updateable resource through its geodatabase.

1. Setting Restoration Priorities

photos 13-15

In short: *The REA provides a context for setting restoration priorities: **what**, **where** and **how** to restore. A basic challenge is determining the ecosystems and areas that are: (1) in reference condition, (2) practically restorable (ecologically and in terms of effort), and (3) at risk of "type conversion". By type conversion we refer to states so departed from reference condition that restoration may be difficult or impossible. We suggest that, in light of past declines in reference condition across southern New Mexico (Fig. 5), all areas currently in reference condition are priorities for management. We further suggest that states in non-reference condition, but that have not lost significant soil or hydrological function (e.g. via soil loss), are practically restorable and priorities. Some of these are at risk of type conversion, which we consider a third priority. For example, Natural Resources Conservation Service ecological site descriptions (ESDs) indicate many woody-invaded grasslands are restorable and at risk, while mesquite dunelands may have already undergone type conversion. Another measure of vulnerability is to identify the landscapes most prone to shifting to non-reference condition. The REA can shed light on this by summarizing ecological sites with high proportions in non-reference condition. Clues about sensitivity to climate change, a growing concern, can also be found in the REA. In which ecological sites, for example, do ESDs suggest climate as a driver of non-reference condition? Finally, restoration goals should be clearly stated and methods should be effective over the long-term, ecosystem-appropriate and minimize negative environmental impacts. ESDs and other resources provide important guidance for management.*

Tip: The Nature Conservancy is working with numerous partners to assess potential climate change effects. Contact The Nature Conservancy in New Mexico to learn more.

In Detail:

The Bureau of Land Management and other agencies have mandates to maintain public land health standards, promote natural ecological processes (e.g. natural fire regime), and safeguard wildlife habitat and sensitive species, while still providing economic and recreational resources to the public.

Private land managers, too, must balance land use with ecological sustainability for long term viability. Related challenges are that resources for restoration are in short supply, as are comprehensive spatial data about ecological condition and restoration opportunity. Research on effective long-term restoration methods, including monitoring treatments to inform adaptive management, may be lacking as well. These issues point out the need to prioritize restoration – what, where and how to restore.

We suggest that reference condition states, states in non-reference condition but practically restorable, and those at risk of type conversion (to states difficult or impossible to restore) are *what* to restore. Reference condition states are included to indicate that ongoing maintenance may be needed. The areas where these states occur are *where* to restore. Management techniques supported by the best available science and professional land management experience that place non-reference condition areas on a trajectory to reference condition, or improved ecosystem functionality, are *how* to restore. Information to help support these objectives is contained in the REA. This is because: (1) the REA is the first major regional assessment of ecological condition and restoration opportunity in southern New Mexico in some time, (2) it provides results that are spatial, and (3) its underlying framework, Natural Resources Conservation Service ecological site descriptions (ESDs), support sustainable land management, describe reference and non-reference condition states, and provide state-specific restoration methods. ESDs also convey information about the ecological and management costs of restoration for different states. This is found both in management options (e.g. if soil restoration is needed), and in the pathways between states shown in state-transition models (e.g. the “ecological and management distance” a state is from the reference state). Fig. 1 (inside cover) illustrates three REA resources for prioritizing restoration: ecological condition, management options and restoration potential.

Details are provided in the remainder of this subsection. Underlying this discussion is the fact that the REA helps establish a context for setting restoration priorities, and finer-scale data can clarify needs and information at the project-level.

What to Restore?

A fundamental task for prioritizing restoration is to determine the ecosystems that are in reference condition, practically restorable, and those at risk of conversion to states that may be difficult or impossible to restore. In the REA, experts mapped reference conditon states based on ESDs, or when ESDs were unavailable or perceived as insufficient, on field knowledge. We suggest reference condition states are a priority for conservation and maintenance because they have decreased substantially across southern New Mexico (Fig. 5), and in the context of limited resources, are often economical to maintain with tools such as prescribed fire.

The REA interpreted restoration potential for NRCS states (Fig. 10). Non-reference condition states for which soil (soil and hydrological) management and cultivation were not indicated by ESDs were interpreted as requiring moderate restoration effort. We suggest that these are a priority because their restoration is also an an efficient use of limited resources. They are described in ESDs as still having elements important to recovery, such as historical plant species and soils that are somewhat intact. We consider these states practically restorable.

States at risk of type conversion to those requiring highly intensive restoration, such as topsoil replacement and creation of barriers to prevent or decrease surface runoff, are also suggested as a priority. If these high risk states undergo transition the ecological and management feasibility of restoration may decline sharply. An important point is that while many of these areas are already in non-reference condition and belong to the practically restorable class (desribed above), some of these areas are reference condition states prone to direct type conversion without passing through a state of moderate alteration. We did not specifically map these states at high risk for type conversion. This would have required a level of interpretation of ESDs beyond the scope of this project. However, the REA state map and relevant ESDs can be used to develop this information. For example, the WP2 Deep Sand Juniper-Invaded state (Box 1) may be restorable through brush control (juniper removal or burning, since lack of fire is described by this ESD as possibly contributing to juniper invasion) and grazing management designed to enhance grass recovery. Its historical grass species and soils are described as altered (patchy and eroded in places) where juniper has invaded but the understory is still viable. We consider this state practically restorable. This state would not be identified as at risk for type-conversion, at least according to the ESD, since its transition to yet another state in which soil management or cultivation are indicated is not depicted. However, managers will want to be aware that the ESD narrative suggests that erosion may be progressive. As an example of a more clearly high risk case, the SD2 Salt Meadow's reference state, Meadow Grassland, can directly lead to several states requiring high management effort (irrigation for salt-flushing and cultivation), and so is considered at risk for type-conversion (the SD2 Salt Meadow ESD is online at http://www.nm.nrcs.usda.gov/technical/fotg/section-2/esd.html).

Another potential use of the REA is to identify areas that may be vulnerable to alteration. The likelihood of landscapes or ecosystems to shift to non-reference condition can be estimated by summarizing the proportions of ecological sites mapped by the REA as non-reference condition states. Results highlight ecological sites that have undergone the largest departure (by area) from reference condition. Departure can be indexed using an area-proportion metric similar to Fire Regime Condition Class (FRCC; Hann et. al, 2005). Results can be mapped and comparatively analyzed between ecological sites. The "ESD-departure" metric is described in Appendix 3.

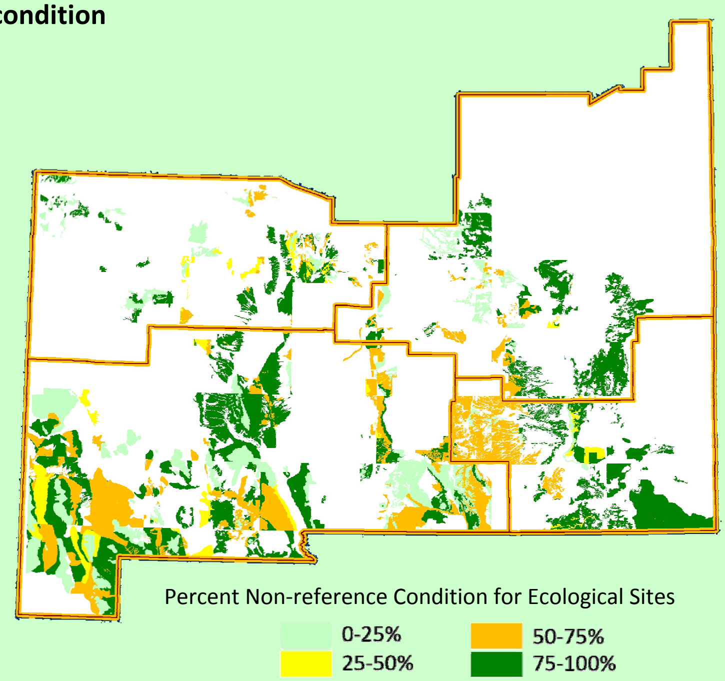
Susceptibility to increasing climate variability can also be explored, because ESDs represent climate as a driver of non-reference condition for specific states. Ecological sites with states subject to climate effects, according to ESDs, states modeled as at risk for crossing thresholds due to climate factors, and those that already crossed climate-driven thresholds, can all be mapped from the REA. This, of course, is limited by our dependence on existing ESDs and their state-transition models. Both of these potential measures of vulnerability are additional resources to identify restoration priorities. Box 7 presents a preliminary analysis of these topics.

Identifying Ecosystems at Risk

Box 7

1. Ecological Sites by percent non-reference condition

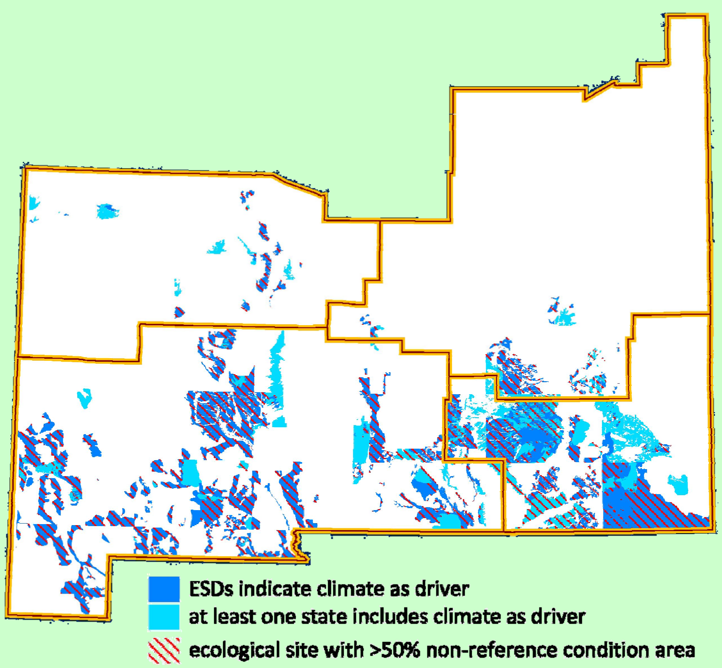
Vulnerability to a shift to non-reference condition is suggested by past trends. This map codes the ecological sites of all REA-mapped states, excluding the unresolved class, by percent non-reference condition area. For example, SD1 Sandy sites were 97% non-reference condition (red) across their mapped extent. In contrast, SD2 Hills and SD4 Shallow Sandy sites were just 6% and 0% non-reference condition, respectively (green). This "ESD-departure" metric provides a proportional measure of departure from reference condition, similar to Fire Regime Condition Class (FRCC), that links to ESDs. **The method is described in detail in Appendix 3. A table of ecological sites by percent non-reference condition is provided in Appendix 1.**



Should ecological sites with large non-reference condition area be considered at risk and prioritized? What do past trends indicate about the future?

2. Ecological Sites where climate may drive transitions

ESDs model climate as a driver of transitions to and between non-reference condition states for some ecological sites. For example, drought is listed as a driver that can shift the reference condition SD2 Sandy grassland state to non-reference condition. This map shows ecological sites where the REA mapped NRCS states and ESDs indicate climate as a driver of departure from reference condition. Hash marks highlight ecological sites with >50% non-reference condition area, suggesting increased vulnerability (see above). This analysis includes the unresolved class where multiple states were mapped at the same location, for which at least one state includes climate as a driver of departure, according to the ESDs. **"Climate-sensitive" ecological sites are listed in Appendix 1.**



Could this be a clue to the ecosystems that might be at riskto effects of increasing climate variability in the future? Should such sites be management priorities?

Tip: To locate "climate-sensitive" ecological sites review the REA state map and ESDs.

Where to Restore?

The REA mapped reference condition and restoration potential across millions of acres in southern New Mexico (Figs. 5, 10). Results can be used to identify areas in reference condition, practically restorable states and states that are at risk, as explained above. The prevalence of these states in different areas and management units, including watersheds and resource management plans, can be analyzed to help focus restoration effort. Other considerations, such as the viability (e.g. size and connectivity) of individual state patches, and their overlap with sensitive species, wildlife habitat and areas with different designations (e.g. multiple use, wilderness), can be explored using the REA state map overlaid with other spatial data.

How to Restore?

Systematic evaluation of the long-term effectiveness of different restoration methods for specific states in southern New Mexico is limited. This is increasingly relevant in light of rising evidence of increasing climate variability. As more information is gained about restoration techniques through monitoring and adaptive management, ESDs provide an evolving information resource based on available scientific and experiential knowledge. They identify opportunites for restorative fire, grazing, soil and vegetation management. In turn, the REA mapped these management options according to the information in ESDs (Fig. 9). The specificity of the management options in ESDs varies based on the available data. We expect that over time more ESDs will be developed and current descriptions refined as knowledge improves. Management options such as "brush control" are often named in ESDs, leaving the specific method of reducing woody vegetation up to the manager. Yet in many ESDs, fire is identified as an important process for controlling woody plants and maintaing reference condition. This variable specificity about fire as a management option was reflected in REA results. Accordingly, we recommend that managers consider using fire as a management tool, as appropriate, for primary or follow-up treatment when reduction of woody vegetation is desired[7]. Likewise, many ESDs highlight the complex and interactive effects of climate conditions, fire and land management practices such as grazing in determining whether areas will be dominated by grass or susceptible to woody encroachment. ESDs suggest managing grazing to restore grass and fine fuels to support a natural fire regime. Thus an integrated approach, in which fire, grazing and other management tools, as appropriate, are used in combination and over time appears warranted. While REA results did not elaborate such integrated long-term strategies, we hope the REA maps and associated ESDs will assist land managers in their identification and development. Relevant information can be found in the REA state map (Appendix 2), the State Attributes table (Appendix 1), and in the ESDs themselves, online at http://www.nm.nrcs.usda.gov/technical/fotg/section-2/esd.html). Project level decisions about restoration methods, of course, require site-specific evaluation and planning.

[7]Research on the role of fire in maintaining historical grasslands and as a management tool is ongoing for semiarid ecosystems in southern New Mexico, and results have been mixed. Careful attention to fire effects through monitoring, and factors such as precipitation prior to and following fire, is important.

Because the long-term environmental effects of various land treatments currently employed by the BLM and others are uncertain, and management options provided in ESDs are evolving, we offer a set of common sense guidelines for restoration that minimizes unforeseen and potentially damaging impacts. Although most are relevant to the project level, we include them since the REA can help identify and prioritize areas, ecosystems and management options as background for finer-scale planning. These guidelines can also enhance the ability of projects to engage multiple stakeholders.

* For each restoration project, prepare a long-term plan (for multiple treatments over several years) that includes landscape context, land use history, projected land use, and ecological dynamics, and identifies the ecological site, current and desired condition (e.g. current and desired states). Since reference condition may not always be the goal, for example if it is not ecologically or financially feasible, document the rationale for different goals.
* Identify underlying causes for a site's departure from reference condition, and design restoration strategies that address the causes rather than the symptoms.
* As a general rule, restore the *natural processes* (such as fire) that are characteristic of ecological sites in their reference condition, rather than restoring structure alone.
* Document assumptions and hypotheses about the effects of the proposed land treatment.
* Test the restoration project's assumptions and outcomes by monitoring ecological effects. The length of post-treatment monitoring can vary, depending on the ecosystem, treatment and management goals.
* Adjust assumptions, goals, objectives and methods as needed in light of monitoring results in an adaptive management framework.

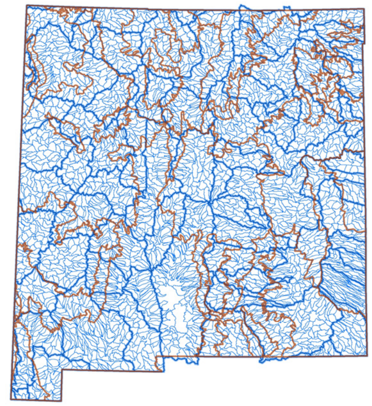
We also offer below a set of restoration principles adapted from the New Mexico Forest Restoration Principles recently adopted by the state's major public land management agencies and private conservation organizations. See http://www.fs.fed.us/r3/spf/nm-restor-principles-122006.pdf for the original document. As with the guidelines above, these pertain to the project level but are related to the REA, which can help provide a context for project implementation.

1. Collaborate actively with a balanced and diverse group of stakeholders on design and implementation.
2. Set regional priorities and strategically target treatment areas based on risk of loss and opportunity for conservation and restoration.
3. Develop site-specific reference conditions.
4. Use low-impact techniques.
5. Protect and maintain watershed and soil integrity.
6. Preserve rare ecosystem elements (e.g. old trees and rare species) while maintaining structural diversity and resilience, in the context of reference or desired condition.
7. Manage to restore historical species composition.
8. Target treatments that restore key ecological processes as well as physical structure.
9. Control and avoid using exotic species.

10. Foster regional heterogeneity.
11. Protect rare or sensitive communities.
12. Plan for restoration using a landscape perspective that recognizes cumulative effects.
13. Manage grazing to achieve desired long-term outcomes.
14. Establish monitoring and research programs and implement adaptive management.
15. Exercise care and use site-specific knowledge in restoring or managing little-understood ecosystems (e.g. semiarid grassland and piñon-juniper ecosystems).

2. *Integrating the REA into a comprehensive restoration strategy*

USGS 8 & 12-digit HUC watersheds overlaid onto NRCS land resource units: a landscape framework for restoration?



