**PROJECT PLAN**
**NP215 – Pasture, Forage and Rangeland Systems**
**October 2012 – September 2017**

**Old Research Project Number**
6235-11210-006-00D

**Management Research Unit**
Range Management Research Unit

**Location**
Las Cruces, New Mexico

**Title**
Management Technologies for Conservation of Western Rangelands

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Vacant (Rangeland Mgmt) .... 1.0
Vacant (Soil Science) ........... 1.0

**Total Scientific Staff Years**
10.0

**Planned Duration**
60 months

# Post-Peer Review

**Richard E. Estell, 6235-11210-006-00D**
**Management Technologies for Conservation of Western Rangelands**

This project plan was revised, as appropriate, according to the peer review recommendations and/or other insights developed while considering the peer review recommendations. A response to each peer review recommendation is attached. If recommendations were not adopted, a rationale is provided. This final version of the project plan reflects the best efforts of the research team to consider the recommendations provided by peer reviewers. The responses to the peer review recommendations are satisfactory.

November 20, 2012

Research Leader or Center/Laboratory Director — Date

The attached plan for the project identified above was created by a team of credible researchers and externally reviewed and recognized by the team's management and National Program Leader to establish the project's relevance and dedication to the Agricultural Research Service's mission and Congressional mandates. It reflects the best efforts of the research team to consider the recommendations provided by peer reviewers. The responses to the peer review recommendations are satisfactory. The project plan has completed a scientific merit peer review in accordance with the Research Title of the 1998 Farm Bill (PL105-185) and was deemed feasible for implementation. Reasonable consideration was given to each recommendation for improvement provided by the peer reviewers.

**Area Director (original signature required)** — Date

# PrePlan Signature Page for ONP Validation(s)

# Pre-Peer Review

**Richard E. Estell, 6235-11210-006-00D, NP215**
**Management Technologies for Conservation of Western Rangelands**

❑ Signature Page Completed for Research Leader through Area Director

☑ The objectives in this PrePlan are those provided in the PDRAM or subsequently approved by the Office of National Programs and the approaches are suitable for achieving the objectives.

__Jeffrey J. Steiner /s/________________________________ _July 19, 2012__________
National Program Leader Date

Comments:

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**PROJECT SUMMARY**

The goal of the Jornada is to develop ecologically based knowledge systems and technologies for management, conservation, monitoring, and assessment of western rangelands. Our long-term research objective is to increase understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation, and restoration. Two key challenges for expanding rangeland capacities are sustaining production while maintaining desirable conditions and restoring capacities of degraded rangelands. For rangelands to achieve their full potential in meeting food security and other ecosystem services objectives, appropriate practices for use, conservation, and restoration must be strategically tailored to the specific conditions of a particular site. Our research plan contains five objectives designed to produce technologies to address regional and national concerns relevant to major land resource areas across the western U.S. We will build upon hundreds of existing data sets from our field station and collaborating sites. We will integrate short- and long-term data sets with simulation modeling, geographic information systems, and remote sensing tools. We will combine short-term experiments to test specific hypotheses with synthetic experiments requiring a complex integration of ecosystem components and drivers. Decision-support tools resulting from this work are intended to meet the needs of public and private land managers, be adaptable across temporal and spatial scales, and be usable for assessing, monitoring, and implementing conservation practices. This is an ambitious proposal that reflects the singular efforts of a collaborative, interdisciplinary group of 10 ARS scientists based at the Jornada working towards a common goal.

**OBJECTIVES**

The goal of the Research Unit based at the Jornada is to develop ecologically based knowledge systems and technologies for management, conservation, monitoring, and assessment of western rangelands. We will develop these knowledge systems and technologies through field experimentation with an increasing emphasis on syntheses of long-term, historical data, and development of landscape-specific ecological models applicable within major land resource areas (MLRAs) of the U.S.

The conceptual framework for our research program (Fig. 1) is based on the notion that ecological sites--kinds of land that differ in potential plant communities and responses to management--provide a useful basis to conduct research on key ecological processes operating within rangelands and to inform management based on that knowledge (USDA-NRCS 2003, Bestelmeyer et al. 2003, 2009). Ecological sites are recognizable, repeating land units that occur within a MLRA (i.e., a region with similar physiography, weather patterns, and land uses) and serve as a framework for explaining historic, current, and future vegetation state changes (USDA-NRCS 2003, Bestelmeyer et al. 2004, 2009, Steele et al. 2012). Spatial and temporal variation in state changes are the result of temporal context and environmental drivers (e.g., precipitation, temperature, human activities) interacting with spatial context (patch characteristics, adjacency, contingency), transport vectors (wind, water, animals), and the soil-geomorphic template (soils, landforms) to influence resource redistribution within and across a range of scales, from individual plants to groups of plants and landscape units (Fig. 1a). These variations are represented for management applications via ecological site concepts, soil and vegetation spatial data, and state and transition models developed for specific ecological sites and groups of sites (USDA-NRCS 2003, Bestelmeyer et al. 2003, 2004, 2011b, Briske et al. 2008). Because ecological sites are already widely recognized in the management community, they provide a useful basis for science-management linkages and the judicious extrapolation of scientific results. The Research Unit based at the Jornada has developed research objectives that couple this framework to expected products and outcomes (Fig. 1b). All elements of Figure 1b are directly linked to our project objectives.

During the next five years we will focus on the following objectives and subobjectives based upon this conceptual framework and rationale:

**Objective 1:** Develop data-driven approaches in the production of ecological site descriptions that guide rangeland conservation and management practices within MLRAs of the western U.S., including New Mexico, Arizona, Oregon, North Dakota, Wyoming, Montana, and Oklahoma.

- **Subobjective 1A:** Produce new approaches for and examples of data-driven ecological site description and state-and-transition model development using analysis of inventory, historical, experimental, and monitoring data, augmented by local knowledge. (Bestelmeyer, Havstad, Herrick, Peters, Vacant Rangeland Mgmt)

- **Subobjective 1B:** Create and populate a national database of ecological dynamics to be used in guiding national ecological site description development and as a mechanism for stakeholder communication, including specific efforts in MLRAs of New Mexico, Arizona, Oregon, North Dakota, Wyoming, Montana, and Oklahoma. (Bestelmeyer, Havstad, Herrick, Vacant Rangeland Mgmt)

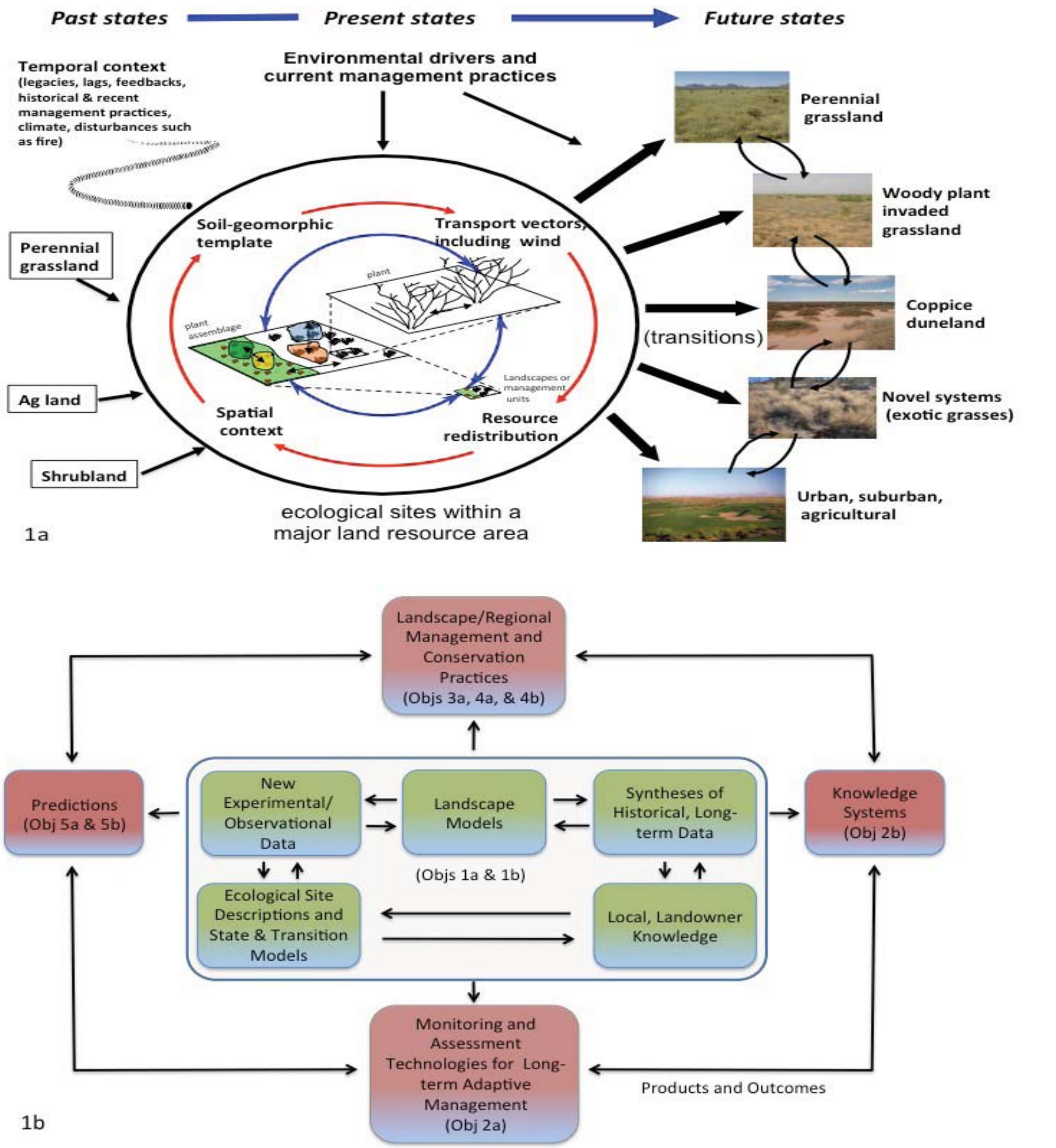



Figure 1. a) An ecological process-based framework for the study of state change in rangelands (Adapted from Peters et al. 2006). Spatial and temporal variation in state changes are the result of temporal context and environmental drivers (e.g., precipitation, temperature, human activities) interacting with spatial context, transport vectors, and the soil-geomorphic template to influence resource redistribution within and across a range of scales, from individual plants to groups of plants and landscape units. These variations in key processes are represented for use in management via ecological site descriptions and related products. b) The core research activities addressing 1a are at the center of 1b and serve as the basis for management-relevant products and outcomes identified in the outer ring of 1b. All elements of 1b are directly linked to our project objectives.

**Objective 2:** Improve techniques, including remotely sensed methodologies, for rangeland monitoring and assessment applicable to landscapes within MLRAs, and more broadly for regional and national scales of assessment.

- **Subobjective 2A:** Develop and evaluate innovative approaches for remotely monitoring land surface conditions in order to improve existing and develop new methods for rangeland monitoring across a range of spatial scales. (Herrick, Rango, Vacant Soil Science, Vacant Rangeland Mgmt)

- **Subobjective 2B:** Develop innovative, integrated, and flexible inventory, assessment, and monitoring techniques and the decision support tools necessary to implement these approaches at local to national scales. (Herrick, Vacant Soil Science, Vacant Rangeland Mgmt, Bestelmeyer, Havstad)

**Objective 3:** Evaluate effectiveness of historic, current, and new grassland restoration practices for dominant ecological sites within specific MLRAs of New Mexico, Arizona, Oregon, and Wyoming.

- **Subobjective 3A:** Design and implement new studies and analyze experimental data from conservation management practices and grazing management efforts on public and private lands in MLRA 41 and 42 of AZ and NM, MLRA 25 in OR, and MLRAs 58B and 67B in WY with respect to multiple ecosystem services. (Bestelmeyer, Vacant Soil Science, Lucero, Havstad)

**Objective 4:** Evaluate livestock management practices suitable for conserving and restoring rangelands within selected MLRAs of the southwestern U.S.

- **Subobjective 4A:** Evaluate grazing management practices and their relationships to ecological state changes within ecological sites in MLRAs 41 and 42 of AZ and NM. (Estell, Havstad, Anderson)

- **Subobjective 4B:** Evaluate low-input livestock production strategies in MLRA 42. (Estell, Havstad, Anderson)

**Objective 5:** Develop mechanistically based predictions of vegetation state changes and site-based wind erosion susceptibilities for landscapes within selected MLRAs under alternative land use-climate change scenarios.

- **Subobjective 5A:** Predict climate-driven vegetation state changes for western landscapes within selected MLRAs. (Peters, Herrick)

- **Subobjective 5B:** Develop and implement a wind erosion monitoring network and standardize protocols for measurement and model-based predictions of changes in horizontal and vertical dust flux on western rangelands, including areas undergoing land use change. (Herrick, Vacant Soil Science)

## NEED FOR RESEARCH

Formal customer input to the ARS during 2011 regarding rangeland research objectives strongly encouraged the agency to develop new management practices, technologies, and strategies to expand the capacity of rangelands to supply high quality food products and other critical ecosystem services. Historically, the capacity of rangelands to supply food and fiber is well documented, but *expanding* the supply of these and other goods and services is a formidable objective (Havstad et al. 2007, Sala et al. 2009, Peters et al. 2012a). There are two key challenges in expanding rangeland capacities: 1) sustaining production while maintaining desirable rangeland conditions, and 2) restoring capacities of degraded rangelands to support this supply.

Our research plan addresses regional and national concerns relevant to MLRAs across the western U.S. For example, a panel of experts recently identified the top 40 science priorities needed for informed conservation and management policy (Fleishman et al. 2011). Much of the research proposed here is directly related to those needs (e.g., "What are reliable scientific metrics for detecting chronic, long-term changes in ecosystems?"; "How does the configuration of land cover and land use affect the response of ecosystems to climate change?"; "What attributes of ecosystems facilitate prediction of impending transitions among alternative states"). Our research will characterize how conservation management practices respond to local variations in vegetation, soils, and climate. We will employ the MLRA delineations of the U.S. as our framework for capturing these local variations. Decision-support tools arising from this work will 1) meet the needs of public and private land managers, 2) be adaptable across temporal and spatial scales, and 3) be usable for inventorying, assessing, and implementing conservation and restoration practices. The ultimate goal is for rangelands to achieve their full potential in meeting food security and other ecosystem services objectives. This goal can be best met by identifying appropriate use, conservation, and restoration practices that are strategically tailored to the specific conditions of a particular site.

A fundamental, science-based understanding of soils, plants, animals, and their interactions is needed to develop strategies to conserve and restore rangeland natural resources. The Research Unit based at the Jornada will build on previous contributions to our understanding of these fundamental pattern-process relationships at plot to landscape and larger spatial scales (Peters et al. 2008, Peters 2010). The next phase of our work will expand on these relationships to take into account the impacts of increased climate variability and changing land use patterns to improve management of human, ecological, and climatic processes across western rangeland landscapes.

In implementing this research program, unit scientists will employ a scientific method that more effectively integrates data-intensive science to identify practices and solutions to specific problems (Fig. 2). This work will contribute directly to the ARS Long-Term Agro-ecosystem Research Network (LTAR), of which the Jornada is a member, and to nationally and globally accessible databases that are critical to finding solutions to key problems facing the conservation and management of rangelands in the western U.S. and worldwide.

The information derived from our research will improve our understanding of the relationships among management practices, ecological processes, and climatic variability at scales relevant to rangeland production, conservation, and restoration. The following general products and decision tools, contextualized for specific landscape settings, are anticipated:

- Ecological site descriptions including state-and-transition models,
- Livestock management practices,
- Woody species management practices,
- Remote sensing techniques,

• Assessments of accelerated erosion, and

• Prediction models of vegetation state changes under future climate-land use scenarios.

## SCIENTIFIC BACKGROUND

Rangeland science has been driven by site-based, reductionist studies seeking simple generalizations about ecological processes (Sayre et al. 2012). Yet, many issues confronting the discipline today are landscape to global in scale and highly complex (Boyd and Svejcar 2009). Management requires technologies that link information about ecological processes to management actions and policy, and that permit monitoring and problem solving at management-relevant scales.

**MLRA/ESD framework:** The Natural Resource Conservation Service (NRCS) has led efforts to describe and map the U.S. according to Major Land Resource Areas (Fig. 3) based on soil, geography, and climate (USDA-NRCS 2006). MLRAs reflect potential uses and serve as a basis for organizing information about regional and national agricultural concerns and for determining research needs (USDA-NRCS 2006). Descriptions of physiography, geology, climate, water resources and use, soils, biological resources, land use, resource concerns, and conservation practices are associated with each MLRA. These descriptions are supported by extensive data sets of biophysical characteristics.

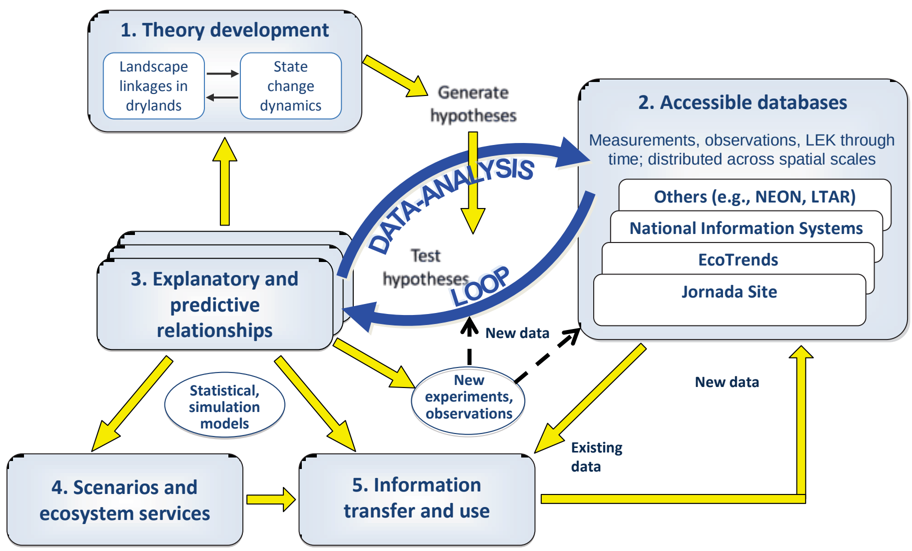



Figure 2. Implementation of a data-intensive, iterative scientific method addressing 1) specific problems requires 2) linkages with long-term data and observations, local environmental knowledge (LEK) derived data products, initial analyses, and visualization tools, 3) explanatory and predictive relationships among drivers, patterns, and processes that are used to develop 4) scenarios of alternative states with assessments of their impacts on ecosystem services, and 5) useable information transferred to a broad audience (From Peters and Havstad, In Preparation).

Ecological sites comprise a soil- and climate-based land classification system within MLRAs based on soil classification and soil mapping of the National Cooperative Soil Survey. Ecological sites are among the finest-grained classifications available over large land areas (mostly rangelands at present) and are well-suited to link management practices to subtle variations in landscape properties (Comer and Schulz 2007, Bestelmeyer et al. 2009). Their basis in soil-geomorphic attributes (e.g., landform, slope, soil texture) enables ecological sites to be related to landscape processes such as water redistribution (Bestelmeyer et al. 2011b). Unlike mapping based on existing vegetation, ecological site classification is based on use-invariant properties (Herrick et al. 2006); thus, the land classification will not change in response to management actions, providing a consistent basis for long-term measurement and comparison of management effects. Each ecological site can be linked to a state-and-transition model (STM) that describes potential vegetation and the ecological mechanisms of plant community change (a well documented example of a STM is illustrated in Figure 4). At a given point in time, an ecological site can exist in one of several ecological states (Suding et al. 2004), each of which is characterized by distinct plant communities, dynamic soil properties, dominant ecological processes, ecosystem services, and management considerations (Stringham et al. 2003, Briske et al. 2008). Three federal agencies (NRCS, Bureau of Land Management [BLM], and U.S. Forest Service [USFS]) recently adopted ecological sites as a common basis for rangeland evaluation (http://www.fs.fed.us/biology/soil/Signed RIESM_2010.pdf).