In short: *We recommend using the REA as part of a comprehensive restoration strategy. This entails partnerships among diverse land managers and the public that cross spatial scales, and takes advantage of multiple information resources. It integrates restoration priority setting, implementation and monitoring in a cost-effective, scientific approach that minimizes environmental impacts. Such a strategy is needed to tackle, in a collaborative spirit, the dramatic shift away from reference condition the REA indicates has occurred across southern New Mexico (Fig. 5). To achieve this strategy we suggest a five part effort: (1) the establishment, by consensus, of restoration principles for rangelands, (2) engagement of partners at landscape scale, such as NRCS land resource areas and watersheds, (3) prioritization of restoration of ecosystems and areas at nested scales (e.g. regionally, then within large watersheds, then smaller), (4) implementation of restoration using cost-effective, scientific and low-impact methods, and (5) cost-effective, long-term, scientific monitoring to measure success. This process should be adaptive. That is, the results of monitoring can update information resources (like the REA and ESDs), and be used to review and modify restoration priorities iteratively. The values of partnering, watershed health and a scientific foundation have been recognized by many agencies and organizations; the next step is to bring these ideas to fruition. The REA is as much an opportunity map as it is a map of condition, and its application in an integrated strategy offers multiple benefits.*

In Detail:

The REA is an important new resource for identifying and prioritizing restoration opportunity. Considering the magnitude of restoration need in southern New Mexico (Figs. 5, 10), the fact that restoration opportunity crosses multiple scales and ownerships, and the scarcity of resources, we recommend integrating the REA in a comprehensive restoration strategy. Built on collaboration and cost-effectiveness, within a scientific and environmentally sound framework, such a strategy would be invaluable for taking on this large, but critical challenge. Keys to thisapproach would be a plan for prioritizing restoration of ecosystems and areas, long-term monitoring to assess restoration success and support adaptive management, and the use of complementary information resources spanning multiple spatial scales. Examples of such resources are Natural Resources Conservation Service ecological site descriptions (NRCS ESDs), the REA, agency and research data (e.g. BLM field and Soil Vegetation Inventory Method data; studies of the New Mexico State University Agricultural Experimental Station, New Mexico Cooperative Extension and USDA Agricultural Research Service-Jornada Experimental Range [ARS-JER]), the ARS-JER remote sensing-based state map, the Southwestern Regional Gap Analysis landcover map (SW ReGAP; Utah State University RS/GIS Laboratory, 2004), and the LANDFIRE Fire Regime Condition Class (FRCC) map. We discuss the combined use of the REA and LANDFIRE specifically in Box 8 and Appendix 3. The ability to update information about ecological condition and restoration opportunity in the future would be essential (e.g. see the next subsection, *Enhancing and Updating the REA*).

We propose five components of a comprehensive restoration strategy:

1. Restoration Principles for Rangelands

Restoration principles for rangelands would provide an underlying structure for a comprehensive restoration strategy. For example, what are the goals of restoration and what information resources spanning different spatial scales can be utilized? A core question is how can ecological restoration be achieved while addressing cost and treatment-effectiveness, low environmental impacts and diverse land uses? For broad-based support, restoration principles can be developed through consensus by professionals working in rangelands, with input from key stakeholders. Participants might include agency (including Native American) and private land managers, industrial land users, scientists, conservation organizations and other public interest groups.

Restoration principles for New Mexico forests and woodlands were reviewed previously and are online at http://www.fs.fed.us/r3/spf/nm-restor-principles-122006.pdf.

2. Engagement at Landscape Scale

For restoration to be ecologically effective, allow the pooling of resources and engage diverse land managers, it should encompass areas that cross land ownership at landscape scale. By landscapes we mean areas that are ecologically delimited and support ecosystem functionality. For example, controlling erosion in one area may be unsuccessful if runoff continues from adjacent, unmanaged areas. Likewise, practical control of invasive woody plants using fire may require continuous burnable tracts.

We suggest the NRCS land resource classification and US Geological Service (USGS) delineated watersheds as a suitable landscape framework for the planning and implementation of treatments. The NRCS classification (NRCS, 2007) includes broad-scale classes that provide an ecological and management context for land managers ranging from BLM to the private sector. They also provide a link to NRCS restoration funding programs. ESDs, an information resource for restoration and the foundation of the REA, are elements of this classification. Watersheds are suggested since they are ecologically important and watershed health is a statewide priority in the New Mexico Forest and Watershed Plan (New Mexico Forest and Water Health Planning Committee, 2004). Watersheds span coarse to fine-scales. A hierarchy of standardized watersheds has been delineated in New Mexico by the USGS. USGS 8-digit HUC (hydrologic unit codes) watersheds, in particular, are being used as a basis for land management by BLM in New Mexico, and to engage multiple stakeholders in restoration.

3. Setting Restoration Priorities at Multiple Nested Scales

A carefully designed approach for prioritizing restoration would efficiently focus limited resources. One idea, based on NRCS ecological site descriptions and the REA, is described in the previous section, *Setting Restoration Priorities*. That approach would prioritize ecosystems and areas in reference condition, those that are "practically restorable" (requiring moderate management effort), and those at risk of type-conversion (to states requiring intensive soil or hydrological restoration or cultivation).

Regardless of the details, a spatially nested prioritization process should be considered. Such a process could maximize restoration success over the numerous ecosystems and extensive areas needing attention (Figs. 5-7). This would permit a "big picture" view of restoration need first. Restoration priorities could then be determined at increasingly finer scales. A nesting scheme could start with large ecological/management units, such as NRCS common resource areas (http://www.nm.nrcs.usda.gov/technical/fotg/section-1/maps/new/cra.jpg), and move down to large watersheds (Fig. 3), sub-watersheds and finally the project-level. Without a nested perspective, restoration might be too scattered and opportunistic to effectively and efficiently address the restoration need.

4. Cost-effective, Scientific, Low Impact Methods

A comprehensive restoration strategy should be cost-effective, rooted in the best available science and emphasize low-impact methods. Although challenging, since restoration science is not well advanced in some areas and economical solutions sometimes conflict with environmental concerns, it would be beneficial ecologically and for building broad-based support to strive for these objectives in tandem. We previously suggested ideas related to cost-effectiveness, in recognition of the large restoration need and limited resources. These were a focus on landscape scale, which facilitates the pooling of resources for a common objective, and prioritizing restoration at nested scales. The monitoring approach described in below also addresses cost.

ESDs suggest restorative management options, specific for different ecosystems (ecological sites and states), that draw on currently available science and experience. The REA mapped ESD management options across southern New Mexico, and results are one resource for identifying treatment methods (Fig. 9). Restoration techniques with low environmental impacts are encouraged. Until more is known about the impacts of uncertain methods, we suggest a conservative approach and that treatment effects should be strictly monitored. This topic is discussed in more detail in the previous subsection, *Settng Restoration Priorities*.

5. Cost-effective, Long-term Scientific Monitoring

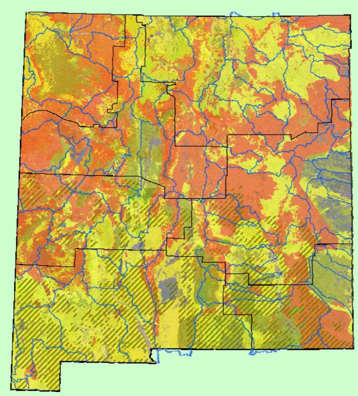
A long-term assessment and monitoring program that is robust yet affordable would be a key part of a comprehensive restoration strategy. Monitoring can answer basic questions – is restoration achieving its goals and if not, do restoration methods need to be changed, or targeted ecosystems and areas re-focused? Monitoring can be especially difficult due to the extensive areas needing scrutiny and the costs of field operations. We suggest staggering monitoring techniques of differing spatial scales, intensities and costs over time. Specifically, field monitoring can establish baselines and periodic ally update information for representative small landscapes (e.g. ecological sites) and land uses. Moderately intensive mapping, like ARS-JER and REA state mapping, can provide baselines and periodic updates across large areas. Comparatively inexpensive rapid assessments, using MODIS and LANDSAT satellite imagery, can be used more frequently for change detection. If change is detected more intensive field monitoring could be efficiently focused on those areas. Appendix 4, *Rapid Ecological Assessment Approach*, illustrates a coarse-scale mapping technique using Landsat satellite imagery.

REA & LANDFIRE FRCC

Box 8

Different types and scales of information can complement each other, once similarities and differences are understood. A case in point is the REA and LANDFIRE fire regime condition class (FRCC). The REA is mid-scale (Box 2) and covers part of New Mexico. LANDFIRE, a multi-agency assessment of altered fire regime and ecological departure from reference condition, is also mid-scale, but national in scope. While similar in objective, the REA is rich in local knowledge (via expert mapping) and uses a different classification, National Resources Conservation Service ecological site descriptions (ESDs), in contrast to LANDFIRE biophysical settings.

LANDFIRE FRCC uses probabilistic models to predict reference condition parameters. The more qualitative state-transition models of ESDs, which underlie the REA , stress ecological thresholds and detail both reference and non-reference condition. FRCC estimates percent-area departure but not restorability (e.g. if thresholds were crossed). ESDs can yield estimates of both departure and restorability (Figs. 5 and 10, Appendix 3).

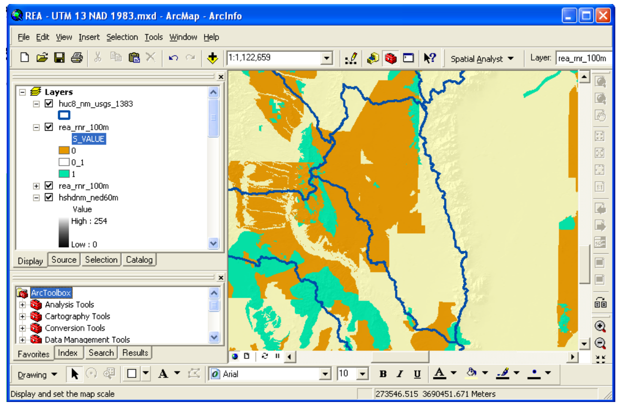


REA (hash marks) overlaid with LANDFIRE FRCC, ReGAP landcover, BLM field offices, USGS 8-digit HUC watersheds & ownership

These differences actually facilitate complementary use. First, LANDFIRE has wall-to-wall coverage, and so can help fill gaps in the REA map. Second, LANDFIRE FRCC can broadly indicate areas in reference condition and departure that can be corroborated by the REA and other finer-scale maps. Third, the REA can enrich the FRCC index (FRCC 1, 2 and 3) with information about restorability and ecological thresholds. Appendix 3 describes "ESD-departure", a departure metric similar to FRCC that links to ESDs, and discusses shared REA and LANDFIRE FRCC application.

Tip: For more about LANDFIRE go to www.landfire.gov. A comparative analysis of ESD & LANDFIRE ecological models is at http://nmconservation.org/.

3. Enhancing & Updating the REA



In short: *The REA provides a snapshot in time of ecological condition and restoration opportunity across millions of acres in southern New Mexico. This is important information to help determine restoration priority for the near term. But how will these factors change in the future, will current management actions have the desired effect, and what ecosystems and areas should be prioritized 5 or 10 years from now? To address such questions the REA was designed to be a dynamic, updateable information resource. It can be modified and expanded with new information. This also addresses limitations discussed previously in A Primer for Understanding Results. For example, REA-mapped areas can be checked using remote-sensing and ground reconnaissance, new areas can be mapped, REA state attributes can be modified, and new ESDs and research incorporated. This is achieved through the REA geodatabase. A geodatabase contains spatial data (GIS layers) carefully structured for quality control and updates. Using the geodatabase, REA states and state attributes can be readily updated and expanded. We also included a beta version application, the REA Data Exploration Tool. This tool allows users to generate custom results from the REA, overlaid with other spatial data if desired. An example is to summarize REA-mapped woody-invaded states within agency resource management plan areas, and compare this to the ARS-Jornada Experimental Range satellite image-based state map, BLM field data, statewide landcover coverages, and the LANDFIRE Rire Regime Condition Class (FRCC) map.*

In Detail:

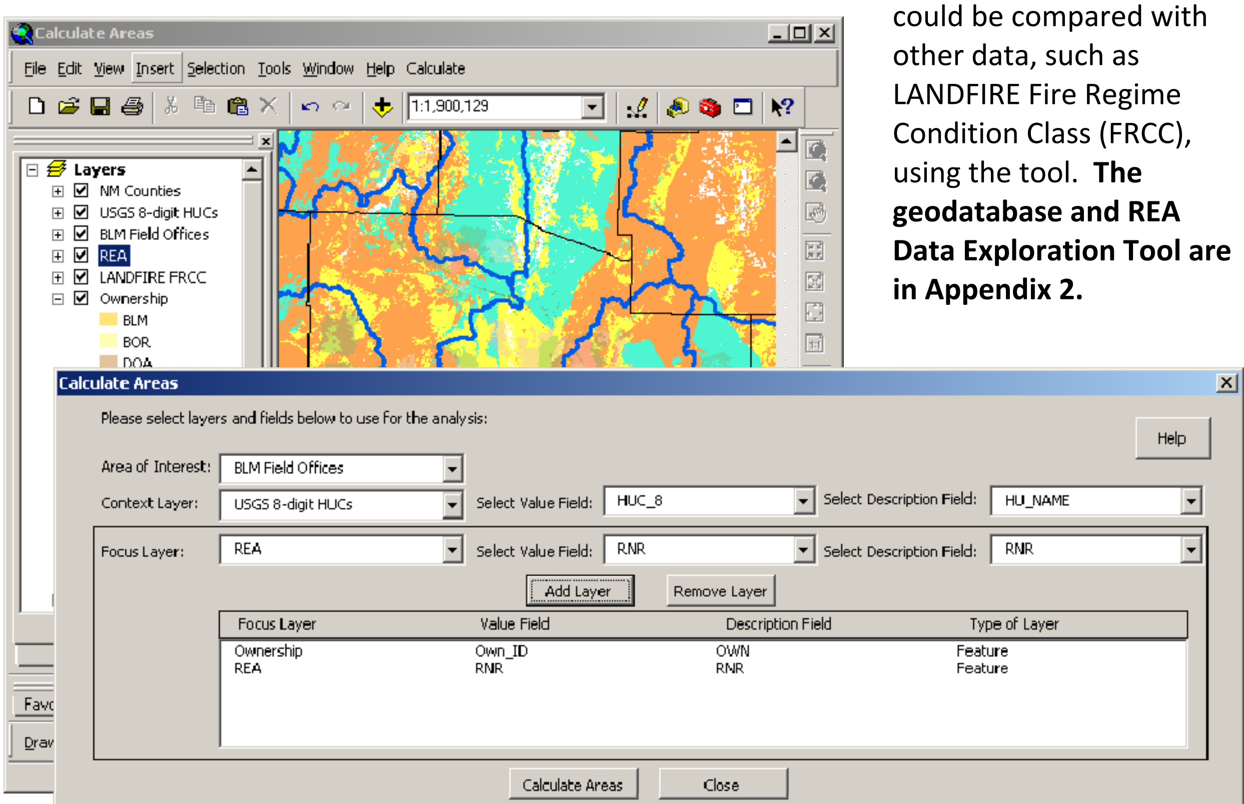
The Geodatabase

The REA mapped ecological condition and restoration opportunity over a large portion of rangelands in southern New Mexico (Fig. 4). An assessment of this scope had not been carried out in decades in southern New Mexico. Results provide valuable baseline data to help prioritize ecosystems, areas and methods for restoration, at mid-scale. However, the REA did not map all areas, and its long-term utility would increase if it could absorb new data as it becomes available. To address these needs, REA data are stored in a geodatabase, a dynamic, updateable information resource (Appendix 2). The geodatabase, which runs in ArcGIS (ESRI), contains the REA spatial data, including the state map and attributes. The REA can be checked, modified and expanded through the geodatabase, which controls data quality and consistency. For example, mapped states can be compared to aerial photos and field data, and changed if needed. State attributes can be checked against Natural Resources Conservation Service ecological site descriptions (NRCS ESDs) and also updated. The REA can be expanded to areas not yet mapped, and when new ESDs become available they can be incorporated (this could increase the areas mapped to NRCS states, as opposed to expert-states).

The geodatabase enables the REA to provide ongoing support for restoration efforts within a consistent framework (ESDs). This requires users to actively maintain and expand the geodatabase. It also entails a commitment from NRCS to continue to improve ESDs. If a comprehensive restoration strategy is desired (previous subsection), a geodatabase provides a central data repository.

The REA Data Exploration Tool

The REA Data Exploration Tool is a beta application that allows users to easily analyze REA data, alone or with other spatial information. The tool is embedded in an ArcMap 9.2 map (mxd). The basic function of the tool is to overlay the REA with areas of interest to the user, and calculate area and percent-area tables. For example, what is the area in reference condition for a resource management planning area, how much of it was mapped by the REA, and where is restorative fire management indicated? Results could be compared with other data, such as LANDFIRE Fire Regime Condition Class (FRCC), using the tool. **The geodatabase and REA Data Exploration Tool are in Appendix 2.**



I. Last Words (contacts, links, references & photos)

Contacts

This report and appendices were prepared by The Nature Conservancy in New Mexico. For information contact:

The Nature Conservancy, New Mexico
212 E. Marcy Street
Santa Fe, NM 87501
Main Number: (505) 988-3867
Fax: (505) 988-4095

Email: nm@tnc.org

Electronc versions (Adobe pdf) of this report and the geodatabase are online at The Nature Conservancy's science website – http://nmconservation.org.