U.S. soil classification and mapping integrate a suite of factors affecting vegetation at different spatial scales, including climate, topography, hydrology, and soil development (USDA-NRCS 2007). Soil components that support similar plant communities in an unmodified state and that respond similarly to environmental drivers are grouped together into ecological site classes. Distinct ecological sites identify important differences in climate, soil profiles, and landscape positions and effectively simplify soil classification to focus on properties relevant to management. Because these geophysical properties tend not to change in response to management, ecological sites reflect relatively stable differences in ‘reference conditions’, ‘site potential’, or ‘potential natural vegetation’ among land areas (Bestelmeyer et al. 2009). Ecological site classes repeat across MLRAs, Land Resource Units (LRU), or ecoregions that feature similar regional climates and soil/landform gradients.

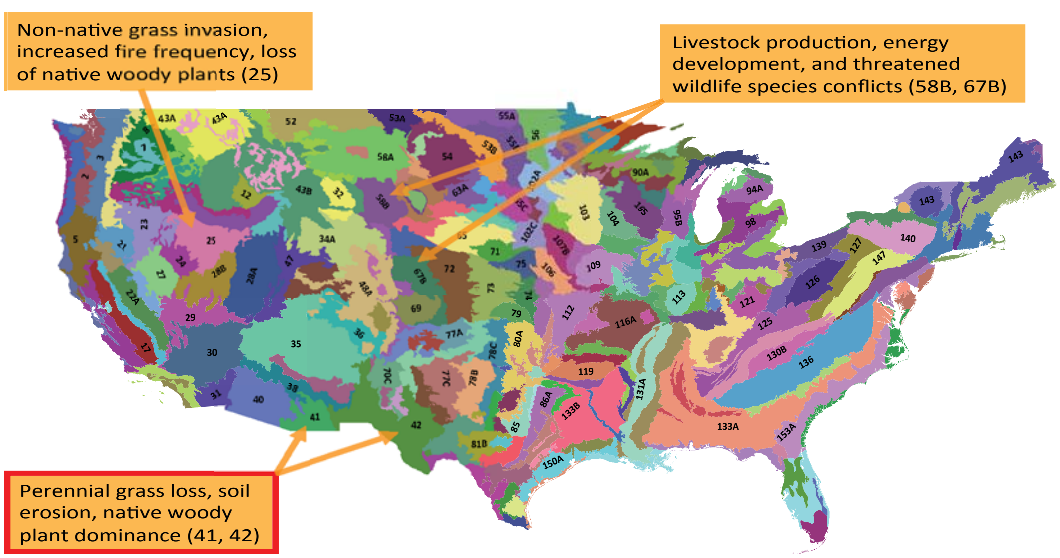



Figure 3. Major Land Resource Areas (MLRAs) of the continental USA distinguish broad differences in potential and types of ecological dynamics based on well known climatic and biophysical boundaries. These areas may also capture unique ecological problems and issues, as illustrated for MLRAs 41, 42, 25, 58B, and 67B that are foci of this project plan (Adapted from USDA-NRCS 2006).

We will use Ecological Site Descriptions (ESDs) for selected MLRAs as the underlying ecological framework for our outcomes and products (as illustrated in Fig. 1b). **Framework development was motivated by an inability of previous frameworks (e.g., range sites) to adequately inform management decisions.** Our research will focus on MLRAs associated with the Jornada (MLRA 42) and other western ARS locations that include Tucson, AZ (MLRA 41), Burns, OR (MLRA 25), Cheyenne, WY (MLRAs 58B and 67B), and El Reno, OK (MLRA 78C).

**Objective 1:** Ecological site descriptions are available for MLRAs containing most western rangelands; thus, MLRAs and ecological sites therein provide a basis for defining the templates for regional research projects. Efforts to classify landscapes based on ecological sites and to characterize their ecological state has been a major research emphasis at the Jornada in recent years (Bestelmeyer et al. 2003, 2004, 2009, 2010). Consideration of ecological sites and STMs in monitoring design and assessment of conservation effects (Bestelmeyer et al. 2006, 2011b, 2011d) is part of this research focus. The continued development of ESDs on U.S. rangelands is essential to guiding rangeland conservation and management practices within MLRAs of the western U.S.

A major concern for rangelands throughout the western U.S. has been the transition of perennial grasslands to shrublands. The proliferation of woody species has occurred in most western MLRAs, particularly in arid and semiarid ecosystems. The causes and consequences have been examined and debated (Archer 1994, Morgan et al. 2007, Van Auken 2009). These state changes to shrub dominance are often accompanied by a loss of soils and biological resources, including aboveground production and biodiversity (MEA 2005, Barger et al. 2011). Shrubland-to-grassland transitions have occurred several times during the Holocene in the American Southwest due to broad-scale climate change (Van Devender 1995, Monger et al. 2009). The most recent shift from grasslands to shrublands occurred at a much faster rate (100-150 years) than previously as an unintended result of improper land management practices acting in concert with periodic drought (Humphrey 1958). **Management aimed at restoring shrub-encroached grasslands has met with limited success (Herrick et al. 2006, Archer et al. 2011). Restoration of grasses following desertification is one of the major challenges facing humanity today (Arnalds and Archer 2000, Reynolds et al. 2007; http://www.unccd.int/).** However, recent studies indicate that alternative states occur in drylands, including shifts from desertified systems back towards native grasslands or to novel systems dominated by exotic annual or perennial grasses under certain climatic and management conditions (Holmgren and Scheffer 2001, Rasmussen et al. 2001, Allington and Valone 2010, Archer 2010, Wilcox et al. 2011). Alternative states are emerging (Fig. 1a), including a reversal from shrublands towards perennial grasslands (Peters et al. 2012b), shifts between shrubland types (Peters et al. submitted), and the invasion of non-native grasses into native grasslands (McGlone and Huenneke 2004).

**Historical and recent degradation episodes (Egan 2006, Stafford Smith et al. 2007) and restoration failures (Kondolf 1995, Hildebrand et al. 2005, Briske 2011) repeatedly confirm the need for systems that enable long-term, adaptive learning in natural resources management.** Variability among landscapes, regions, and time periods precludes simplified generalities from ecological science (Shrader-Frechette and McCoy 1993, Simberloff 2004, Reiners and Lockwood 2009). Without generality or context, it is difficult to apply the lessons learned from one place or time period to another (Palmer et al. 1997). Different locations in a landscape, featuring different stakeholders, histories, biota, soils, and influences of landscape context are likely to require different conservation approaches (Sayre 2005, Bestelmeyer et al. 2009, Morton et al. 2010). Different locations may also experience different effects from the same approaches, often recognized by local knowledge holders. Variations in conservation effects are due not only to variation in ecological sites and initial states, but also to surrounding ecological sites and states because spatial interactions among locations in a landscape can govern responses (Bestelmeyer et al. 2011b,d). Thus, conservation planning involves not only selection of appropriate practices based on the vegetation and soils at a locality, but also the spatial context of the locality with respect to relevant spatial processes (Connelly et al. 2000, Tian et al. 2002).

**Objective 2: Land Management is constrained by limited technologies for monitoring and assessing landscapes at scales necessary to address regional problems, by limited accessibility of relevant data, and limited tools for landscape level analyses. Remote sensing technology is advancing rapidly, but improved resolution is needed, and the ability to acquire and process remotely sensed data for large tracts of land over long timeframes is problematic.** The Jornada is at the forefront of this technology development using unmanned aerial vehicles (UAV) for fine-scale remote sensing of the land surface (Rango et al. 2006, 2009, 2011, Laliberte et al. 2010). Development of database systems and the integration of field and remote sensing techniques for monitoring and assessment is also a focus of research at the Jornada (Karl 2010). The Landscape Toolbox (LT) project is an effort initiated jointly by the Jornada and The Nature Conservancy to help land managers apply the most effective techniques and data sources for inventory, assessment, and monitoring of rangeland resources (Karl et al. 2011). The LT is a collection of online references, software tools, and decision support systems. A core product being developed for the LT is an Integrated Knowledge System (IKS; Fig. 5; Karl et al. In Press) to capture, organize, interpret, and synthesize land management information in an ecological site framework (illustrated in Fig. 1b). This IKS is currently being used by BLM (Toevs et al. 2011) and Department of Defense land managers to predict the outcomes of disturbances and management actions on vegetation dynamics (Karl and Herrick 2010).

**Objective 3: Our ability to evaluate past management practices and to effectively manage woody species has lagged, in part because of interactions between characteristics of ecological sites and impacts of management practices. An ecological site-based conservation system is needed to evaluate the effectiveness of past and future restoration practices on dominant ecological sites.** Land management (e.g., treatment application decisions, evaluation of success) on an ecological site basis provides a common denominator for comparisons at appropriate scales. Recently, Jornada scientists have begun to integrate ecological site framework into the evaluation of large-scale conservation practices. For example, as part of the Restore New Mexico program of the BLM, researchers at the Jornada collaborated with BLM staff to implement experimental monitoring as part of brush control projects implemented since 2007 (Bestelmeyer et al. 2011d). Within each treatment area, paired study plots were matched based on ecological site and initial state, with one of each pair serving as the control. This design was repeated across brush control treatments that varied in ecological site (and soil variations within ecological sites), climate, and initial vegetation composition and cover (Fig. 6). This approach has been published (Steele et al. 2012) and preliminary results from these analyses have shown that ecological sites influence treatment responses (Williamson et al. 2011).

**Objective 4: Livestock management practices that are profitable, conserve natural resources, and promote restoration are crucial across ecological sites in the western U.S. Animal numbers and demand for red meat are projected to escalate globally for the next 30 years (FAO 2003, 2009), yet grazing allotments are not fully exploited in many**

**MLRAs in the southwestern U.S**. For example, only about 50-75% of the permitted Animal Unit Months (AUMs) in the Las Cruces Grazing District allotments were used at any given time during the past 10 years (Fig. 7). A combination of several factors may drive this underutilization. Allotments may support fewer animals than when AUMs were originally allocated, or ranchers may be exiting the business for reasons unrelated to economics. It is likely, though, that these fluctuations and underutilized allotments are also due to a clientele that is responsive to a system with high variability. In addition, landscapes may have undergone state changes that reduce the actual available forage. The relationship between livestock management and state transitions specific to ecological sites is poorly quantified. However, knowledge of state changes over lengthy time periods such as those depicted in Figure 8 would allow for evaluation of the impacts of known livestock management practices on state changes on different ecological sites.

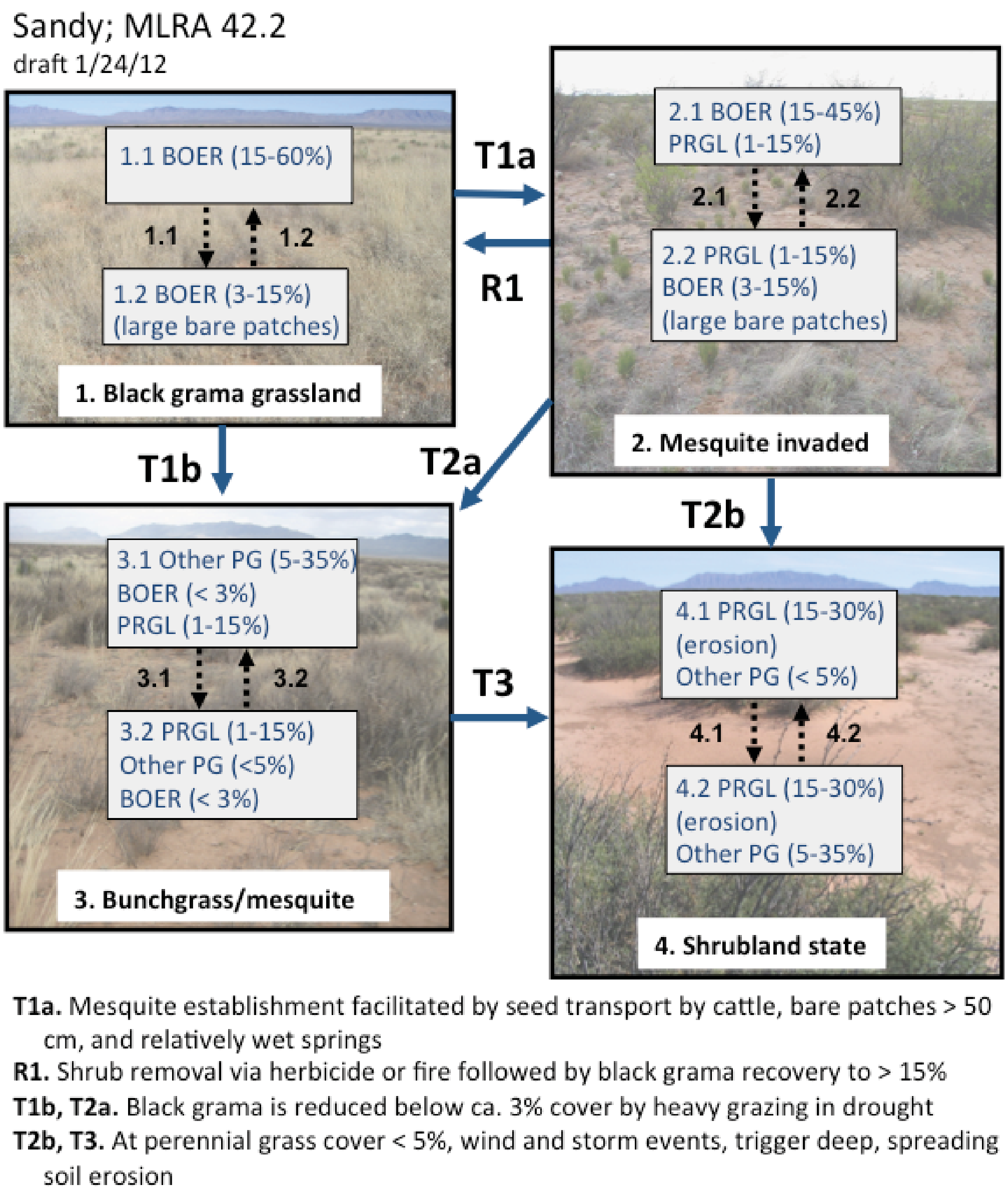



Figure 4. A state-and-transition model for a sandy ecological site within MLRA 42 in southern New Mexico. The states-and-transitions are evidence-based, including experimental data and local landowner knowledge (From Bestelmeyer et al. In Preparation).

Although global livestock numbers are increasing, grasslands are in decline, particularly in more arid climates (FAO 2003), and producers will likely be forced to rely more on shrub-dominated rangelands (Estell et al. 2012). Concurrently, animals entering confinement operations from rangeland environments are trending heavier to reduce feed costs, which may place even more stress on existing forage resources. In addition to shrubby conditions and highly variable precipitation, rangeland livestock in the Southwest (primarily MLRAs 41 and 42) are often faced with rough terrain, long distances between watering points, and irregular forage distribution and quality. Producers in these regions must respond to extreme climatic events and sparse forage either by periodically destocking/restocking or supplementing alternative forages. **Mechanisms are needed to avoid or minimize these cyclic responses without resorting to expensive supplemental feeding. Cattle breeds that are adapted to harsh environments may be more suited to low input sustainable livestock production in arid MLRAs of the southwestern U.S. (Peinetti et al. 2011, Estell et al. 2012).** Criollo cattle have a long history grazing southwestern desert rangelands; these cattle originally arrived in the 1500s and were common until the mid/late 1800s when British breeds rose in popularity. However, British breeds often need to be supplemented to prosper on arid rangelands, a practice that has become less economical

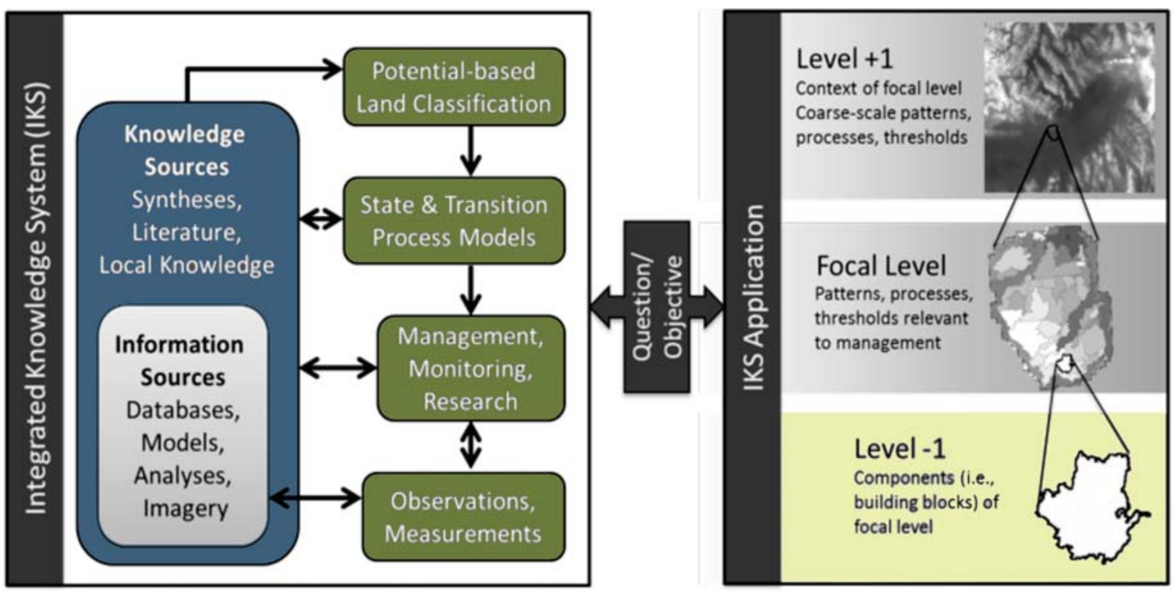



Figure 5. A vision for rangeland management based on best available knowledge and information. An Integrated Knowledge System (IKS) should be structured around knowledge and information pertinent to objectives. Potential-based land classifications systems (such as ecological site based systems) and state-and-transitions models help identify relevant knowledge and how that knowledge can be used in management or research. Knowledge from an IKS can be used to identify appropriate spatial and temporal scales to address specific questions and objectives (From Karl et al. In Press).

as feed and fuel costs have risen. Very little information is available on the physiology, behavior, or dietary preferences of Criollo cattle. Because Criollo are small-framed and use the landscape more uniformly than their Angus-cross counterparts (Peinetti et al. 2011), they may forage more efficiently, have lower feed requirements, require fewer inputs, and have less impact on a given area in arid regions such as those represented in MLRAs 41 and 42 (Fig. 9).