Links

The REA was developed with the assistance of many people and organizations. Other organizations may have information resources that can be used in combination with the REA. This can help address the need for assessment and restoration at multiple scales. The use of varied resources also can provide more geographically comprehensive and diverse information than the REA can offer alone. Some internet links to organizations that participated in the REA as well as others that may have relevant information are:

- **Bureau of Land Management New Mexico** http://www.blm.gov/nm/st/en.html
- **USDA ARS-Jornada Experimental Range** http://usda-ars.nmsu.edu/
- **USDA ARS-Jornada Experimental Range** http://usda-ars.nmsu.edu/
- **Natural Resources Conservation Service (NRCS) New Mexico** http://www.nm.nrcs.usda.gov/
- **NRCS ecological site description main website** http://esis.sc.egov.usda.gov/
- **NRCS ecological site descriptions for New Mexico** http://www.nm.nrcs.usda.gov/technical/fotg/section-2/esd.html
- **NRCS National Range & Pasture Handbook** http://www.glti.nrcs.usda.gov/technical/publications/nrph.html
- **Intepreting Indicators of Rangeland Health** http://www.blm.gov/nstc/pubs.html
- **NMSU Cooperative Extension** http://extension.nmsu.edu/
- **NMSU Range Improvement Task Force** http://cahe.nmsu.edu/programs/ritf/index.html
- **LANDFIRE** http://www.landfire.gov/
- **Earth Data Analysis Center (EDAC)** http://edac.unm.edu/
- **Natural Heritage New Mexico** http://nhnm.unm.edu/
- **Fire Regime Condition Class** http://frames.nbii.gov
- **NMHU Forest & Watershed Restoration Institute** http://www.nmhu.edu/nmfwri/
- **New Mexico Forest Restoration Principles** http://www.fs.fed.us/r3/spf/nm-restor-principles-122006.pdf

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Photo Index

The photographs scattered throughout this report illustrate some of the diversity in rangeland ecosystems in the REA project area. Most were taken in 2005-2006 on Bureau of Land Management lands by an REA field crew. These photos are not intended to represent the full range or relative abundance of ecological sites or states assessed by the REA. Vegetation and county locations are summarized below.

Photo	Description
1 (cover)	Blue grama, ear muhly, Russian thistle, soaptree yucca; REA field crew; Otero County, New Mexico
2 (cover)	Blue grama, oneseed juniper; REA field crew; Socorro County, New Mexico
3 (cover)	Tobosa grass, mesquite; REA field crew; Hidalgo County, New Mexico
4	Scattered shrubs on gravelly bajada; Southwest Regional GAP Analysis Project field crew; USGS 8-digit Jornada Draw watershed, Sierra County, New Mexico
5	Mesquite; REA field crew; Hidalgo County, New Mexico
6	Creosotebush, black grama; REA field crew; Hidalgo County, New Mexico
7	Blue grama, snakeweed; REA field crew; Socorro County, New Mexico
8	Creosotebush, bush muhly; REA field crew; Dona Ana County, New Mexico
9	Tobosa grass; REA field crew; Luna County, New Mexico
10	Black grama, cane cholla, REA field crew, Socorro County, New Mexico
11	Blue grama, rabbitbrush, REA field crew, Catron County, New Mexico
12	Tobosa grass, black grama, tarbush, REA field crew, Hidalgo County, New Mexico
13	Creosotebush, bush muhly, tobosa grass, soaptree yucca; REA field crew; Luna County, New Mexico
14	Creosotebush, bush muhly; REA field crew; Luna County, New Mexico
15	Annual forbs, creosotebush, tarbush; REA field crew; Otero County, New Mexico

black grama – *Bouteloua eriopoda*, blue grama – *Bouteolua gracilis*, bush muhly – *Muhlenbergia porteri*, cane cholla – *Cylindropuntia imbricata*, creosotebush – *Larrea tridentata*, ear muhly – *Muhlenbergia arenacea*, mesquite – *Prosopis glandulosa*, oneseed juniper – *Juniperus monosperma*, rabbitbrush – *Ericameria nauseosa*, Russian thistle – *Salsola tragus*, soaptree yucca – *Yucca elata*, tarbush – *Flourensia cernua*, tobosa grass – *Pleuraphis mutica*

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Appendices

Appendices 1 and 2 are electronic files only on CD-ROM or online at http://nmconservation.org.
Appendices 3 and 4 follow this introduction.

Appendices

1. REA Details (state attributes table & results)
2. REA Data (the geodatabase)
3. An ESD-based Departure Metric
4. Rapid Ecological Condition Mapping Approach

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New Mexico Rangeland Ecological Assessment Appendix 3:

An Ecological Site Description Based Departure Metric

a preliminary approach for calculating current ecological departure from reference conditions based on Natural Resources Conservation Service Ecological Site Descriptions, that can be used as an alternative and complement to Fire Regime Condition Class (FRCC)

March, 2008

a LANDFIRE Application Project prepared by Steven Yanoff, Patrick McCarthy, Lara Miller, Anne Bradley and Dave Gori of The Nature Conservancy in New Mexico

The Nature Conservancy
Protecting nature. Preserving life.™

Abstract

The goal of this project was to develop a pilot method to calculate current ecological departure from reference conditions based on Natural Resources Conservation Service ecological site descriptions (ESDs). This method, ESD-departure, is needed to provide a direct link to the ESD assessment and management framework, and facilitate coordination with users of Fire Regime Condition Class (FRCC). ESDs are widely used by land managers for ecological assessment and management, and are specialized for semiarid rangelands, yet there has been no standard method for calculating ESD based departure. Knowledge of reference condition and departure helps clarify current ecological condition and management objectives, and supports restoration priority-setting for policy makers, land managers and the public. ESD-departure measures the proportions of landscape units departed from reference conditions (percent-area departure). Depending on the scale it is calculated, it summarizes the departure of ecosystems across their range of historic variation, or it can be targeted at more narrow and practical management scales. It can be used in conjunction with ESD related applications, such as the state map in the accompanying New Mexico Rangeland Ecological Assessment report. ESD-departure is both an alternative and complement to FRCC. FRCC also calculates percent-area departure, using a somewhat different framework, but ESD and FRCC use is often not coordinated between rangeland and fire management programs. ESD-departure, along with associated information about ecological thresholds and restoration options in ESDs, will enrich FRCC and promote shared use of both tools. As part of this project, ESD-departure was calculated and compared across spatial scales and to the national LANDFIRE FRCC dataset in southern New Mexico.

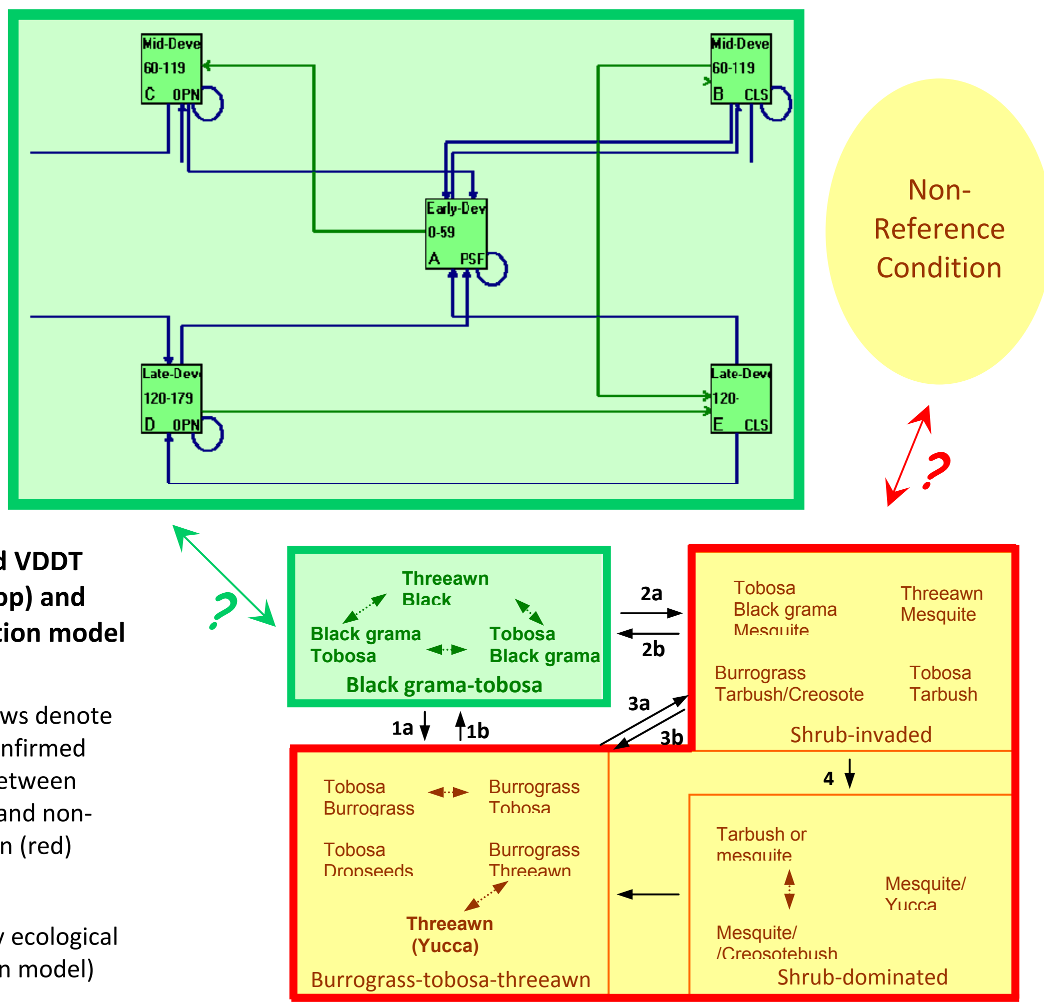


Fig. 1. Simulated VDDT model output (top) and ESD state-transition model (bottom)*

The two large arrows denote potential but unconfirmed correspondence between reference (green) and non-reference condition (red) components.

*(NRCS SD2 Loamy ecological site state-transition model)

Contents:

Figures

Tables

1. Acknowledgements

This document was prepared as part of a LANDFIRE Application Project and was generously supported by LANDFIRE (www.landfire.gov), a national project carried out by multiple federal agencies and other partners that provides information and spatial data about vegetation, current ecological departure from reference conditions, wildland fuels and fire regimes across the United States. In addition to LANDFIRE national Fire Regime Condition Class (FRCC) data layers and National Resources Conservation Service ecological site descriptions (ESDs), this project utilized information from three main sources: (1) the New Mexico Rangeland Ecological Assessment, a regional ecological assessment of The Nature Conservancy (TNC) and USDI Bureau of Land Management (accompanies this document), (2) a USDA Forest Service supported study that compared ESDs and FRCC (Yanoff et al., 2007), and an ESD-based mapping study supported by a TNC grant from the Rodney Johnson/Katharine Ordway Endowment (RJKose program).

2. Objective

The narrative, maps and tables in this document describe a pilot method for calculating current ecological departure from reference conditions based on Natural Resources Conservation Service ecological site descriptions (NRCS ESDs; NRCS, 1997). This method, called ESD-departure, is needed to support federal land management agencies and others that apply ESDs in assessment and management across extensive areas in New Mexico and elsewhere. ESDs are specialized for application in semiarid rangelands, model reference and non-reference conditions, and provide ecosystem-specific information about ecological thresholds (e.g. that lead to desertification), ecological and human-related drivers of non-reference condition (e.g. altered fire regime), and restorative management options (e.g. prescribed fire and grazing management). However, no standard approach for spatially calculating departure from reference conditions within the ESD framework has been available. By linking to state-transition models and other content of ESDs, ESD-departure provides this resource. This ESD-departure method also will meet a need to facilitate coordination between users of ESDs and another important ecological departure metric, Fire Regime Condition Class (FRCC). This is increasingly important as ESDs are often used in rangeland management programs and FRCC in fire management, so the opportunity exists to improve cross-program effectiveness through complementary application.

We define reference condition as the prevailing biotic and abiotic attributes and processes, including natural disturbances, that existed on the landscape prior to intensified human settlement[1]. Information about the magnitude and spatial distribution of current departure from reference conditions is important for several reasons. It provides data about the ecological condition of ecosystems and areas. It

[1]This definition conforms to that of the Historic Climax Plant Community, described in the NRCS National Range and Pasture Handbook (NRCS, 2007). We term this the reference condition state, which is one of several states described by NRCS ecological site descriptions. In New Mexico we considered the reference condition state to exist prior to intensified human settlement of the mid to late 1800s.

clarifies current conditions in the context of reference conditions, and so can help identify management goals (desired conditions). It supports restoration priority-setting by identifying areas currently in reference condition that may benefit from conservation, and areas in non-reference condition that may be candidates for restorative management. ESD-departure, which measures departure from reference condition and links to other information in ESDs, will serve as a significant resource for policy-makers, land managers and the public.

Technically, ESD-departure is a proportional measure of current ecological departure from reference condition for ecosystems and their context landscapes. Results are provided as percent-area departure, for example of a desert grassland ecosystem and generalized across all ecosystems, within a user-selected landscape unit. Calculated at broad scales, ESD-departure summarizes current departure relative to the historic range of variation of ecosystems. Calculated more locally, it can be focused on management-defined priority areas. ESD-departure was developed to provide an appropriate measure of departure that can be applied to assessments based on ESDs, including the spatial data produced in the New Mexico Rangeland Ecological Assessment (Yanoff et al., 2008; accompanies this document). ESD-departure also provides both an alternative and complement to Fire Regime Condition Class (FRCC), which also calculates percent-area departure from reference condition, using a somewhat different framework. As part of our analysis, we compared results of ESD-departure calculated at different scales, and also compared results to LANDFIRE FRCC, which is a national dataset that maps ecological departure. The comparison with LANDFIRE FRCC was carried out to meet the objectives of this LANDFIRE Application Project, and also to improve our knowledge of how ESD, LANDFIRE and FRCC related resources compare and can be used to complement each other.

3. A Note on Fire Regime Condition Class (FRCC)

This document provides a spatial comparison of ESD-departure to the LANDFIRE national FRCC map in southern New Mexico. However, we focus on the methodology of ESD-departure and not LANDFIRE or FRCC. We cover some similarities and differences in the text, Box 1 and a report produced by Yanoff and others (2007). For background and to learn more about LANDFIRE FRCC and FRCC methodology we recommend the LANDFIRE (www.landfire.gov/) and FRCC websites (http://frames.nbii.gov/frcc/).

4. Methods

A map of states described in ESDs (NRCS states), or designated by rangeland professionals using ESDs as guides (expert-states), was developed over 14 million acres in southern New Mexico for the New Mexico Rangeland Ecological Assessment (REA). The map was created by rangeland professionals, who drew state polygons onto templates printed with NRCS soil maps, which are correlated to ecological sites. Ecological sites are the biophysical landscape units in which states are nested, and under reference condition were completely covered by reference condition states. Results were digitized and georeferenced in a Geographic Information System (GIS). All states were attributed with reference or non-reference condition from the ESDs or based on expert knowledge. NRCS states were further attributed with their generalized state (e.g. shrub-invaded former grassland), drivers of departure (e.g. altered fire and grazing processes) and restorative management options (e.g. prescribed fire and modified grazing) from the information in ESDs. NRCS states were also attributed with restoration potential, which was our interpretation of the management effort required for restoration based on the management options. Restoration potential was assigned as maintenance for areas mapped as reference condition states, moderate for non-reference condition states for which ESDs did not indicate restorative soil work or cultivation, and high for non-reference condition states requiring soil work or cultivation. The REA state map is described in detail in the accompanying main report.

For ESD-departure, the percent-area of REA-mapped non-reference condition states was calculated by ecological site within a USGS 10-digit hydrologic unit code (HUC) watershed (current reference condition states can occupy portions of ecological sites, see Box 1). The procedure was to sum the area of all mapped non-reference condition states for each ecological site across the HUC 10 watershed, then divide this by the total area of all mapped reference plus non-reference condition states for each ecological site across the watershed. The formula is *ESD-departure = sum(non-reference condition state area)/sum(reference condition + non-reference condition state area)* 100*, for each ecological site across a summary unit. ESD-departure was then calculated for these same ecological sites within two progressively larger summary units: the surrounding 8-digit HUC watershed and the surrounding NRCS subresource area (Fig. 2). Departure was reported for individual ecological sites and indexed similarly to FRCC. ESD-departure 1 is <33% non-reference condition across each ecological site's total area within a summary unit, ESD-departure 2 is 33%-66% non-reference condition, and ESD-departure 3 is >66% non-reference condition. To generalize results to summary units, areas in ESD-departure 1, 2 and 3 were summed across ecological sites. This allowed us to report the percent of each summary unit in each departure class. ESD-departure was compared between ecological sites and summary units.

We also compared ESD-departure to LANDFIRE FRCC, which calculates FRCC for biophysical settings (similar to but coarser than ecological sites) within ecoregional subsections across the United States (http://www.landfire.gov/). The existing LANDFIRE National FRCC map was clipped to the ecological sites identified in the HUC 10 watershed, where they had been mapped by the REA in the two watersheds, subresource area and one ecoregional subsection (Fig. 2). FRCC was summarized for these areas in these 4 summary units. Results were generalized to summary units and not analyzed for individual ecological sites, because it is unclear how well ecological sites and biophysical settings correspond (see Key Findings and Box 1). FRCC was not recalculated for the watersheds or subresource area. Finally, we overlaid ESD state attributes – generalized states, drivers of departure, management options and restoration potential – in the two watersheds to illustrate the information in ESDs.