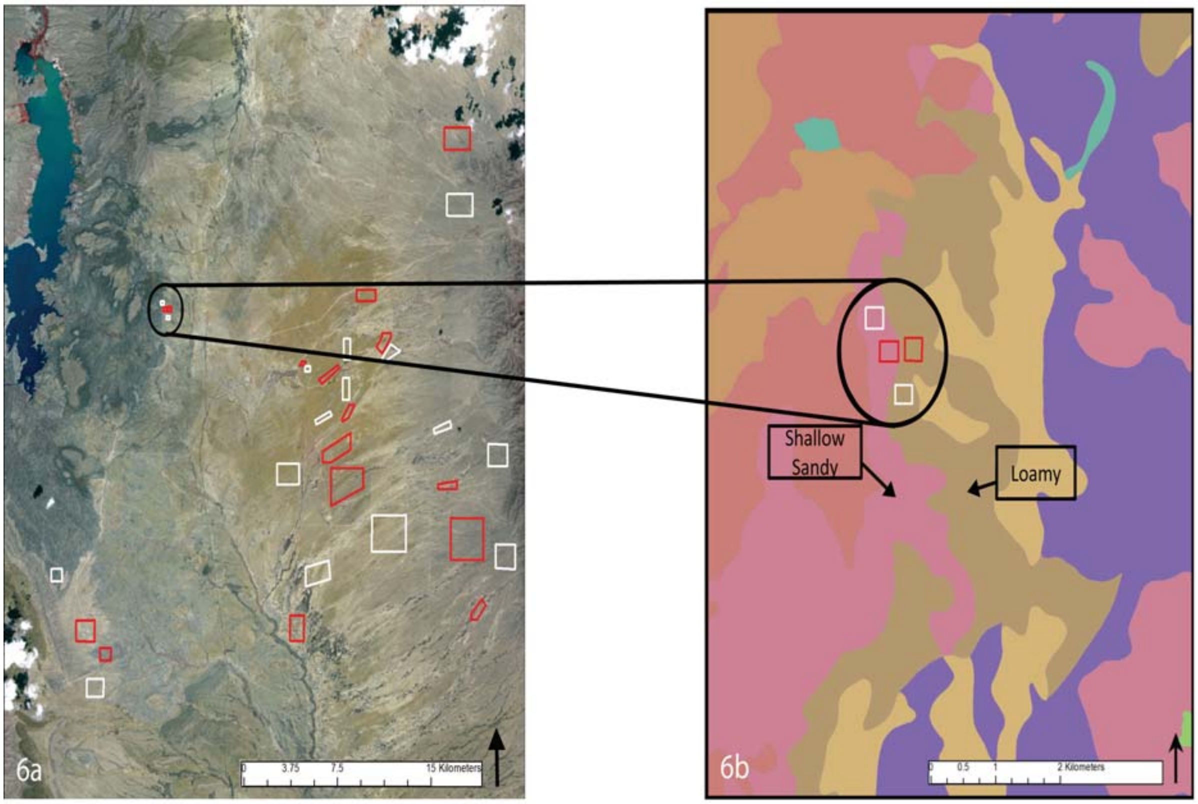
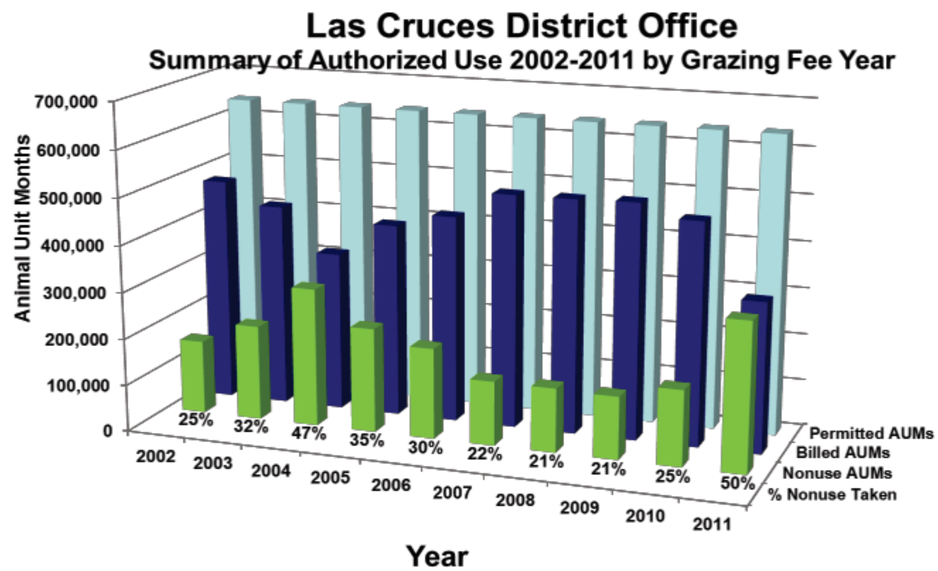



Figure 6. Integration of ecological site and vegetation state mapping into evaluation of large scale brush control treatments in MLRA 42 of southern New Mexico. a) brush control treated areas (red boxes) have been georeferenced within a recent LANDSAT image. b) appropriate control areas (white boxes) have been paired to matching treatment areas based on ecological site and initial vegetation state at time of treatment (From Browning et al. In Preparation).

**Objective 5:** Landscape transitions among past and future states (e.g., agricultural lands, perennial grasslands, shrublands, alternative states) are prevalent throughout the western U.S. (Fig. 1a). Resulting vegetative states within an ecological site are affected by human activities and can impact ecosystem services (Fig. 10). Spatial and temporal variation in state change dynamics are the result of: 1) patch structure and spatial and temporal context interacting with 2) transport vectors (wind, water, animals) and 3) environmental drivers (e.g., precipitation, temperature, human activities) that 4) influence resource redistribution across a range of scales 5) as mediated or constrained by geomorphic and topoedaphic features (Peters et al. 2006) with 6) significant effects on ecosystem goods and services (Havstad et al. 2007). **Improved mechanistic understanding of processes will enhance our ability to integrate, predict, and extrapolate state change dynamics across spatial and temporal scales up to and including those relevant to land management and policy.** Complexity, contingency, lags, thresholds, feedbacks, and the interdependence of system components are major obstacles to prediction in ecosystem science.

Vegetation dynamics among ecological sites differ in ways that are often not predictable from short-term studies (Havstad et al. 1999, Peters et al. 2006). Cross-scale interactions driving spatial and temporal variation in rates and patterns of woody plant expansion are highly complex and involve numerous feedbacks among drivers and transport vectors (wind, water, animals). The ecological responses to these interactions vary depending on spatial scale and context, and result in multiple scales of spatial heterogeneity in outcomes (Dekker et al. 2007, Ravi et al. 2007, D'Odorico et al. 2010, Turnbull et al. 2011). Wind and rainfall are both important drivers of erosion, though wind is the dominant driver of soil erosion and deposition in arid systems and is less well studied than water (Okin et al. 2006). Our ability to predict susceptibility of a given ecological site to wind erosion and climate change is limited, and a better understanding of their impacts on different ecological sites is needed for proactive rangeland management.




| Year | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|
| % Nonuse Taken | 25% | 32% | 47% | 35% | 30% | 22% | 21% | 21% | 25% | 50% |
| Nonuse AUMs | 157489 | 203552 | 296906 | 223714 | 194242 | 137440 | 136906 | 133821 | 161948 | 317119 |
| Billed AUMs | 480694 | 434631 | 341277 | 414469 | 443941 | 500743 | 501277 | 504362 | 476235 | 321064 |
| Permitted AUMs | 638183 | 638183 | 638183 | 638183 | 638183 | 638183 | 638183 | 638183 | 638183 | 638183 |

Figure 7. Permitted vs. used AUMs in the Las Cruces BLM grazing district in the last 10 years (Courtesy of the Bureau of Land Management).

Recent observations suggest that grasses can recover under some conditions (e.g., following a sequence of wet years; Peters et al. 2012b). Depending on location, global climate models predict either a directional increase or decrease in precipitation in arid regions with global warming (Burke et al. 2006, IPCC 2007, Seager et al. 2007). A drier climate is expected to promote continued shrub dominance and expansion whereas increased precipitation is predicted to promote grass expansion and a reversal of shrub dominance (Peters et al. 2012b). Annual precipitation has increased in some regions over the past 50 years (Karl and Wright 1998), justifying the need to understand the mechanisms involved in grass recovery and reversing shrub encroachment (Peters et al. submitted). In contrast to many studies (e.g., Knapp et al. 1998, Huxman et al. 2004), grass production in shrublands was not related to precipitation during this wet period, but increased nonlinearly as the number of wet years increased. Results from rainfall manipulation experiments suggest that dominant $C_4$ grasses have greater physiological responses to increased summer rainfall compared with $C_3$ shrubs (i.e., mesquite) (Throop et al. 2012). **An improved understanding and ability to predict vegetation dynamics and species and ecosystem responses to altered rainfall (e.g., season) and distribution of rain events (large vs. small) is needed. A better understanding of the complex, multi-scale interactions among system components will enhance our ability to predict future states and dynamics in response to climatic shifts.**