Fig. 2. Study Area in Southern New Mexico

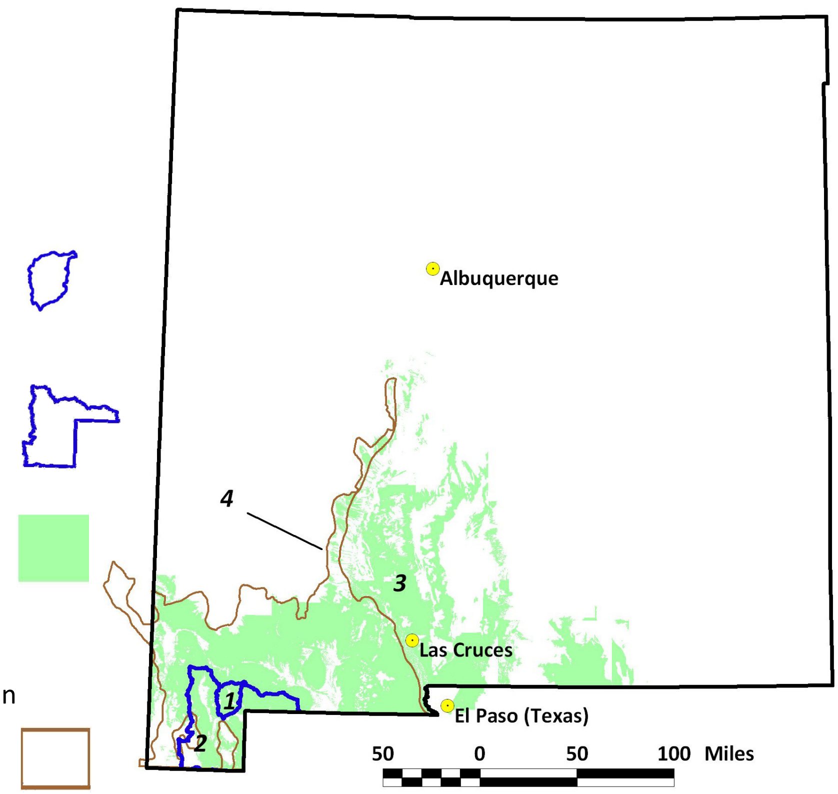
Summary units for calculating departure:

1 - USGS HUC 10 Watershed *Headwaters Hatchita Valley* (115,358 acres)

2 - USGS HUC 8 Watershed *Playas Lake* (1,075,907 acres)

3 - NRCS subresource area *Southern Desertic Basins, Plains and Mountains (SD2)* (7,950,188 acres; delineated from NRCS county soil surveys)

4 - LANDFIRE ecoregional subsection (5,995,008 acres; clipped to LANDFIRE map zone 25)



ESD-departure was calculated for selected ecological sites in summary units 1-3 in this project. LANDFIRE FRCC was calculated previously for summary unit 4, and FRCC was overlaid onto areas mapped to these ecological sites.

Analyses excluded areas mapped to multiple states that conflict in ecological site or reference and non-reference condition. Results pertain only to the mapped extent of the 8 ecological sites in each summary unit, and percents are relative to these areas. This provided a consistent basis for comparing different size summary units, enabling us to examine scale as a factor since ESD-departure and FRCC are proportional metrics. This appendix describes ESD-departure in detail for selected ecological sites. ESD-departure was also calculated across the REA mapped area. Results are summarized in Box 7 of the accompanying report, and provided in detail in Appendix 1.

5. Results

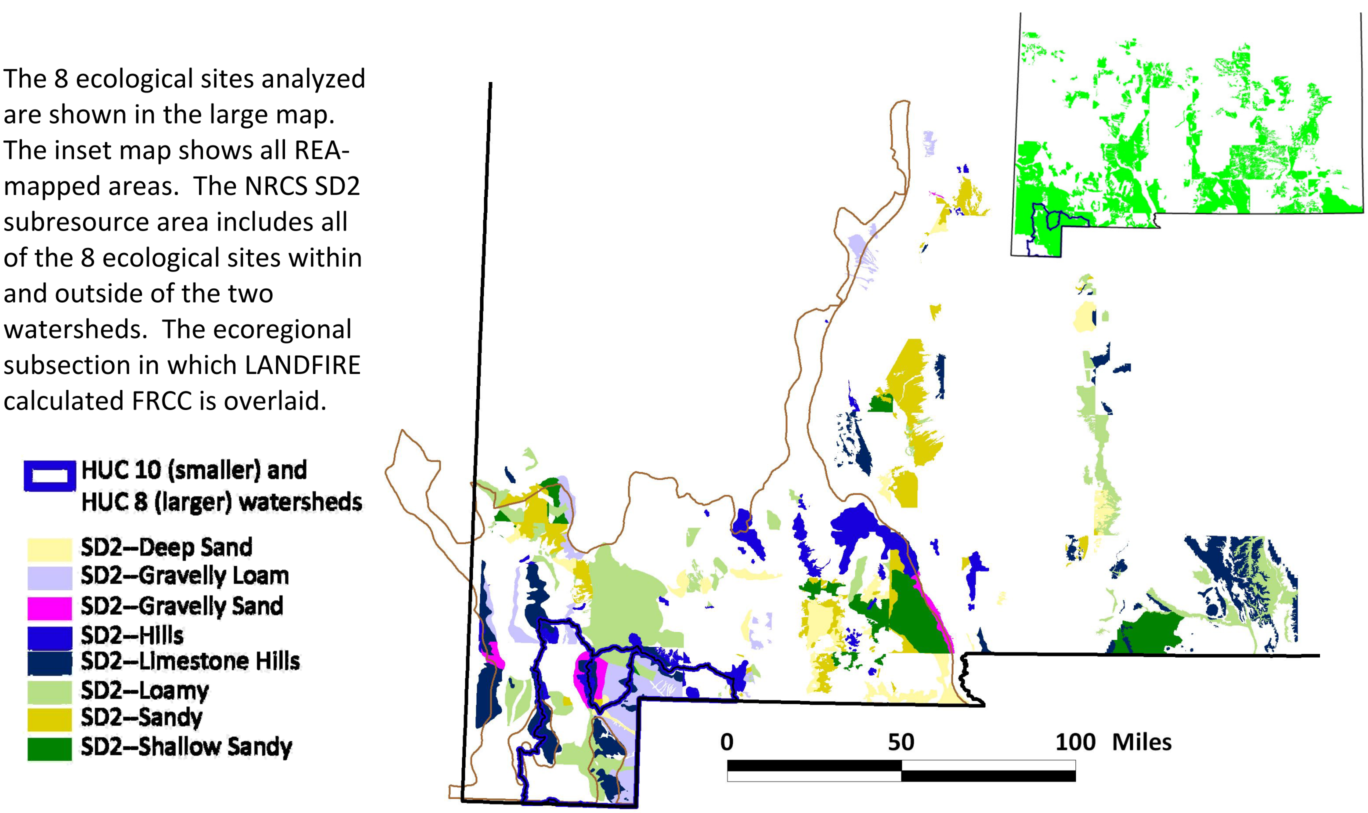
A. ESD-departure for Ecological Sites within Summary Units

The HUC 10 watershed was over 99% mapped by the REA (115,331 acres). It contained 8 ecological sites (Fig. 3), and each ecological site was completely mapped to reference or non-reference condition states. Four ecological sites were entirely reference condition and four were entirely non-reference condition. Hence percent-area departure was 0% (ESD-departure 1) for four ecological sites and 100% (rounded) for the other four (ESD-departure 3; Tbl. 1, Fig. 4).

The REA mapped 81% of the larger HUC 8 watershed. The same 8 ecological sites (Fig. 3) covered 650,490 acres in this watershed. These were mapped to 13 states, with 4 of the cological sites including both reference and non-reference states. Percent area departure ranged from 0% to 26% (ESD-departure 1) for 3 ecological sites and 76% to 100% for 4 sites (ESD-departure 3; Tbl. 1, Fig. 4).

Fig. 3. Location of Eight Focus Ecological Sites in southern New Mexico

The 8 ecological sites analyzed are shown in the large map. The inset map shows all REA-mapped areas. The NRCS SD2 subresource area includes all of the 8 ecological sites within and outside of the two watersheds. The ecoregional subsection in which LANDFIRE calculated FRCC is overlaid.



The REA mapped 49% of the NRCS Southern Desertic Basins, Plains and Mountains subresource area (SD2), based on the delineation of SD2 from NRCS county soil surveys (Soil Survey Staff, SSURGO, [online]). This delineation is tentative, however, because the REA mapped some areas as SD2 that were not assigned subresource areas by the soil surveys, and the soil surveys assigned some areas to subresource areas that differed from those mapped in the REA. In SD2 the 8 ecological sites covered 3,632,569 acres and included 38 states (Fig. 3). All 8 ecological sites mapped included both reference and non-reference states. Percent area departure was 6% to 32% (ESD-departure 1) for 3 ecological sites, 59% for one site (ESD-departure 2) and 70% to 88% for 4 sites (ESD-departure 3; Tbl. 1, Fig. 4).

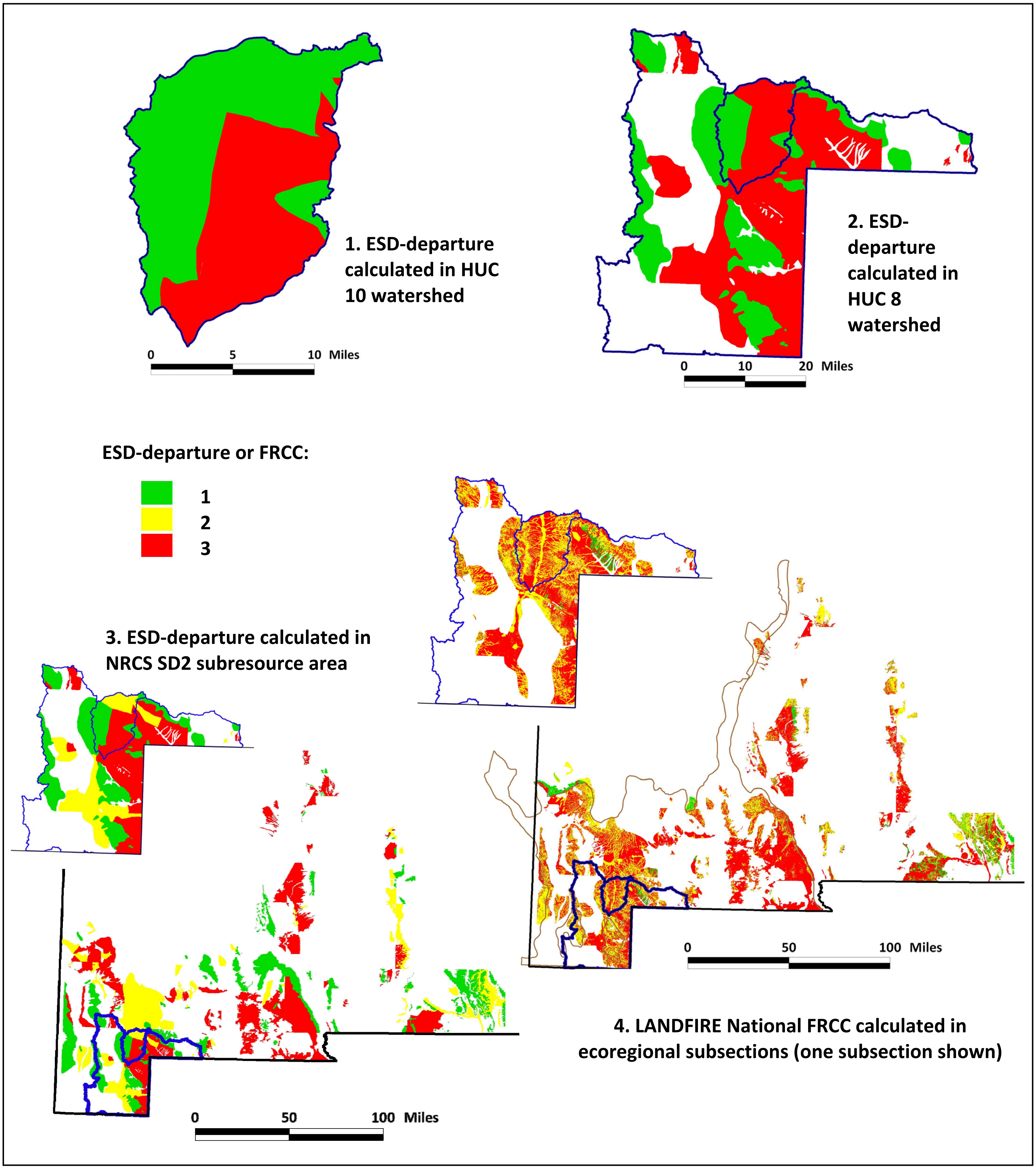
The most variable ecological site in terms of ESD-departure across the two watersheds and SD2 was SD2 Loamy. This site was completely reference condition in the HUC 10 watershed and 76% non-reference condition in the HUC 8 watershed (Tbl. 1). SD2 Loamy was also the only ecological site indexed as ESD-departure 2, and that was in the SD2 summary unit. The other ecological sites had negligible to modest ESD-departure differences between summary units.

Tbl. 1. ESD-departure of Eight Focus Ecological Sites in Three Summary Units*

	1. HUC 10				2. HUC 8				3. SD2 NRCS subresource area			
Ecological Site	**Total**	**Non-reference Condition**	**% Non-reference condition**	**ESD-Departure Index**	**Total**	**Non-reference Condition**	**% Non-reference condition**	**ESD-Departure Index**	**Total**	**Non-reference Condition**	**% Non-reference condition**	**ESD-Departure Index**
SD2--Deep Sand	4,661	4,661	100%	3	14,883	14,883	100%	3	331,106	290,387	88%	3
SD2--Gravelly Loam	40,752	40,752	100%	3	228,813	190,105	83%	3	375,389	297,958	79%	3
SD2--Gravelly Sand	18,963	0	0%	1	38,300	0	0%	1	82,441	26,739	32%	1
SD2--Hills	4,721	0	0%	1	41,142	10,777	26%	1	366,288	21,106	6%	1
SD2--Limestone Hills	16,803	0	0%	1	161,738	0	0%	1	662,292	49,563	7%	1
SD2--Loamy	24,342	0	0%	1	153,094	116,829	76%	3	948,910	559,493	59%	2
SD2--Sandy	3,365	3,365	100%	3	8,447	8,447	100%	3	479,262	451,183	94%	3
SD2--Shallow Sandy	1,724	1,724	100%	3	4,072	4,072	100%	3	386,882	271,050	70%	3

*Areas is in acres. ESD-departure 1 is <33% non-reference condition area, ESD-departure 2 is 33%-66% non-reference condition area,; and ESD-departure 3 is >66% non-reference condition area; calculated across all REA-mapped state polygons of each ecological site within each summary unit.

Fig. 4. Generalized ESD-departure and LANDFIRE FRCC



ESD-departure was analyzed for the 8 ecological sites identified in the HUC-10 watershed. It was calculated for each ecological site in both watersheds and SD2, and results generalized to these summary units. For comparison, LANDFIRE FRCC, previously calculated for biophysical settings in ecoregional subsections, was clipped to the 8 ecological sites in both watersheds, SD2 and in the ecoregional subsection shown. The two inset maps zoom in on the watersheds. ESD-departure and FRCC 1 is <33% non-reference condition area; ESD-departure and FRCC 2 is 33%-66% non-reference condition area, and ESD-departure and FRCC 3 is >66% non-reference condition area.

B. ESD-departure Index and LANDFIRE FRCC generalized to Summary Units

ESD-departure 1 covered proportionally more area in the HUC 10 watershed than ESD-departure 3 (Tbl. 2, Fig. 4). Conversely, ESD-departure 1 was lower than ESD-departure 3 in its other summary units, and LANDFIRE FRCC 1 was lower than LANDFIRE FRCC 3 in all summary units. LANDFIRE mapped very small proportions of any summary unit in LANDFIRE FRCC 1 (<4%). ESD-departure 1 comprised similar proportions of the HUC 8 watershed and SD2 (31-37%). ESD-departure 2 was not mapped in the two watersheds, but comprised 26% of SD2. LANDFIRE FRCC 2 covered 22% to 51% of summary units, and ESD-departure 3 and LANDFIRE FRCC 3 covered 43% to 63% of summary units.

Tbl. 2. ESD-departure and LANDFIRE FRCC Generalized to Four Summary Units

see text for an explanation of how to read this table

	1. HUC 10		2. HUC 8		3. SD2 NRCS subresource area		4. Landfire ecoreg. subsection
ESD-Departure or FRCC	**% ESD-departure**	**% LANDFIRE FRCC**	**% ESD-departure**	**% LANDFIRE FRCC**	**% ESD-departure**	**% LANDFIRE FRCC**	**% LANDFIRE FRCC**
1	**56%**	**0%**	**37%**	**3%**	**31%**	**4%**	**1%**
2	**0%**	**51%**	**0%**	**47%**	**26%**	**22%**	**36%**
3	**44%**	**49%**	**63%**	**51%**	**43%**	**35%**	**55%**

The preceding analysis (Tbl. 2) reviewed ESD-departure classes and LANDFIRE FRCC as proportions of summary units, but not their spatial agreement. The spatial overlap between ESD-departure classes, and between those classes and FRCC, was also analyzed across summary units. Specifically, we determined the proportion of each HUC 10 ESD-departure class overlapped by its equivalent ESD departure class of the HUC 8 watershed and SD2 subresource area, and overlapped by LANDFIRE FRCC. We also assessed the proportion of each HUC 8 ESD departure class overlapped by its equivalent ESD departure class of the SD2 subresource area, and overlapped by LANDFIRE FRCC.