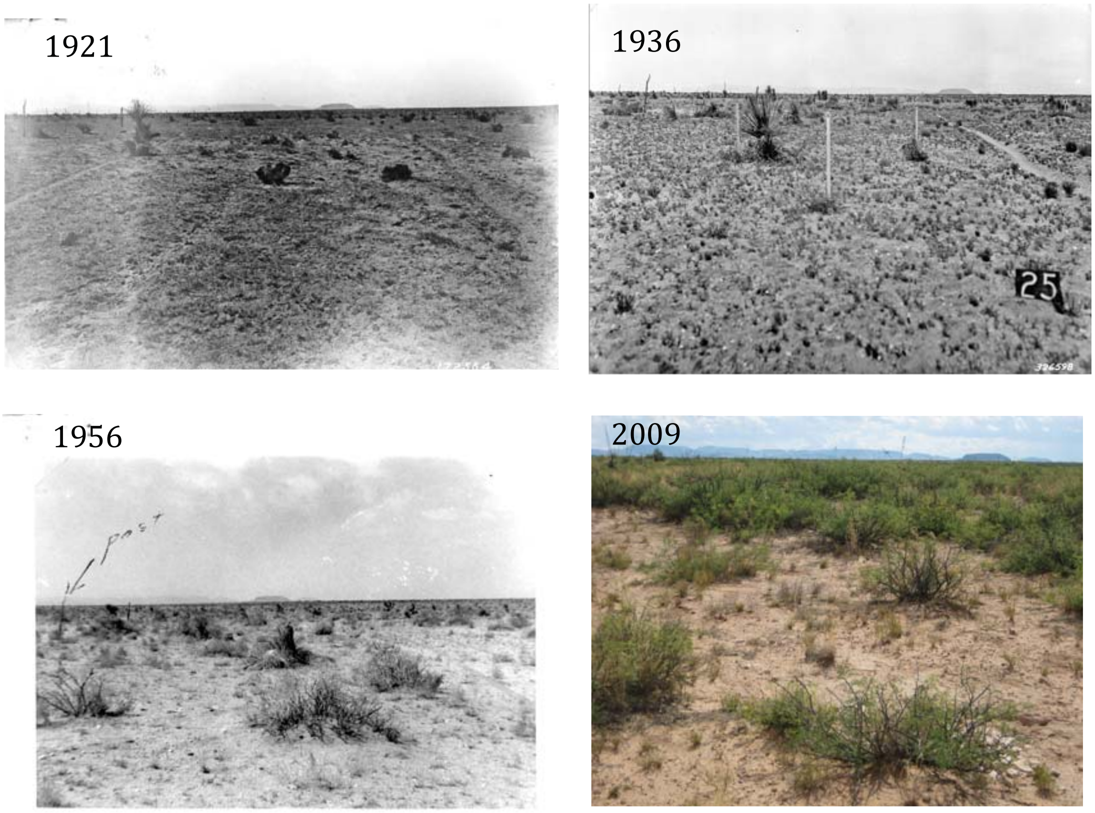



Figure 8. Photographic illustration of the transition of a sandy ecological site within MLRA 42 from a desert grassland state to a shrubland state during the 20th century. The photographs span nearly 9 decades, but the actual transition occurred in less than a decade between the late 1940s and the mid 1950s (From Bestelmeyer et al. 2011a).

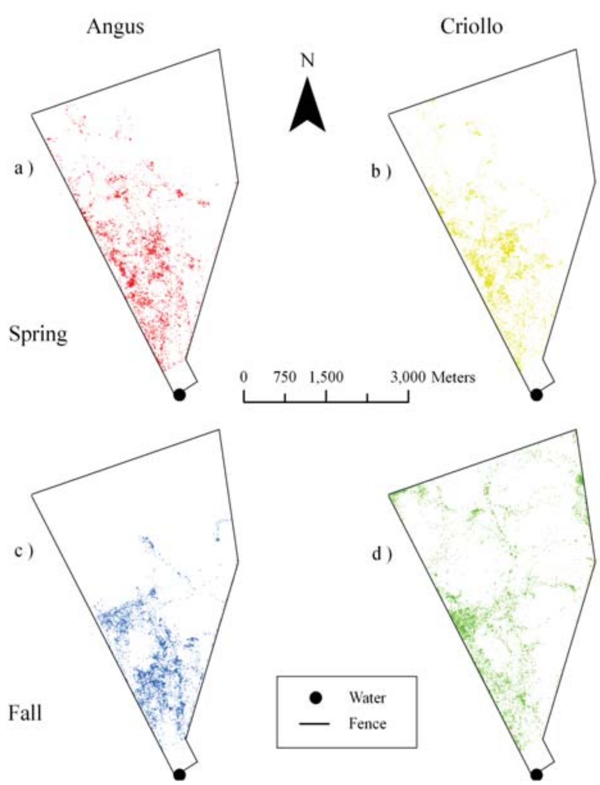



Figure 9. Used (color) and unused (white) pixels for foraging by Angus and Criollo breeds during the spring and fall seasons on the Jornada. Pixel size is 20 X 20 m, and use of the area near the water point is not shown (From Peinetti et al. 2011).

**RELATED RESEARCH**

This project plan was developed with an explicit awareness of ARS project plans of the Rangeland Resources Research Unit in Cheyenne, WY, and the Pasture and Meadows Research Unit in Burns, OR. In addition, this project plan was structured to be cognizant of project plans of the Grazinglands Research Laboratory in El Reno, OK; the Southwest Watershed Research Unit in Tucson, AR; and the Northwest Watershed Research Unit in Boise, ID, in order to facilitate interactions during the 2012-2017 period.

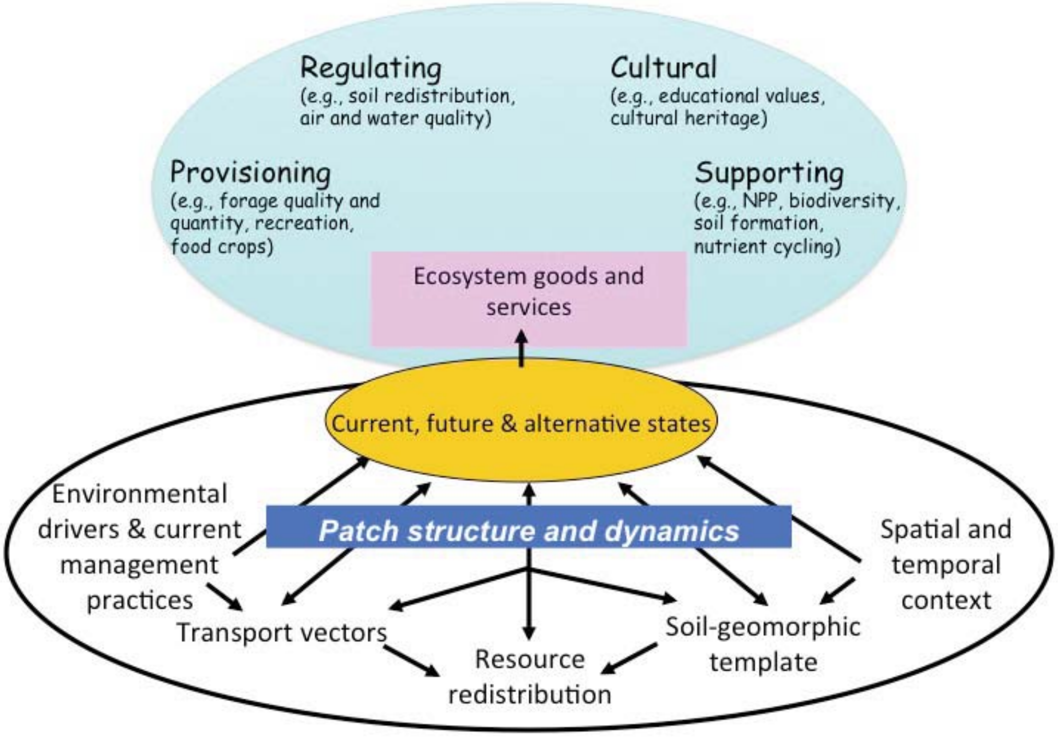



Figure 10. Each vegetative state characteristic of any specific ecological site can potentially provide a suite of ecosystem services (From Peters et al. 2006, Havstad et al. 2007).

Of additional significance is the inclusion of the Jornada in the 10-site LTAR Network of the ARS established early in 2012. Though the specific initial research collaborations of this network have yet to be formally established, this project plan was developed in anticipation of pending network activities. In particular, we emphasized development and accessibility of our many long-term data sets that are essential to the research required to address most of the sub-objectives in our plan (see: http://jornada.nmsu.edu/data-catalogs; Appendix Table 3).

A search of current CRIS projects revealed 21 other main projects addressing rangeland management objectives. These projects are based in the 17 western states. Of these 21 projects, 6 address ecological and/or management principles, 2 emphasize development of inventory, assessment, and/or monitoring techniques, 2 are devoted to global change effects and adaptation needs, 4 address development of germplasm for restoration, 6 address weed and/or invasive species control objectives, and 1 addresses erosion control and watershed management objectives. Many of these 21 projects involve 4 investigators or fewer. A few projects are focused on identifying ecological principles with application to land management, and none of these are in hot, arid environments. There are no other range management projects that involve 10 or more scientists, there are no other projects integrated more broadly across the west, and there are no projects that integrate ecological principle objectives with livestock management objectives or objectives to develop an array of technologies suitable for land management.

**APPROACH AND RESEARCH PROCEDURES**

**Objective 1:** Develop data-driven approaches in the production of ecological site descriptions that guide rangeland conservation and management practices within major land resource areas (MLRAs) of the western U.S., including New Mexico, Arizona, Oregon, North Dakota, Wyoming, Montana, and Oklahoma.

- **Subobjective 1A:** Produce new approaches for and examples of data-driven ecological site description and state-and-transition model development using analysis of inventory, historical, experimental, and monitoring data, augmented by local knowledge. (Bestelmeyer, Havstad, Herrick, Peters,Vacant Rangeland Mgmt)

**Research Goal 1A:** Systematic, data-driven approaches for the development and use of ESDs and STMs that serve as a basis for the design and implementation of management actions, assessment and monitoring, simulation modeling, and data interpretation.

**Rationale Statement:** Ecological site information and associated STMs (i.e. ESDs) can serve as a basic framework for the application and assessment of rangeland management practices for several reasons. First, ESDs are directly linked to soil classification and spatial data (soil mapping) of the National Cooperative Soil Survey, providing a stable (but updatable), spatially explicit database structure for information storage and retrieval at a national scale. Second, STMs within ESDs can carry ecological process-based predictions about management effects that link to regional (e.g., MLRA) bodies of science information. Third, ESD development involves both data synthesis and local knowledge (USDA-NRCS 2003, Knapp and Fernandez-Gimenez 2009), so ecological site development can be explicitly collaborative. Fourth, the recent multi-agency adoption of ESDs as a basis for management ensures that this approach will have increasingly broad applicability to rangelands, forests, and cropland across the U.S. Current ESDs, however, have generally not been data-supported or developed systematically, thereby limiting their potential utility for decision making and adaptive management.