As an example of how to interpret results, 62% of the area mapped to ESD-departure 1 in the HUC 10 watershed (map 1 of Fig. 4) was overlapped by the HUC 8 watershed's ESD-departure 1 area (map 2, Fig. 4), and 56% of the HUC 8 watershed's ESD-departure 3 area was overlapped by LANDFIRE FRCC 3. Spatial overlap is summarized in Tbl. 3. Overall, there was moderate agreement for ESD-departure 1 between the HUC 10 watershed and both the HUC 8 watershed and SD2. There was also moderate agreement for ESD-departure 3 between the HUC 10 watershed and LANDFIRE FRCC 3. There was complete agreement between for ESD-departure 3 between the HUC 10 watershed and both the HUC 8 watershed and SD2. ESD-departure 1 of the HUC 8 watershed completely agreed with that of SD2, and ESD-departure 2 of the HUC 8 watershed moderately agreed with ESD-departure 2 of SD2 and LANDFIRE FRCC 3. The most obvious divergence in spatial overlap was poor agreement of either watershed's ESD-departure 1 with LANDFIRE FRCC 1 (since LANDFIRE mapped very little FRCC 1 in these areas).

Tbl. 3. Spatial Overlap of ESD-departure and LANDFIRE FRCC in Four Summary Units

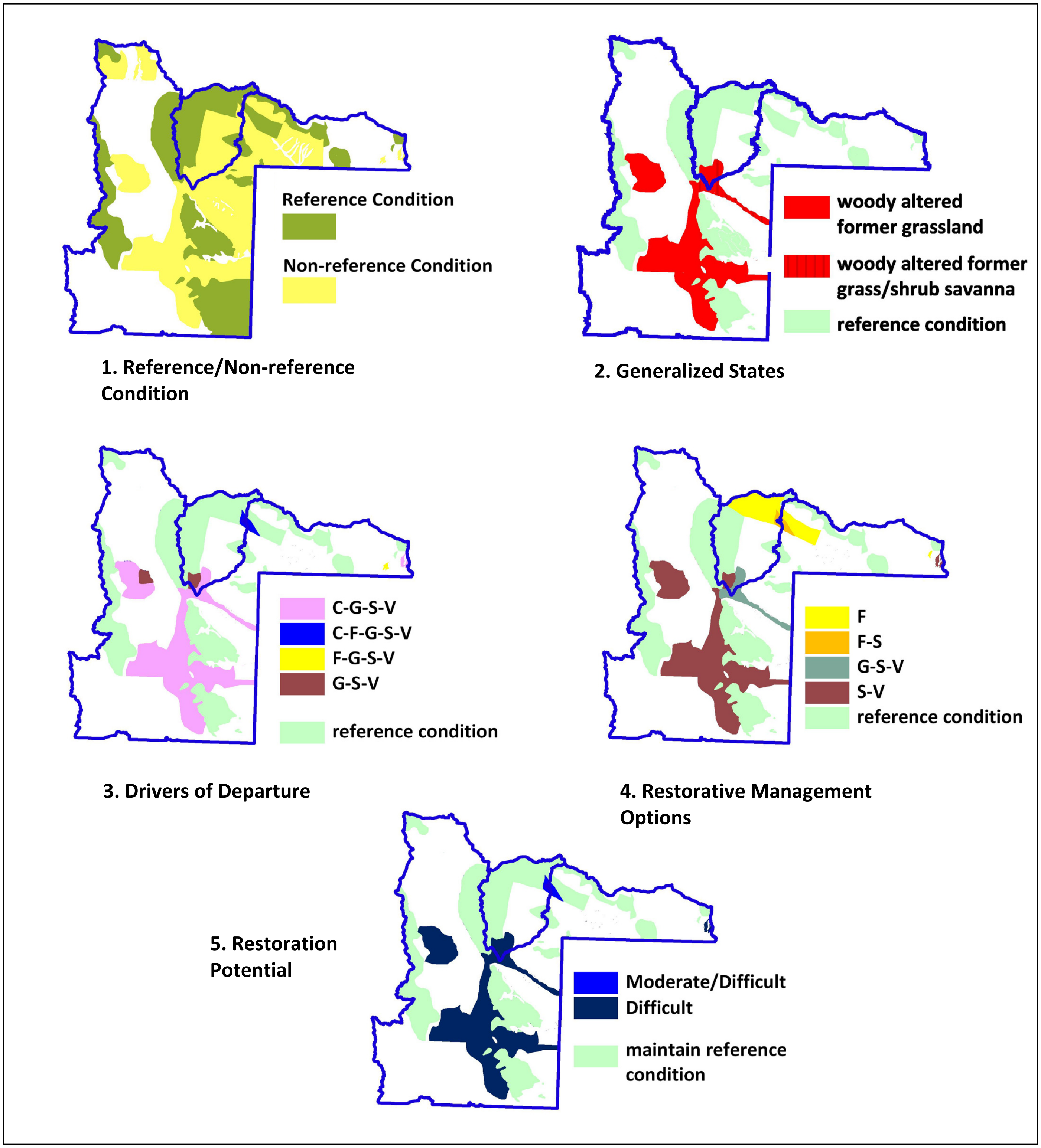
see text for an explanation of how to read this table

		ESD-Departure or FRCC		
% of:	**overlapped by:**	**1**	**2**	**3**
1. HUC 10	**HUC 8**	**62%**	**na**	**100%**
	SD2	**63%**	**na**	**100%**
	LANDFIRE FRCC	**0.2%**	**na**	**47%**
2. HUC 8	**SD2**	**100%**	**na**	**63%**
	LANDFIRE FRCC	**3%**	**na**	**56%**

C. State Attributes

Reference or non-reference condition, generalized states, drivers of departure, restorative management options and restoration potential were overlaid onto the HUC 10 and HUC 8 watersheds in Fig. 5. We did not analyze their acreages or percentages for this appendix, although further analysis for this HUC 8 watershed (Playas Lake) is provided in the accompanying main REA report and Appendix 2. In the Discussion section below we elaborate how these state attributes can enrich ESD-departure and FRCC (Fig. 4) with information about departure processes and restoration opportunity.

Fig. 5. State Attributes



ESD attributes are shown for the two watersheds. Areas where more than one state was mapped at the same location having conflicting attributes are excluded. Except for reference/non-reference condition, which includes both expert and NRCS states, only NRCS states are shown (see Methods). **Key:** ***Generalized States*** – woody altered = shrubs or trees dominant compared to reference condition, grass absent or sparse, highly altered ecological processes; ***Drivers of Departure from Reference Condition*** – C = climate-related (e.g. drought), F = fire-related (e.g. fire suppression), G = grazing-related (e.g. overgrazing), S = soil-related (e.g. erosion), V = vegetation-related (e.g. grass-cover loss); ***Management Options*** – F = fire mgt (e.g. prescribed fire), G = grazing mgt (e.g. modified grazing), S = soil mgt (e.g. erosion control), V = vegetation mgt (e.g. remove invasive woody plants; ***Restoration Potential*** – maintenance (reference condition states), moderate = non-reference condition states, no soil work/cultivation required, difficult = non-reference condition states, soil work/cultivation required

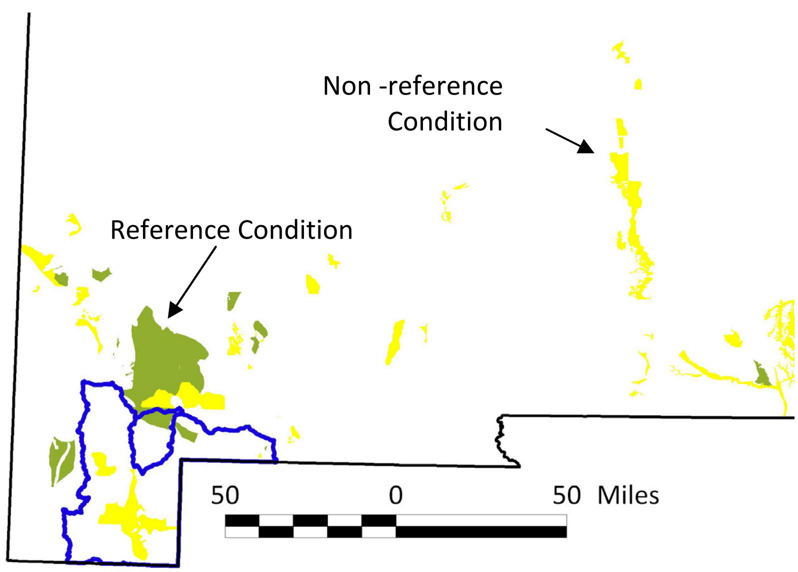
6. Key Findings and Conclusion

Key Findings

The major findings of this project are summarized and interpreted as follows:

(1) *Percent-area departure varied for ecological sites across summary units, and an intermediate departure class was only identified in the largest summary units. Some underlying patterns of departure are not conveyed by percent-area departure metrics. These points have implications for the scale of assessment and the kind of information these metrics provide.* Considering that the same ecological sites (or in the case of LANDFIRE the areas they occupy) were analyzed in each summary unit, and that ESD-departure and FRCC are proportional metrics, variable results were not unexpected since summary units differed in size and configuration. This is illustrated by examining the distribution of the SD2 Loamy ecological site across summary units in Fig. 6.

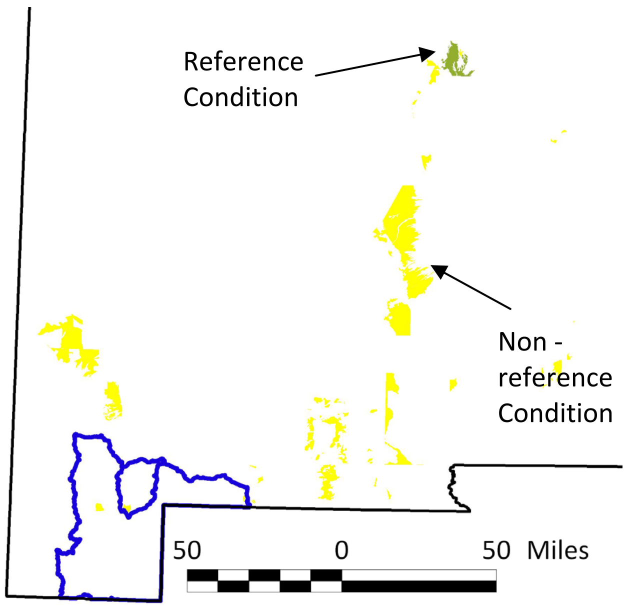
Fig. 6. SD2 Loamy Ecological Site Reference and Non-Reference Condition



Reference condition states (grassland) are green and non-reference condition states (altered by non-historic grass or shrub-invaded or dominated) are yellow. The small HUC 10 watershed only contains reference condition area for this ecological site, and so is not in departure if that watershed is the summary unit (Tbl. 1). Much of this ecological site (76%) is non-reference condition in the context of the HUC 8 watershed, yielding an ESD-departure index of 3. Across the SD2 subresource area (all colored areas in this map) there is more of a mix of reference and non-reference condition states, and here the ESD-departure index for the SD2 Loamy ecological site is 2.

The other major trend, that of little difference between departure for the same ecological site across summary units, is illustrated in Fig. 7. Here, non-reference condition states of the SD2 Sandy ecological site dominate regardless of summary unit and ESD-departure is high (Tbl. 1). The single patch of reference condition area in the northeast moderates ESD-departure for the SD2 subresource area, which is 94% as opposed to 100% in the two watersheds.

Fig. 7. SD2 Sandy Ecological Site Reference and Non-Reference Condition



Clearly, percent-area departure metrics such as ESD-departure and FRCC are sensitive to the underlying distributions of ecosystems (e.g. states) and the scale (e.g. size and configuration) of the summary units. It is interesting that some ecological sites appear more susceptible to departure or have fairly uniform distributions of reference and non-reference condition areas (e.g. SD2 Sandy), while others may be resistant to departure or have uneven distributions (e.g. SD2 Loamy). Such differential susceptibility to ecological change in association with distinct biophysical environments has been identified by Herbel et al. (1972), Asner et al. (2003) and others. The significance of uneven geographic patterns for management may not be captured well in percent-area departure metrics. For example, the intermediate levels of percent-area departure signified by ESD-departure 2 and FRCC 2 may not translate into management priority, compared to ESD-departure 1 and FRCC 1, which suggest conservation and maintenance need, and ESD-departure 3 and FRCC 3, which suggest high restoration need. However, such an interpretation would overlook the importance of the extensive SD2 Loamy reference condition grassland just north of the HUC 8 watershed, (Fig. 6). This 300,000 acre area was by far the largest single reference condition grassland mapped in the REA, and so may be a management priority for maintaining reference condition.

The differences in departure between summary units for selected ecological sites underscore three key features of percent-area departure. First, it is important to review results for individual ecosystem components which are not obvious in the more generalized ESD-departure and FRCC summaries (e.g. Tbl. 2). Second, some crucial patterns of departure, as demonstrated by our review of the SD2 Loamy ecological site, simply are not conveyed by percent-area departure metrics and need attention to be evaluated to support informed decisions. Third, it is important to evaluate percent-area departure at different scales. A broad scale context, such as NRCS subresource areas and ecoregional subsections, provides a summary evaluation of departure over the historic range of variation (HRV) of ecosystems. This can help alert managers to the overall status of different ecosystems at regional scales. More narrow summary units, such as HUC 8 and HUC 10 watersheds, which may truncate HRV for some ecosystems and so be less informative about overall status, can help managers assess restoration priorities at targeted management scales[2].

(2) *High generalized departure was associated with all summary units despite variability among ecological sites, summary units and ESD-departure vs. LANDFIRE FRCC.* Table 2 bears this out, in which ESD-departure 3 and FRCC 3 accounted for large proportions of each summary unit. This “consensus” among scales and methods indicates the considerable extent of departure from reference condition in the study area.

(3) *LANDFIRE reported much smaller areas of FRCC 1 than ESD-departure 1 in each summary unit, and overall spatial correspondence was poor to moderate.* This pattern held even when comparing ESD-departure calculated in SD2 to LANDFIRE FRCC in SD2 or in the ecoregional subsection (Tbl. 2), which are summary units of comparably large size and area of overlap. This suggests that scale differences were not pivotal. Investigating the details as to why results differed was beyond the scope of this project. Among other things, this would require an accuracy assessment of the maps used for each method, examination of the different components of LANDFIRE FRCC, including its VDDT models and biophysical settings, and explicit comparisons between those models and biophysical settings and ESDs. However, based on our familiarity with these approaches we speculate that several factors may have contributed.

First, the expert mapping protocol of the REA state map, which was the basis for establishing current condition in the ESD-departure calculation, intrinsically encouraged the delineation of blocks of areas that followed soil map unit and topographic features. In contrast, LANDFIRE’s map of existing vegetation (which was compared to that predicted under reference condition) was largely based on 30-meter pixel resolution Landsat satellite imagery. The finer grain of LANDFIRE mapping products is evident by

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[2]We note, however, that parameters of HRV such as the ideal size and configuration of summary units, were not systematically determined for individual ecological sites in this project. We hypothesized that NRCS subresource areas reflected the range of historic variation of their nested ecological sites, for example, that HRV for the SD2 Sandy ecological site can be represented by the SD2 subresource area within which it was classified. We further hypothesized that the HUC 8 and HUC 10 watersheds were increasingly less representative of HRV. However, in the absence of ecological site-specific details about reference condition, such as natural disturbance regime size and frequency, or landscape patch structure, our assumptions about sufficient HRV scales are unconfirmed.

comparing the maps in Fig. 4. This difference in map detail potentially enabled the LANDFIRE FRCC calculation to distinguish more complex variation in vegetation distribution, and could contribute to different percent-area departure results. However, this explanation may not account for all differences, since it is also evident from Fig. 4 that many areas simply do not correspond. For example, several extensive ESD-departure 1 areas in map 3 of Fig. 4 strongly contrast with the spatially corresponding FRCC 3 dominated areas in map 4 of Fig. 4.

The existence of certain non-reference condition states described in ESDs that may be difficult to detect by remote sensing mapping methods, such as that used by LANDFIRE, may also have contributed to different results. Remote-sensing vegetation mapping can be limited in its ability to distinguish between different grassland types or to pick out low cover vegetation. This is especially true in arid and semiarid environments where soil signals can obscure vegetation signals (Marsett, et al., 2006). The mid-resolution Landsat satellite imagery used by LANDFIRE can also be limiting. Non-reference condition states described in ESDs that may be difficult to identify using remote sensing include grasslands dominated by non-historic species with high bare ground cover (e.g. burrograss, *Scleropogon brevifolius*) and shrub or tree-invaded grasslands in which the woody plants have low cover (e.g. <20% canopy cover). In contrast, the expert mappers in the REA were able to map these states based on field experience.

A third potential factor is that the two methods utilize different ecological classifications. LANDFIRE biophysical settings, which establish reference condition, are broad in vegetation type and abiotic features compared to ESDs, which are classified at the level of plant communities and NRCS county soil survey soil map units. Conversely, LANDFIRE enumerates the succession classes that comprise reference condition and current vegetation, and their height and cover classes, more stringently than ESDs. ESDs assume that the appropriate succession classes, their dynamics, and vegetation parameters are embedded in states without explicitly quantifying them. ESDs expressly delimit reference condition states by ecological thresholds, whereas biophysical settings may not do so consistently. Indeed, Yanoff et al. (2007) found that some ecological sites and biophysical settings in southern New Mexico did not fully crosswalk, in part related to such threshold boundaries. Since LANDFIRE FRCC was calculated for biophysical settings and not ecological sites, our method of clipping the existing LANDFIRE FRCC map to ecological sites for analysis may have juxtaposed contrasts that go beyond scale. Such variation could be reflected in percent-area departure results.