**Research Approach:** We will develop an **approach composed of a series of interlinked steps** for the development and use of ESDs based primarily on our local efforts within the Chihuahuan Desert region (MLRA 42 and 41) and secondarily via activities with outside groups, linking directly to other ARS units and their local collaborations with NRCS and other organizations. First generation ESDs (usually featuring minimal data support) have been developed in many project areas (including ESDs in MLRA 42 that Jornada helped create) and serve as a basis for subsequent development. In other areas, informal ecological site concepts already exist or can be extrapolated from adjacent areas as a starting point. The sequence of steps includes: 1) meetings with stakeholders to identify a focal set of management issues **(e.g., invasive species proliferation, shrub encroachment, soil erosion; however, these issues will be site specific and impacted by previous management history)** and ecological sites (typically dominant or of specific regional management importance), 2) mapping ecological sites or key soil variations based on soil data from the Soil Survey Geographic Database, 3) stakeholder focus group/workshops and field visits to gather local knowledge on the properties of ecological sites and to develop detailed STMs that specify conditions and processes believed to mediate the management (conservation practice) effects on each site, 4) identify suitable existing datasets including historical information (General Land Office, Bureau of Land Management adjudication maps), aerial and ground photography (Digital Ortho-Quarter Quads, agency photographic monitoring), and inventory and monitoring data (from federal agencies) and the locations of cases (and their land holders) featuring spatial variations in conservation success, 5) training of stakeholders in the use of data collection tools developed by Jornada (e.g., Database for Inventory, Monitoring, and Asessment; [DIMA]; http://jornada.nmsu.edu/monit-assess/dima), including data collection forms and application for mobile devices to provide new inventory and management data for specific locations that can be used in ESD development, 6) develop mapping approaches and database tools to represent ecological states spatially as a basis for management decisions, and 7) work with, and obtain feedback from, stakeholders in the use of ESDs and mapping/database products to improve ESDs and their utility. Specific approaches we will use are described in Bestelmeyer et al. (2009), Knapp and Fernandez-Gimenez (2009), Knapp et al. (2011), Skaggs et al. (2011), Steele et al. (2012), and Karl et al. (2011). Statistical analyses of inventory and monitoring data will employ multiple regression, least-absolute deviation regression, ordination, and classification and regression trees to provide quantitative support for ecological site concepts. Our work will lead to revised ESDs in MLRA 42 and we will coordinate with and assist MLRA-level projects with cooperators in other MLRAs.

**Contingencies:** This multifaceted subobjective depends on interactions with stakeholders and cooperators to identify information-rich locations, contribute concepts and data, and incorporate the resulting approaches into national programs. Thus, elements of our project are difficult to specify in advance. Nonetheless, researcher-stakeholder interactions and the integration of science with management are clearly needed for the development of useful ESDs. It is also clear that we need to experiment with how the variety of data resources and tools used (or that could be used) in ESD development work together, rather than approaching them in a piecemeal way. Our working relationships with local and national stakeholder groups and experience with the tools will allow us to adapt our approaches alongside the decisions of our cooperators.

**Collaborations:** Cooperative Agreements pertaining to Subobjective 1A have been formalized in Project No. 6235-11210-006-97-R, 6235-11210-006-07-S, and 6235-11210-006-80-R (Appendix Table 2).

- **Subobjective 1B:** Create and populate a national database of ecological dynamics to be used in guiding national ecological site description development and as a mechanism for stakeholder communication, including specific efforts in major land resource areas of New Mexico, Arizona, Oregon, North Dakota, Wyoming, Montana, and Oklahoma. (Bestelmeyer, Havstad, Herrick,Vacant Rangeland Mgmt)

  **Research Goal 1B:** Develop a method for representing general models of ecological dynamics in rangelands within a publically accessible database and to develop such models for specific MLRAs.

  **Rationale Statement:** Ecological site descriptions provide a useful technology for conveying the ecological potential of specific land types and the possible responses of vegetation and soils to management. Yet some of the same traits that lend ESDs their management utility (e.g., narrative format and site-specific focus) also make them an inefficient resource for broader-scaled analyses, such as comparing ecological processes among regions or producing regional and national maps of conservation successes or needs. Such objectives would be better served by a database in which ecological information for a region can be 1) readily queried and 2) easily analyzed in a geographic information system (GIS). The National Ecological Dynamics Database (NEDD) was conceived to help facilitate communication and analysis of natural resource issues at broad spatial scales.

**Research Approach:** We propose to structure this database around four primary features: 1) generalized STMs that synthesize and describe the ecological dynamics of primary management concern within each MLRA or LRU, 2) a relational database that stores the data associated with MLRAs/LRUs and their generalized STMs, 3) within the database, key phrases associated with generalized STM elements will provide the primary mechanism for summarizing, comparing, and contrasting the ecological dynamics of multiple MLRAs and for applying land management knowledge across regions, and 4) synthetic data products derived from National Resource Inventory (NRI) data, conservation practice use, and conservation assessments will also be databased with reference to generalized STMs and MLRAs/LRUs. The NEDD database will be designed by Jornada staff and generalized STMs will be developed via syntheses of existing, ecological site-specific STMs, literature review, and workshops/interviews following approaches outlined in Knapp et al. (2011), including web-based interfaces. NRI data will be analyzed to identify and assess the frequency of different types of states and practices (which we have had access to; e.g. see: Herrick et al. 2010).

**Contingencies:** MLRAs will differ in amount of available information and in the way models are usefully represented. With each model that is developed, we will consider modifications to the model and NEDD structure. The success of NEDD ultimately depends on successful collaborations within national and state-level land management agencies and other interested stakeholder groups.

**Collaborations:** Cooperative Agreements pertaining to Subobjective 1B have been formalized in Project No. 6235-11210-006-97-R and 6235-11210-006-80-R (Appendix Table 2).

**Objective 2:** Improve techniques, including remotely sensed methodologies, for rangeland monitoring and assessment applicable to landscapes within MLRAs, and more broadly for regional and national scales of assessment.

- **Subobjective 2A:** Develop and evaluate innovative approaches for remotely monitoring land surface conditions in order to improve existing and develop new methods for rangeland monitoring. (Herrick, Rango, Vacant Soil Science, Vacant Rangeland Mgmt)

  **Research Goal 2A**: Inform and support land management decision-making through the development and use of analytical methods that capitalize on data collected using multiple remote sensing platforms.

  **Rationale Statement:** Stewards of federal lands are charged with managing natural resources for an increasingly diverse array of ecosystem services that manifest at different spatial scales. Remotely sensed data are valuable for mapping and monitoring changes in the land surface in a consistent manner and are inherently scale-dependent with observations ranging from centimeters (i.e., individuals plants) to kilometers (i.e., landscapes). The spatial extent and rugged remote nature of rangeland ecosystems challenge field-based assessments; yet, such important perspectives can be informed by remotely sensed data collected at the appropriate spatial scale. However, an operational framework to inform decision making at spatial scales relevant to land management has yet to be implemented. We propose that a hierarchical framework leveraging multiple sources of remotely sensed imagery is an integral component to a workable solution. Moderate resolution satellite imagery provides repeat depictions of the land surface in a consistent manner across large landscapes; however, it does not allow evaluation of patterns at finer spatial resolutions. While satellite and conventional aerial photography have improved in spatial resolution to about 25-50 cm, they still are not widely used for range management, hydrology, and ecosystem applications. Numerous studies using unmanned aerial system (UAS) platforms yielding approximately 5-cm spatial resolution have proven to be immediately applicable to these fields of study. Experience with these sensors on UAS will lead to recommendations for the optimum sensor package and specific UAS platform.

**Research Approach:** Providing strategies and image products relevant to decision-making will entail 1) devising an operational hierarchical work flow that promotes integration of disparate data sets and accommodates problem-solving at multiple spatial scales and 2) testing and evaluating the acquisition, processing, and analysis of super-high resolution imagery from UAS as a novel approach to quantifying land surface conditions in rangelands. This research employs two existing UAS aircraft based at the Jornada and a skilled and experienced staff flight crew.

*Operational hierarchical work flow:* Remote sensing products will be generated and verified relevant to land management goals. This is contingent on *a priori* development of a framework that bridges (scale-specific) management objectives with relevant information retrieved from field data, satellite, or air-borne imagery. Multi-scale approaches integrating field-collected data, 5-cm UAS imagery, and satellite imagery will be implemented based on recent experiences (Laliberte et al. 2010, 2011a) **and using the same area for which we have extensive measurements**.

*UAS data development:* We will enhance landscape mapping capabilities using UAS imagery and validate image products using a combination of field spectroscopy and established field-based protocols (Laliberte et al. 2011a,b). New techniques will be tested for seamless mosaicing of UAS images to provide high resolution coverage over larger areas. Enhanced mapping capabilities afforded by very high spatial resolution (e.g., 5 cm) are one advantage of UAS imagery, but the spectral resolution limitations of digital cameras require improvement**, which will be achieved by using data from a newly acquired six-band multispectral camera flying in the same UAS as the digital cameras.** Working primarily within MLRA 42, we will generate and verify image products derived from multispectral and thermal infrared cameras and exploit the capabilities of LIDAR, RADAR, and hyperspectral sensors as these become readily available. **Efforts to access and query available UAS image mosaics will be facilitated through a geospatial image catalog database that will enable users to search for imagery by location and date range.**

**Contingencies:** Both MLB Co. BAT 3 and BAT 4 UAS are available but addition of new instruments to the sensor package (e.g., a thermal infrared camera and a miniaturized LIDAR) is contingent on when sensors become available. A flight crew trained according to FAA requirements must be maintained. The Landsat Data Continuity Mission will be launched in late 2012 or early 2013 to provide Landsat follow-on data. Until then, SPOT and similar satellite data will be used to fill any data gaps in the imagery record used for rangeland monitoring applications.

**Collaborations:** Cooperative Agreement pertaining to Subobjective 2A has been formalized in Project No. 6235-11210-006-05-N (Appendix Table 2).

- **Subobjective 2B:** Develop innovative, integrated, and flexible inventory, assessment and monitoring techniques and the decision support tools necessary to implement these approaches at local to national scales. (Herrick, Vacant Soil Science, Vacant Rangeland Mgmt, Bestelmeyer, Havstad)

  **Research Goal 2B:** Develop and implement techniques, tools, and decision-support systems to better design and implement inventory, assessment, and monitoring programs, integrate field and remotely sensed data, and analyze results at relevant scales within western MLRAs.