A related factor is that the models that underlie LANDFIRE FRCC and ESDs are functionally different, and may yield estimates of reference condition that do not conform. FRCC uses probabilistic quantitative models to predict the proportions of succession classes that would occur under reference condition. ESD s and their state-transition models largely describe, rather than quantify, ecological dynamics within and between reference and non-reference condition states. There is also some opinion that the parameters (e.g. frequency) and interactions of natural disturbances, which FRCC models use as inputs to predict reference condition, are too poorly known and unpredictable in semiarid ecosystems to generate reliable results. Comparisons between ESD-departure, FRCC and related components are elaborated in Box 1.

(4) *The information in ESDs can be used to enhance both ESD-departure and FRCC in terms of ecological condition and restoration opportunity.* ESD-departure and FRCC are valuable measures of departure, but as simple percent-area metrics they convey limited information about ecological condition and restoration opportunity. While the VDDT models and other LANDFIRE FRCC components are informative, they focus on dynamics within reference condition, which do not necessarily address management needs. ESDs explicitly describe state-specific ecological thresholds, pathways between reference and non-reference condition states, drivers of departure and restorative management options that can significantly enhance percent-area departure results. Such information can be used to help distinguish areas and ecosystems that should be prioritized for restoration, different levels of departure and restoration potential, especially with regards to thresholds, and effective treatment methods.

This is illustrated by comparing the departure results of Fig. 4 with the ESD state attributes in Fig. 5, overlaid onto the same areas. For example, both ESD-departure and LANDFIRE FRCC assigned the "peninsula" south of the HUC 10 watershed and within the HUC 8 watershed (separated from the HUC 10 watershed by the north-south "isthmus") as highly departed (maps 2 and 4 in Fig. 4). The ESD state attributes (Fig. 5) indicate this area as a woody plant-altered former grassland (map 2). This means that woody plants (shrubs) dominate the landscape, that grass is minor or absent, and that the ecological processes that supported the historical grassland are highly altered. Drivers of departure for this state, according to the ESDs, are or were (ESDs do not specify the time period of drivers) climate-related (e.g. drought), grazing-related (e.g. overgrazing), soil-related (e.g. erosion) and vegetation-related (e.g. loss of grass cover; map 3). Restorative management options include soil (e.g. restoring fertility) and vegetation (e.g. removing shrubs) management (map 4). Since intensive soil management is indicated for restoration, we interpreted restoration effort as difficult for this state (map 4). The specific state mapped in this area was SD2 Loamy Shrub-dominated, which is not shown in Fig. 5 but can be reviewed online at http://www.nm.nrcs.usda.gov/technical/fotg/section-2/esd.html). The SD2 Loamy ESD's state-transition model depicts this particular state as having crossed a significant ecological threshold possibly including high sheet erosion, soil truncation and other soil alterations. Taken together, this information suggests that other areas may be higher and more practical priorities for restoration, despite the ESD-departure 3and FRCC 3 designations.

Notes on REA map extent and application scale for the REA and LANDFIRE:

The fact that the REA did not completely map summary units, except for the HUC 10 watershed, should be noted, since we relied on the REA state map both to delimit the analysis scope (the 8 ecological sites) and on its mapped states to calculate ESD-departure. It is probable that some portions and occurrences of these 8 ecological sites were not mapped in the study area. ESD-departure could change if these unmapped areas differ substantially in reference and non-reference condition from the mapped areas. That said, the REA mapped these ecological sites over substantial portions of the HUC 8 watershed (over 650,000 acres), SD2 subresource area (3.6 million acres) and ecoregional subsection (2.2 million acres; Fig. 3 - areas not mapped by the REA are uncolored in the inset map). It is conceivable, then, that the REA map provided an adequate sample of these 8 ecological sites, although this was not systematically tested. A further test of the impact of the unmapped areas could be carried out in the future by incorporating other ESD state maps, such as the one prepared by the USDA Agricultural Research Service-Jornada Experimental Range in southern New Mexico.

LANDFIRE was developed for national and sub-national (e.g. regional) applications, and the REA for application at state and sub-state scales (e.g. agency district and management plan boundaries within New Mexico). The implications for applying these products at finer scales is uncertain, so the results presented in this report may best represent broad trends rather than exact values.

Conclusion

ESD-departure is a promising method for summarizing percent-area departure and is well suited for ESD-based assessments. Since ESD-departure is based on ESDs, which in turn are specialized for the complex, nonlinear and threshold-mediated ecological dynamics of semiarid ecosystems, ESD-departure may offer unique benefits when applied in semiarid regions. ESD-departure is conceptually similar to FRCC and can be used both as an alternative and complement to FRCC. The shared application of ESD and FRCC based methods will take advantage of their different strengths, and encourage efficient coordination between rangeland and fire management, since these disciplines often apply one or the other approach (Box 1). ESDs contain ample information about ecological condition and restoration opportunity to enrich the simpler results of percent-area departure metrics, including ESD-departure and FRCC. It is important to review departure results for component ecosystems (e.g. ecological sites) and not just the generalized results for summary units. The scale (size and configuration) of summary units and the distribution (e.g. geographic unevenness) of component ecosystems can significantly influence percent-area departure. It is unclear why ESD-departure and FRCC differed in our analysis, particularly in their proportions of the low departure class (ESD-departure 1 vs. FRCC 1), but factors ranging from mapping techniques to different classifications and underlying models may have played a part.

Box 1. Comparing ESD-departure and LANDFIRE Fire Regime Condition Class

ESD-departure is conceptually similar to Fire Regime Condition Class (FRCC; Hann et al., 2005). Both calculate percent-area departure from reference condition for ecosystems and their context landscapes, and can be applied at varying scales. ESD-departure can report departure using the same percent-area index as FRCC (FRCC-1 < 33% departed by area, FRCC-2 33-66% departed, FRCC-3 >66% departed). When mapped across large areas, both ESD-departure and LANDFIRE FRCC (www.landfire.gov/) chiefly depend on comparing existing vegetation to that expected under reference condition, rather than on specific details about disturbance processes. Both methods are most informative, then, about departure in vegetation rather than in disturbance regimes.

ESD-departure, LANDFIRE FRCC and their components differ in several ways: (1) ESDs and their state-transition models describe the vegetation, terrain, soils and disturbances of reference and non-reference condition states in largely qualitative terms. They often do not specify the succession classes that occur within reference condition nor predict their relative proportions. In the ESD framework, a reference condition state would entirely cover its related ecological site. Ecological sites are landscape units that encompass the historic range of biophysical variation of the reference condition state. FRCC uses probabilistic models (Vegetation Dynamics Development Tool or VDDT; Beukema, 2008) to predict the types and relative proportions of succession classes that would occur under reference condition. VDDT output is integrated into biophysical settings, which include both descriptive and quantitative properties of reference condition. Under reference condition, the types and proportions of succession classes predicted by VDDT would entirely cover the related biophysical setting. (2) The state-transition models in ESDs formally incorporate ecological thresholds and nonlinear (e.g. uneven in spatial and temporal rate) sometimes irreversible pathways (e.g. desertification) between reference and non-reference condition states (Bestelmeyer et al., 2004). The VDDT models that underlie FRCC may have the technical capacity for such inputs and can represent reference and non-reference condition, but LANDFIRE VDDT focuses on succession within reference condition. Additionally, the complexity of thresholds and nonlinear processes, and a lack of data about their behavior, may impede their quantification into probabilities for input into VDDT (Bestelmeyer et al., 2004; a simulated VDDT model and an ESD state-transition model are illustrated in Figure 1). (3) ESDs describe both reference and non-reference condition states in detail. Thus ESDs are informative about the extent of departure from reference condition for individual non-reference condition states (e.g. in terms of thresholds and altered ecological function). ESDs also describe restorative pathways that can be used to manage non-reference condition states towards or to reference condition. Such information is important for assessing restoration potential and setting restoration priorities. As noted, LANDFIRE VDDT models emphasize reference condition, although

Box 1 continued:

they have the ability to model non-reference condition as well. FRCC does not explicitly address restoration and management beyond coding ecosystems and their context landscapes with percent-area departure. While FRCC 1 indicates areas that may be conservation priorities, and FRCC 3 indicates areas that may be restoration priorities, information about the level of departure and management options specific for the underlying ecosystems, and the geographic patterns of departure, would significantly enrich the FRCC index. LANDFIRE does, however, produce other data valuable for restoration and management, including succession-class and existing vegetation spatial layers. Likewise, VDDT can be used to predict the effects of different management strategies. (5) ESD-assessments can spatially identify reference condition state "patches" occupying portions of their related ecological sites (map 1, Fig. 5). In this case, the ecological site has some area in departure (non-reference condition states), so the viability of the reference condition fraction is undetermined, especially in relation to its historic range of variability. FRCC typically does not spatially identify reference condition areas within biophysical settings that are in departure, since it uses the relative proportions of succession classes to determine reference condition. Such reference condition areas could be identified by calculating FRCC for increasingly smaller summary units within biophysical settings.

In our view, these differences between ESD-departure, LANDFIRE FRCC and their components support their complementary application. Specifically, both LANDFIRE FRCC and ESD-departure can be used to assess departure from reference condition and results can be compared and evaluated. VDDT can be expanded to model non-reference condition and management scenarios (Provencher et al., 2007). ESD-departure, which requires state maps that can be intensive to develop, can be focused efficiently to corroborate and inform regional LANDFIRE FRCC. ESD-departure may be especially advantageous for semiarid ecosystems, such as rangelands where thresholds are considered to be a driving force behind ecological change. The information in ESDs can enrich both ESD-departure and FRCC. The use of ESDs and FRCC can foster integrated land management, since ESDs tend to be used separately by rangeland managers and FRCC by fire managers. Additionally, federal agencies including the US Forest Service and Bureau of Land Management (BLM) are required to report FRCC in relation to performance measures, and ESDs have been adopted by these agencies as an assessment and management tool.

For further discussion of ESDs, FRCC and related topics see Yanoff et al., 2007.

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New Mexico Rangeland Ecological Assessment Appendix 4:

A Rapid Ecological Condition Mapping Approach

a pilot project to develop a method for mid-scale mapping and interpretation of land condition and restoration opportunity and for monitoring using Landsat satellite imagery in the USDI Bureau of Land Management Socorro Field Office, New Mexico

March, 2008

Prepared by The Nature Conservancy in New Mexico and Earth Data Analysis Center (EDAC) and Natural Heritage New Mexico (NHNM) of the University of New Mexico

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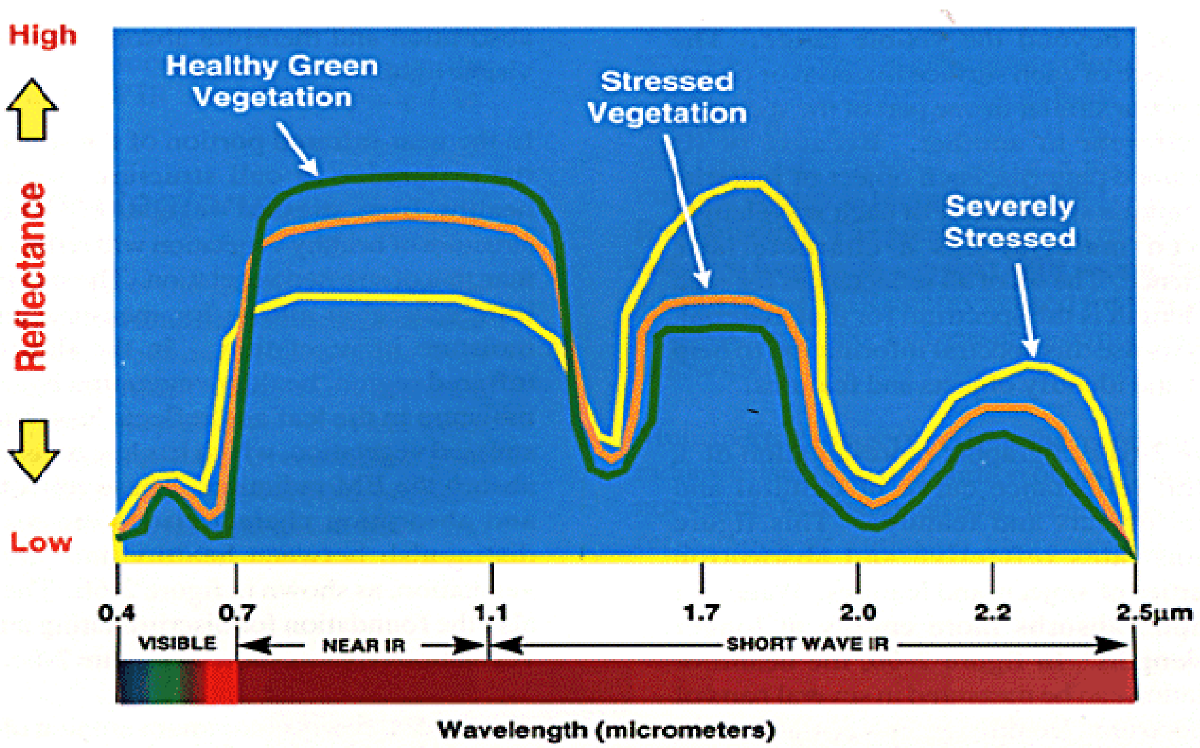
Contents:



Spectral reflectance of vegetation from Hhttp://www.csc.noaa.gov/products/sccoasts/html/rsdetail.htm

1. Overview

Introduction

The purpose of this project was to develop an economical, rapid, and reliable method for mid-scale mapping of vegetation cover for interpreting land condition, restoration opportunities, and to support monitoring. The need for such a tool has been identified by the USDI Bureau of Land Management (BLM) to support affordable and timely ecological assessment and adaptive management of BLM-managed public land. Fine-scale tools such as mapping ecological states as described in Natural Resource Conservation Service ecological site descriptions (NRCS ESDs; NRCS, 2007), or high-resolution satellite imagery and aerial photo analysis , or field reconnaissance, while important, are expensive and time consuming to implement across large areas. Hence, they may be most practical for periodically establishing and updating baseline data, but of are limited use in detecting and responding to fast ecological change. In contrast, the rapid assessment method presented here can be used to produce maps and other spatial data to provide an initial evaluation of a large area and help focus finer-scale information gathering tools. The rapid assessment method can also complement coarser-scale techniques such as MODIS satellite imagery-based change detection, and can be incorporated into a comprehensive restoration strategy, such as the one described in section H, Applying the REA, in the accompanying main report.

The rapid assessment method developed for this project estimates the percent canopy cover of herbaceous and woody plants and barren areas based on analysis of Landsat 30-meter resolution satellite imagery and limited field data. When interpreted by natural resource professionals and others with first-hand knowledge of surveyed areas, canopy cover measurements can be coarse indicators of states described in ESDs. These states can signify ecological condition, including reference condition and departure from reference condition, as well as management options for maintaining areas currently in reference condition and restoring non-reference condition states. ESDs and states are further described in the accompanying main report. By overlaying NRCS soils maps and associated ESD described reference condition states onto canopy cover, we can estimate current condition relative to reference condition. For example, soils corresponding to states that ESDs describe as grassland under reference condition that now have moderate grass, woody plant and barren area cover, suggest woody-invaded former grassland states. Knowledge of such areas can inform restoration priority-setting and help target follow-up with finer-scale tools such as ESD state mapping and field reconnaissance to confirm conditions on the ground.

This rapid assessment method also addresses the need to support cost-effective monitoring. It can be repeated over time at different intensities to assess post-treatment change at the level of these generalized cover classes, (e.g. decreasing or increasing barrenness), and in turn also target finer-scale tools such as state-mapping and field reconnaissance to support adaptive management.

This project is part of the New Mexico Rangeland Ecological Assessment (REA), which is supported by an assistance agreement between the BLM and The Nature Conservancy (TNC). The University of New Mexico Earth Data Analysis Center and Natural Heritage New Mexico developed the technical procedure described in this document.

Contents of this Document

This document illustrates a rapid assessment method carried out in a pilot study area managed by the BLM Socorro Field Office. We tested three methods with the goal of identifying the most cost-effective but reliable means to identify indicators of ecological condition related to states described in ESDs: (1) Image Segmentation/Pattern Recognition (Visual Learning Systems Feature Analyst software), (2) Total Vegetation Fractional Cover, and (3) Canopy Cover Regression. Canopy Cover Regression was the most promising, considering the objectives of resource-efficiency and the ability to map features relevant to key rangeland attributes. In this method a regression function was created that predicted percent canopy based on limited field data and Landsat satellite imagery analysis. This was an expansion of a method developed previously by Natural Heritage New Mexico and the Earth Data Analysis Center on BLM and Department of Defense lands (Muldavin et al. 2001). Results were not assessed for accuracy as this stage of the project focused on initial development of a technical procedure. If the project is extended new maps will be developed for a somewhat larger area based on a larger field data sample and an accuracy assessment will be implemented.

Next Steps

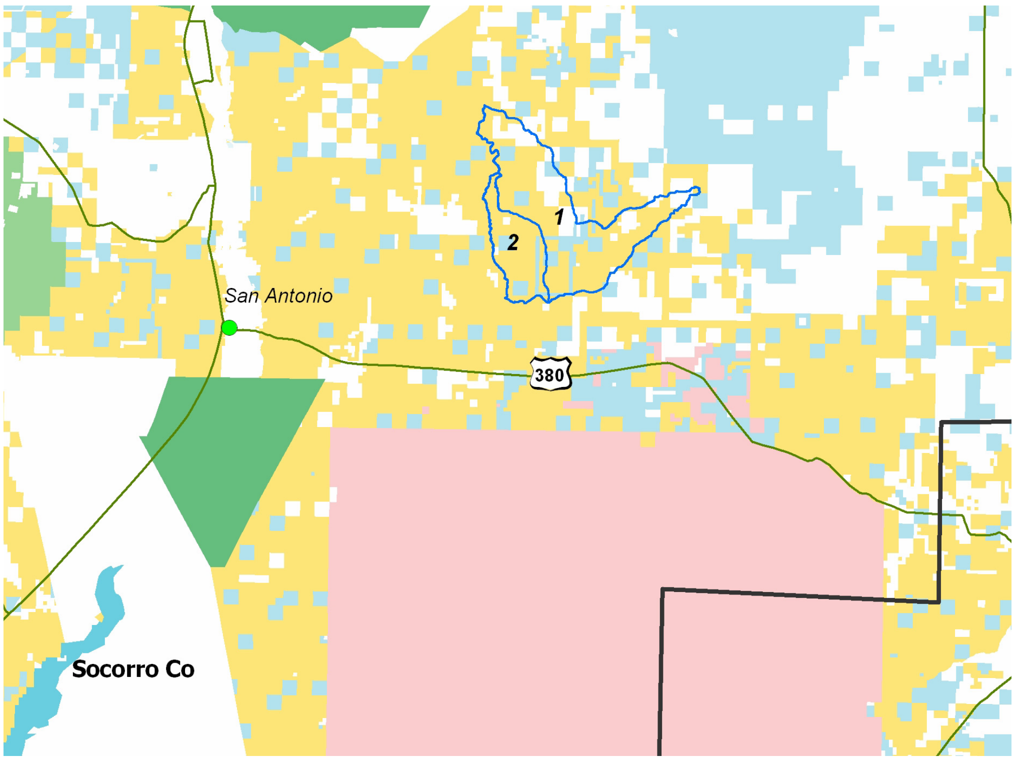
A next step for developing this project would be to increase the field plot sample size and produce percent canopy cover maps stratified by ecological sites (soil-based land units described in ESDs) across the Pecos-Canadian Plains and Valleys (CP3) NRCS Major Land Resource Area (MLRA) in Socorro County. Stratifying by ecological site would control for soils and other factors that confound spectral analysis. This area is significant because it contains extensive piñon-juniper woodlands, savannas and tree-invaded grasslands. Some of these areas are planned to receive vegetation treatments by BLM in the future, so the availability of an assessment and monitoring method such as the one developed in this project will be essential.

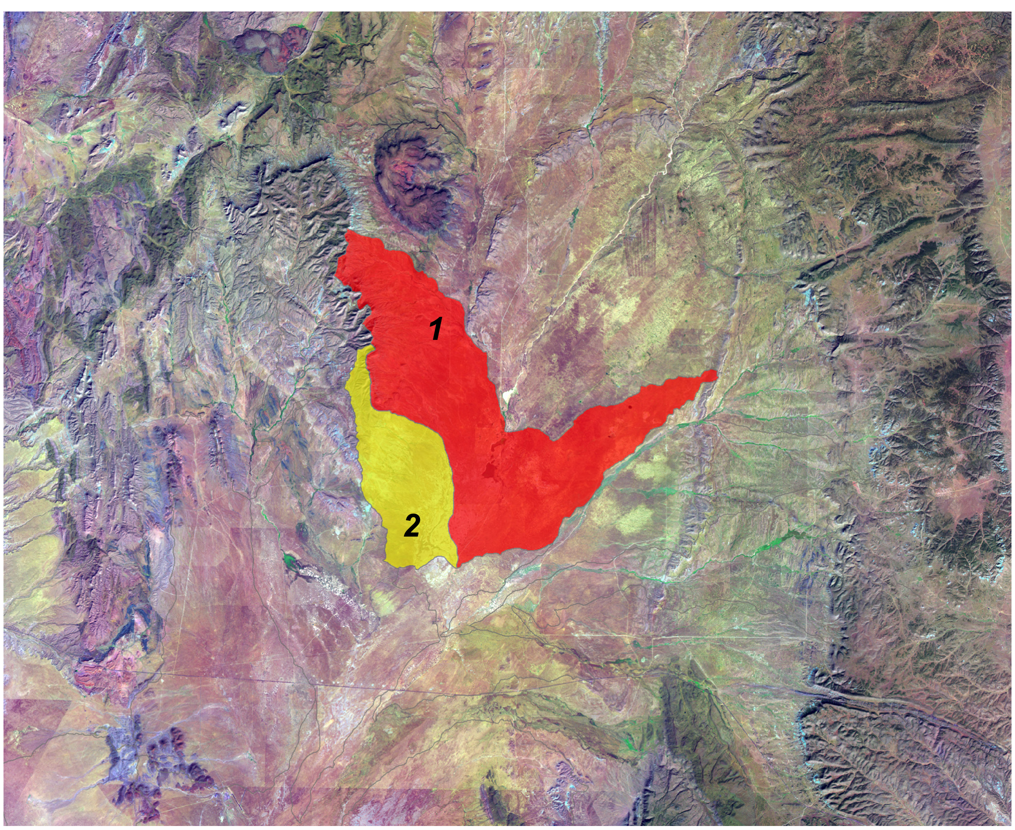
A project extension would also include experimenting with different levels of resources (e.g. number and sources of plots, and season, number and timing of satellite images) to better gauge resource efficiency. The ultimate goal of this effort would be to provide BLM and other land managers a field-tested procedure, but any extension of this project will depend on renewed funding.

2. Methods

a. Location

The study area included the Coyote Springs-Chupadera Arroyo (#1; 39,163 acres.) and Coyote Springs (#2; 12,191 acres) USGS 12-digit HUC watersheds. These are located in the BLM Socorro Field Office, in Socorro County north of US Highway 380, southeast of Socorro and east of San Antonio, New Mexico. The top map is color-coded by ownership, with orange indicating BLM land, light blue state land and white private ownership. The lower map shows the two watersheds overlaid onto a false-color LANDSAT satellite image.





b. Exploratory Method 1: Image segmentation and pattern recognition

We used Feature Analyst geographic information systems (GIS) image segmentation and pattern recognition software (Visual Learning Systems) to analyze one-meter resolution 2005 digital orthophoto quadrangles from 2005. This method did not require field data since DOQQs provided training data for image analysis. In this example tree polygons were created as training data to "find other trees" (used 7x7 Bullseye3 Filter in Feature Analyst). This approach had potential but was time consuming, computer-intensive and needed further development (e.g. note non-tree polygons in image below).

Example of results using image segmentation and pattern recognition software to distinguish tree polygons.

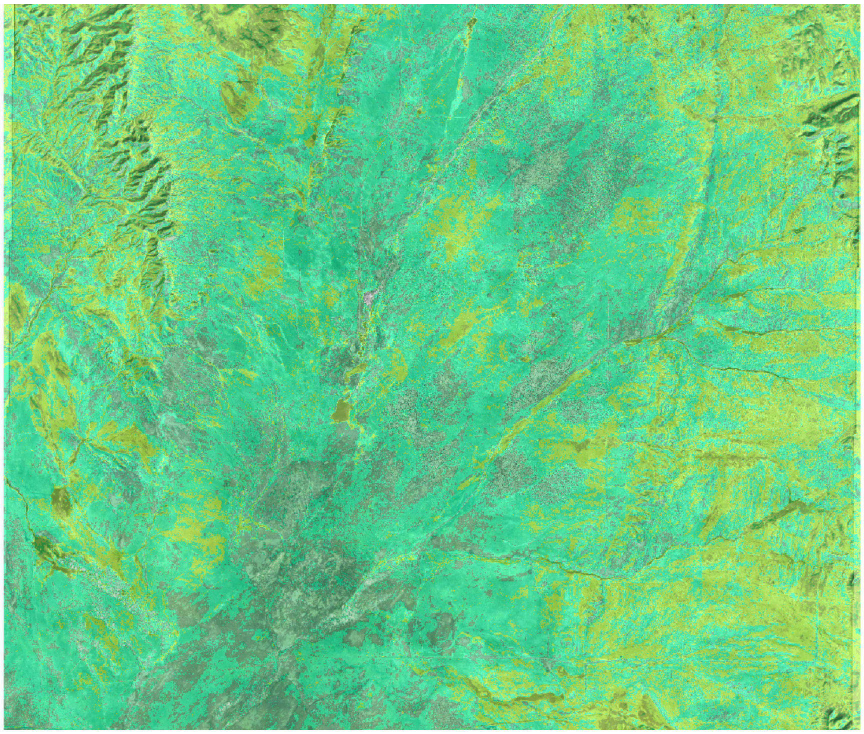
c. Exploratory Method 2: Total Vegetation Fractional Cover

The Total Vegetation Fraction Cover (TVCF) as proposed by Marsett et al. (2006) is a method to monitor semi-arid rangelands using 30-meter resolution Landsat imagery. It does not require field data since it is an index of Landsat image reflectance. Previously, techniques similar to this assumed all vegetation was green, which is not necessarily the case for the different warm and cool season plant species of the Southwest. Accordingly, Marsett and colleagues developed the Soil-Adjusted Total Vegetation Index (SATVI), designed to be more sensitive to both green and senescent vegetation, and enhance vegetation while adjusting for soils. They then modified SATVI to create TVCF as follows.

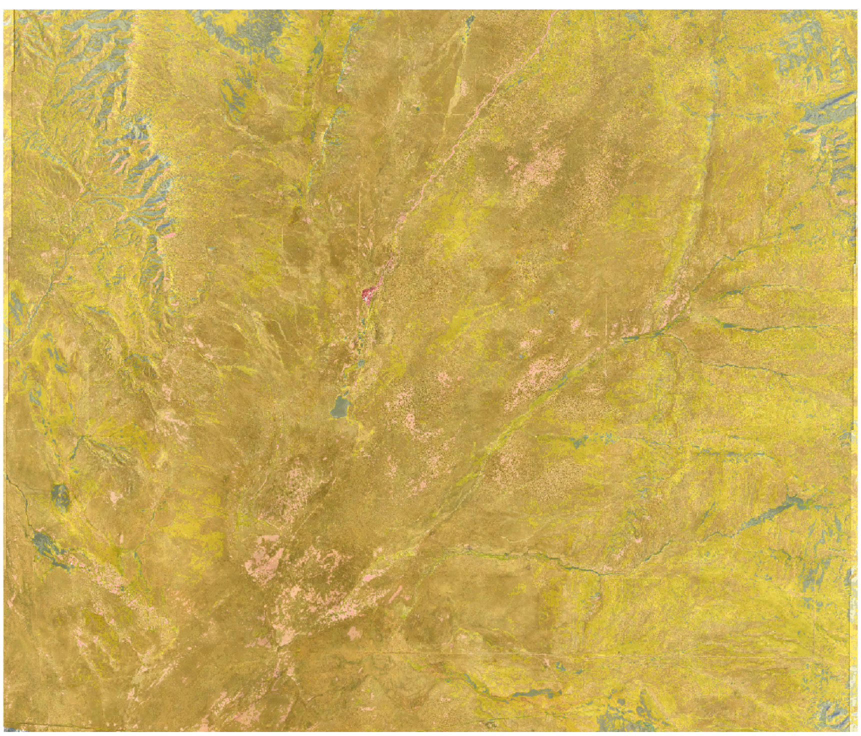
SATVI = ((B5 – B3)/(B5 – B3 + L)*(1 + L)) – (B7/2) where B is the image band (see *Landsat Satellite Bands and Indices below*) and L is a coefficient of 0 to 1 to based on increasing barrenness of the area of interest. Usually in semi-arid environments an L values of 0.5 is used. The SATVI response is then normalized into the TVCF to create percentage values from 0 – 100% using the formula TVCF = ((SATVI – SATVI*min*)/(SATVI*max*-SATVI*min*))*100, where SATVI*min* is the lowest SATVI value and SATVI*max* is the greatest SATVI value for the image.

Based on rapid field reconnaissance, we found results to be moderately successful. However, further development would be needed to improve accuracy. This approach lumped vegetation types so it was best for distinguishing vegetated vs. barren areas, and not different vegetation types.

TVCF vegetation image (from yellow-green to dark green indicting increasing vegetation cover)



TVCF barren complement image (yellow-gray to dark brown indicting increasing barreness)



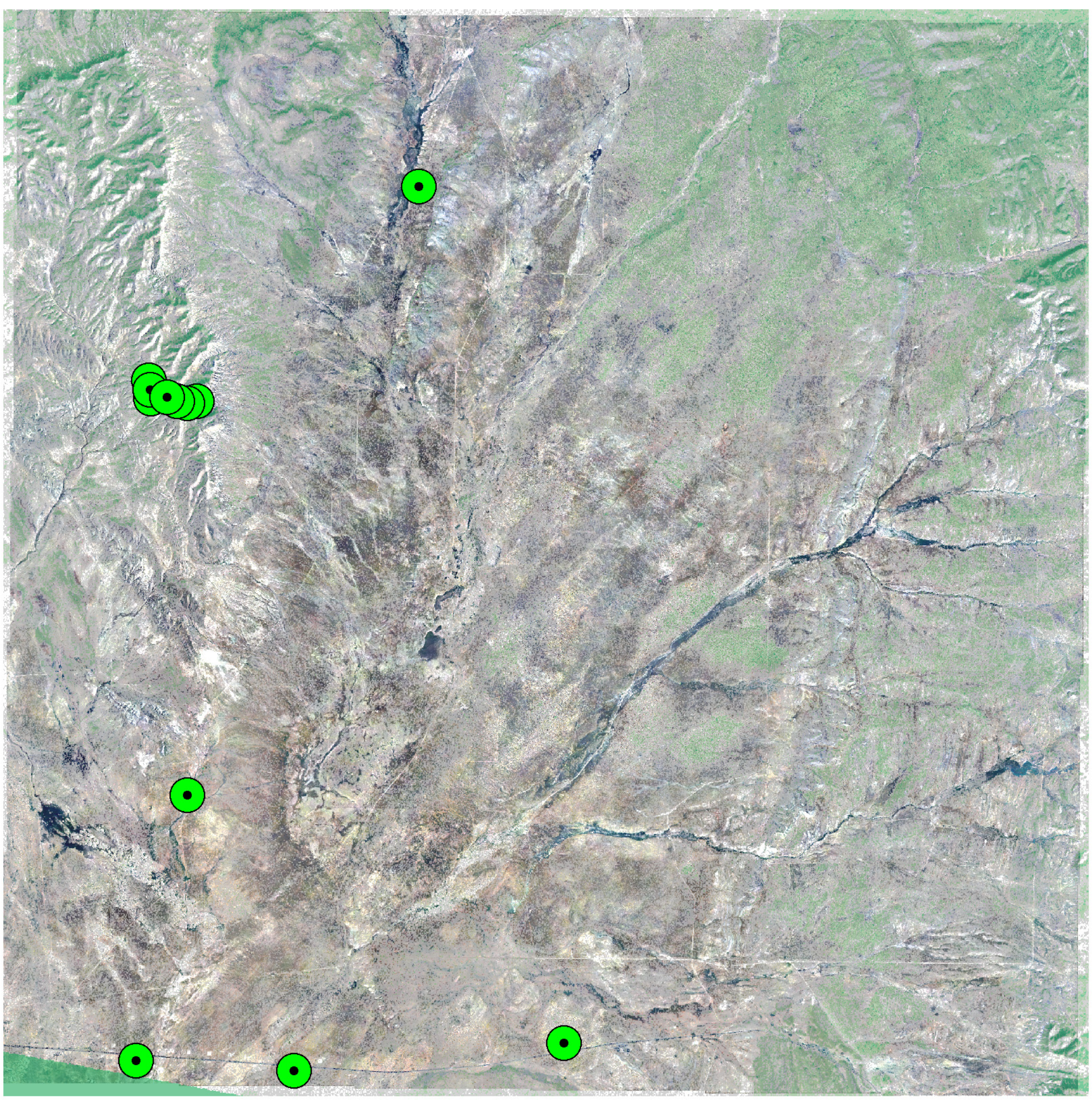
d. Exploratory Method 3: Canopy Cover Regression (LANDSAT imagery)

This approach entailed a regression of tree, shrub, grass and non-vegetated percent canopy cover with 30-meter resolution LANDSAT satellite image reflectance. It generated a regression function to predict vegetation and barren cover based on limited field plots proximal to but outside of the study watersheds, since we only used existing plot data. High coefficients of determination (R^2s) indicate the regressions were good predictors of cover, given the ground data (e.g. R^2 of 0.89 indicates the function accounted for 89% of the variability in cover). However, since the field sample was small (n = 12) variability in cover, species, soils etc. across the study area was likely under-represented. We tested this method on several images from different time periods. Results were not assessed for accuracy due to the small sample size. As indicated above in *Next Steps*, if the project is extended we will increase sample size and develop new regressions and maps stratified by ecological sites across Socorro County (stratifying by ecological site controls for soils and other confounding factors).

1. Tree cover: R^2 = 0.89 for October, 1999 image, but based on small sample. Increasing brightness of superimposed color indicates increasing %cover (cover can be reported from 0-100%, although lowest cover values may be unreliable).

<u>Regression Function for Tree Cover</u> (B = image band; see *Landsat Satellite Bands and Indices below*):
Tree cc% = 29.69377 - (0.44599*B1) + (0.816813*B2) - (0.43372*B3) + (0.147962*B4) – (0.37435*B5) + (0.292304*B7). F-significance = 0.02271, all variables but B4 being highly significant (at 0.05 level).

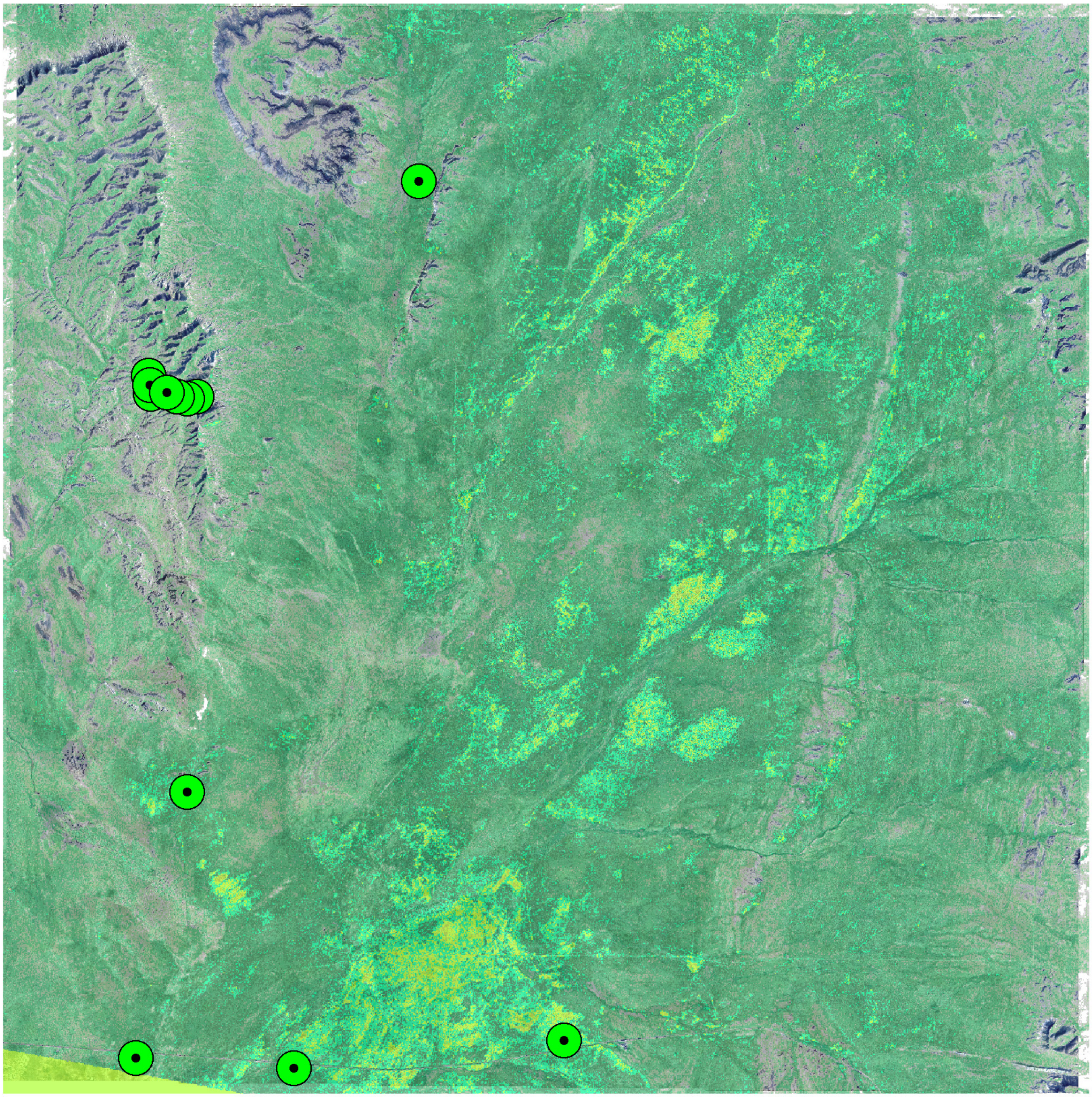
Points are field plots but we used existing plots which were outside of pilot watersheds.



2. Shrub cover: R^2 = 0.93 for May, 2000 image, but based on small sample. Increasing brightness of superimposed color indicates increasing %cover (cover can be reported from 0-100%, although lowest cover values may be unreliable).

<u>Regression Function for Shrub Cover</u> (B= image band; see *Landsat Satellite Bands and Indices below*):
Shrub cc% = 54.73288 - (1.61508*B1) + (0.357238*B2) + (0.322905*B3) + (0.062251*B4) + (0.228361*B5) - (0.200948*B7)
F-significance of 0.052853 and only B1 was significant (at the 0.1 level).

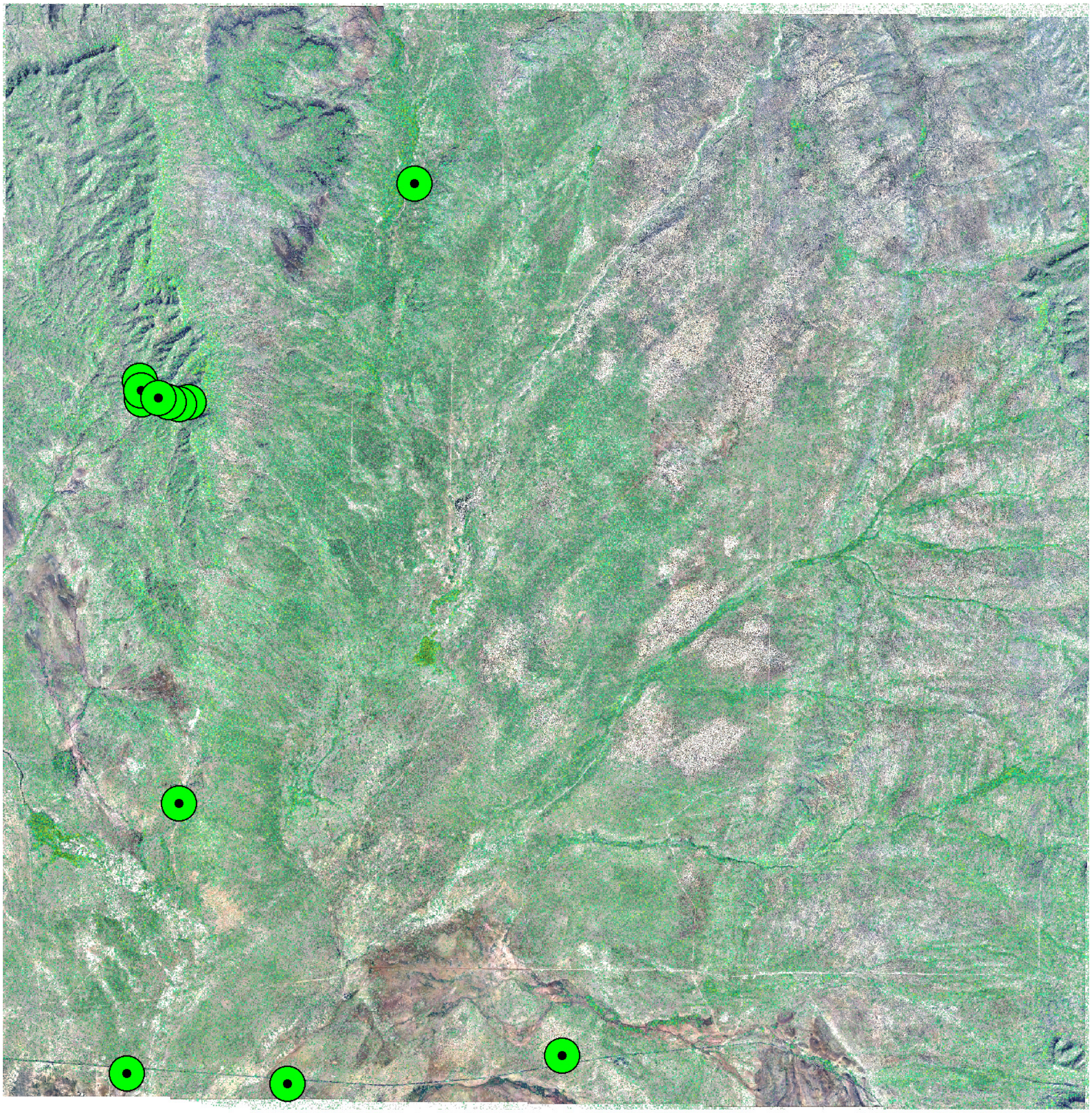
Points are field plots but we used existing plots which were outside of pilot watersheds. The graphic is of a regression function on an October, 1999 image, which had R^2 = 0.85.



3. Grass cover: R^2 = 0.58 for October, 1999 image, but based on small sample. Increasing brightness of superimposed color indicates increasing %cover (cover can be reported from 0-100%, although lowest cover values may be unreliable)

Regression Function for Grass Cover (B= image band, R = band index; see *Landsat Satellite Bands and Indices below*):
Grass cc% = -3862.07 + (6.353898*R1) - (31.8321*R2) + (10.1354*R3) + (28.22375*R4) + (0.25.35464*R5)
F-significance of 0.125595 and R2 and R4 were highly significant (at the 0.5 level).

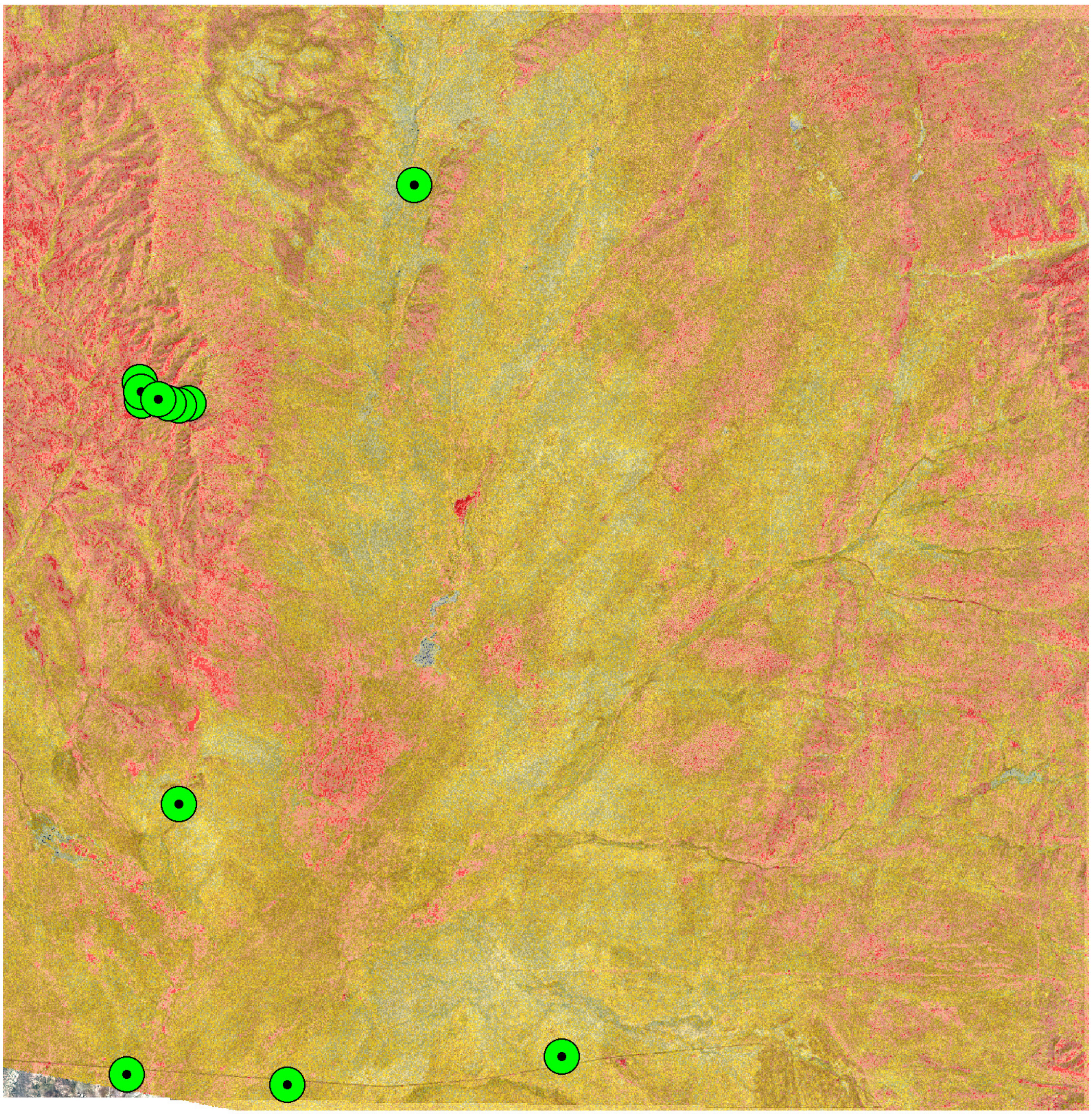
Points are field plots but we used existing plots which were outside of pilot watersheds.



4. Barren cover: R^2 = 0.75 for October, 1999 image, but based on small sample.
Increasing brightness of superimposed color indicates increasing %cover (cover can be reported from 0-100%, although lowest cover values may be unreliable)

Regression Function for Barren Cover (B= image band; see *Landsat Satellite Bands and Indices below*):
Barren % = -143.93658 + (2.9964*B1) - (0.31561*B2) - (1.72202*B3) + (1.01485*B4) - (0.98855*B5) + (0.80611*B7)
F-significance of 0.1631 and only B1 was significant (at the 0.1 level).

Points are field plots but we used existing plots which were outside of pilot watersheds.



4. Summary of Canopy Cover Regression Approach

Review of Potential Applications

1. *Assessment* – Rapid and economical mid-scale mapping of coarse indicators for interpreting land health and restoration opportunity across large areas. Indicators are related to but coarser than NRCS ecological site descriptions and states: grass, tree, shrub and barren percent-canopy cover.
2. *Prioritization* – assessment results can indicate restoration priorities, such as woody-invaded grasslands. Interpretation by natural resource professionals and overlaying ecological sites (from NRCS soil surveys) with these canopy cover layers depicts reference condition for evaluating current departure from reference condition, For example, historical grasslands that currently have moderate grass and tree cover may be tree-invaded.
3. *Monitoring* – Full assessments and change detection using this method can be carried out regularly to detect broad changes in relative cover possibly related to treatments, land use, climate, fire or other factors.
4. *Accuracy Estimate* – the accuracy of full assessment and change detection maps can be evaluated.

Assessment Method

Stratify the project area by ecological site (= area of interest or AOI). Obtain grass, tree, shrub and barren percent canopy-cover data (e.g. from plot data or DOQQ interpretation) for AOI. Develop regression with acceptable coefficient of determination (R^2) of percent-canopy cover vs. Landsat satellite image spectral reflectance. Use regression function to predict and map percent canopy-cover across AOI.

Monitoring Method

Full assessments using updated canopy-cover data and Landsat satellite images can be repeated over the original AOI as described above and compared to the original map. Two types of less intensive change detection can also be implemented: (1) run original regression functions on updated Landsat imagery to predict and map canopy cover change; (2) compare original and updated Landsat imagery – significant changes in spectral reflectance may indicate changes in canopy cover or other factors. This last method does not indicate what type of change occurred (e.g. grass or tree cover, and in what direction). Although repeating a full assessment is most informative and the last change detection method is least, all of these methods are limited by how well the original and updated Landsat images match across multiple variables (e.g. season, current and preceding precipitation, etc.).

Accuracy Estimate Method

Accuracy can be estimated by obtaining and overlaying vegetation and barren canopy-cover data onto assessment and change detection maps (these data must be different than those used to produce the maps).

Resources Needed

Canopy-cover data, Landsat imagery and staff to obtain and process canopy-cover data and imagery. The exact level of resources depends on the frequency and comprehensiveness of assessments and monitoring results desired and practical. If this project is extended we will experiment with different levels of resources, such as the number and sources of plot data, the number and seasons of images, and the synchrony between plot data and images, to estimate how results differ using different levels of resources. We also will test the use of proxies for plot data such as high resolution satellite imagery and aerial photos.

Possible Application of Canopy Cover Regression in an Integrated Land Management Approach

1. *State-mapping* (re: states described in NRCS ecological site descriptions) can provide detailed baseline information. Costs may limit state-mapping to infrequent or targeted (e.g. geographically limited) applications.
2. *Canopy Cover mapping* provides more frequent and economical summaries for assessment and monitoring across large areas, and indicates priority areas where more resource-intensive and finer-scale tools can be efficiently applied.
3. *MODIS-based change detection* is a coarser-scale method that can be combined into a cost-effective and temporally phased assessment strategy.

5. Landsat Satellite Image Bands and Indices

Landsat satellite image bands are: B1 = visible blue, B2 = visible green, B3 = visible red, B4 = near infrared , B5 = mid-infrared, B6 = thermal, B7 = shortwave infrared

Indices were created for each of the images and multiplied by 100 to make them 8-bit. They were combined into one file for each season in this order:

R1: (B7 – B3)/(B7 + B3); NSVDI using band 7 to enhance senescent vegetation response
R2: (B4 – B3)/(B4 + B3); NDVI to enhance green vegetation response
R3: (B4 – B5)/(B4 + B5); Infrared index to enhance vegetative moisture response
R4: (B5 – B7)/(B5 + B7); Mid-infrared index to enhance both vegetative and soil moisture response
R5: (B5 – B3)/(B5 + B3) MSVDI using band 5 method to enhance senescent vegetation response

6. References

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