  **Rationale Statement:** Evidence-based land management requires inventory, assessment, and monitoring information. State and federal agencies and private landowners spend hundreds of millions of dollars annually collecting data on rangelands, but data are sometimes not used or misused in making management and policy decisions. In some cases, data are insufficient, redundant, or inappropriate for the management question. Tremendous opportunity exists to increase the efficiency, cost-effectiveness, and relevance of rangeland inventory, assessment, and monitoring techniques. Our unit is committed to continuing to exploit these opportunities through research and development of decision support tools.

**Research Approach:** Four sets of tools are required to enhance rangeland inventory, assessment, and monitoring: 1) a standardized set of core ground-based indicators and methods relevant to multiple management objectives, 2) statistically sound sampling frameworks that can be adapted to multiple objectives, 3) a framework for optimizing integrated field and remote sensing-based strategies, and 4) a web-based support system that allows managers to easily design and implement monitoring at local levels in a manner that also facilitates scaling necessary to respond to regional and national questions. For each of these areas, we will work with cooperators to develop techniques and protocols, perform validation/calibration studies, and develop software tools and training materials to support cost-effective and relevant inventory, assessment, and monitoring on rangelands.

*1. Standardized set of core ground-based indicators and methods:* Method calibration studies will be completed on an as-needed basis to compare data (provided through existing cooperative agreements) from BLM/NRCS core standard methods to data collected using legacy and other methods. Wherever possible, we will assist agency and academic partners in collecting these data by providing database, statistical design, and analysis support, as we have for the past decade (Herrick et al. 2010, MacKinnon et al. 2011, Toevs 2011).

*2. Sampling frameworks:* In cooperation with agency and academic partners, we will develop guidelines for robust, statistically based sample designs that can meet multiple management objectives and be used at multiple scales. Additionally, we will conduct research with partners to identify approaches for incorporating legacy, non-statistical sampling locations into modern statistically based sample designs based on concepts described by Brus and DeGruitjer (1993), Gregoire (1998), Thompson (2002), and Larsen et al. (2008). **We will work with academic partners to determine the conceptual and theoretical merits of different approaches and**

**will use statistical simulations to illustrate how combinations of statistical and non-statistical sampling locations affect indicator estimates for different objectives. We will also work with agency partners to demonstrate these techniques in locations where legacy non-statistical monitoring data on species composition have been collected.** Statistically based geospatial sampling design tools will be developed to allow natural resource professionals to optimize sampling to meet requirements with available budgets and to allow them to clearly communicate to managers the tradeoffs between number and type of indicators generated and precision of the estimates.

*3. Optimizing integrated field and remote sensing-based strategies:* A framework for optimizing integrated field and remote sensing-based strategies will be developed based on new and existing knowledge of the complementary strengths and limitations of the two types of approaches. When necessary, new analysis tools will be developed, particularly for high-resolution aerial photography widely used by NRCS, BLM, and USFS.

*4. Decision support system:* A web-based support system will be developed that allows natural resource professionals to easily design and implement monitoring at local levels in a manner that also facilitates scaling necessary to respond to regional and national questions. To this end, we will work to improve the Landscape Toolbox (see: http://www.landscapetoolbox.org/) in cooperation with agency and non-profit partners. The modular system will include the ability to select and apply indicators, methods, and systems for data collection, storage, analysis, and synthesis based on 1-3 above.

**Contingencies:** We have a number of Specific Cooperative Agreements (Appendix Table 2) in place that will enhance our ability to develop and apply these tools.

**Collaborations:** Cooperative Agreements pertaining to Subobjective 2B have been formalized in Project No. 6235-11210-006-02-R, 6235-11210-006-04-G, 6235-11210-006-95-M, and 6235-11210-006-88-R (Appendix Table 2).

**Objective 3:** Evaluate effectiveness of historic, current, and new grassland restoration practices for dominant ecological sites within specific MLRAs of New Mexico, Arizona, Oregon, and Wyoming.

- **Subobjective 3A:** Design and implement new studies and analyze experimental data from conservation management practices and grazing management efforts on public and private lands in MLRA 41 and 42 of AZ and NM, MLRA 25 in OR, and MLRAs 58B and 67B in WY with respect to multiple ecosystem services. (Bestelmeyer, Vacant Soil Science, Lucero, Havstad)

  **Hypothesis 3A:** Restoration treatments will have measureable, positive impacts on rangeland attributes of interest (e.g., perennial grass cover, bird community structure), subject to variations induced by ecological site and ecological state at the time of restoration. Our goal is to promote a general approach for linking evaluations of conservation effectiveness to ESDs within MLRAs.

  **Rationale Statement:** The effectiveness of conservation or restoration practices such as seeding or brush removal are generally not adequately monitored on rangelands (Briske 2011) nor tailored to variations within ecosystems (Bernhardt et al. 2005, Hildebrand et al. 2005). Such variations may be due to differences among ecological sites, the initial state or plant community, or the landscape mosaic structure within which a practice is applied. Thus, we are often unable to use scientific evaluations of conservation practices to improve their application in the face of spatiotemporal heterogeneity in practice effectiveness (Bestelmeyer et al. 2011d). There is a clear need to develop database systems that link knowledge about conservation actions to specific locations in the landscape with predictions represented in ESDs, STMs, and landscape simulation models. Such systems would allow us to learn how different locations and temporally varying conditions mediate the effects of practices, such that this information can be represented within ESDs and derivative map products. Such long-term “adaptive restoration” employs structured, experimental approaches to intervention carried out in a variety of settings to facilitate collaborative learning (Zedler and Callaway 2003).

**Research Approach:** Tests of the effects of conservation practices will use pre-planned, paired treatment and control sites for each new conservation project (e.g., using pre-planned untreated areas for brush control applications) or, where this is not feasible, structured monitoring within treated and untreated areas (e.g., ranch-scale grazing management). **Past brush control practices consisted primarily of herbicide application (e.g., 2,4-D, Tebuthiuron, Chlorpyralid) and mechanical control (e.g., chaining) but future treatments could potentially include other forms of shrub control (e.g., fire, biocontrol). Other restoration practices include reseeding and erosion control.** Predictions will be developed based on interpretations within ESDs and interactions with stakeholders. Mapping and field evaluations of ecological sites, ecological states, and plant community phases will be used to plan treatments or select monitoring areas (Bestelmeyer et al. 2011d, Steele et al. 2012). Monitoring will employ methods consistent with national NRCS and BLM protocols (Herrick et al. 2005). Local application of this approach, directly supported by Jornada staff, will be centered on brush control applications of the Restore New Mexico program in cooperation with the BLM, NRCS, and Malpai Borderlands Group. The primary datasets will be collected and analyzed as a cooperative project between the BLM and the Jornada. We will work with collaborators to establish similar approaches on other MLRAs.

**Contingencies:** Tests carried out in the context of real-world management actions are subject to a variety of complications, including timing and communication between managers and scientists. Nonetheless, we have established good working relationships with BLM staff in southern New Mexico in the context of such studies within MLRA 42, and will rely on similar relationships in other MLRAs.

**Collaborations:** Cooperative Agreement pertaining to Subobjective 3A has been formalized in Project No. 6235-11210-006-03-R (Appendix Table 2).

**Objective 4:** Evaluate livestock management practices suitable for conserving and restoring rangelands within MLRAs of the southwestern U.S.

- **Subobjective 4A:** Evaluate grazing management practices and their relationships to ecological state changes within ecological sites in MLRAs 41 and 42 of AZ and NM. (Estell, Havstad, Anderson)

  **Hypothesis 4A:** Changes in carrying capacity between 1930 and present within MLRAs 41 and 42 reflect changes in ecological states (Fig. 8), which vary among ecological sites. Changes in carrying capacity through time are related to management and vary among ecological sites in their responses to grazing management.

**Rationale Statement:** Demand for red meat is escalating, yet many public land grazing allotments in MLRA 42 have not been stocked at permitted AUMs (Fig. 7). It is unknown whether allotments truly support fewer AUMs than permitted or whether animal numbers cannot be maintained simply because of the lag time required to respond to annual variability in forage production through adjustments in stocking rate. Carrying capacity may have changed over time because of vegetation dynamics during the 20th century and state changes (e.g., shrub invasion) due to slow drivers such as overgrazing and extended drought. Management practices that cause states (particularly grasslands) to persist or degrade (e.g., physical changes, fire regime, invasive species, human factors, etc.) interact with ecological site to affect state change. Thus, modern day permitted AUMs may not reflect actual carrying capacities for some ecological states/sites in MLRA 42.

**Research Approach:** A number of large data sets, associated data layers, and maps are available at various scales that contain information about ecological properties of landscapes (Williamson et al. 2011). Ecological site descriptions and ecological states are available for rangelands in MLRA 41 (Southeastern Arizona Basin and Range) and 42 (Southern Desertic Basins, Plains, and Mountains). These two MLRAs contain the Jornada and BLM's Las Cruces Grazing District (MLRA 42) and the Malpai region (MLRA 41). The Jornada is involved in several active research projects in both MLRAs. Ecological site and state data are available for many of these areas dating back to the 1930's. For example, the Las Cruces Grazing District (6 counties and 603 allotments) has ESDs and over 70 years of vegetation data dating back to the 1930's, and over 900 data layers exist for this area (Williamson et al. 2011). Both areas are well mapped (soils, vegetation characteristics, precipitation patterns, etc.) (USDA-NRCS 2006).

Nationally, animal inventories and statistical data exist by state and county through the National Agricultural Statistics Service. Stocking rate data are also available for allotments within a grazing district from the BLM. For many areas in the western U.S., livestock numbers on a particular landscape at a given point in time are not well documented. Animal records through time are available from BLM public records (billed AUMs by allotment). In some cases, local knowledge may be tapped to determine historical and current carrying capacities on specific ranches.

Maps of ecological states through time will be analyzed concurrently with dynamics in livestock stocking rates to assess the role of livestock use in state changes using approaches described by Williamson et al. (2011, 2012) and Steele et al. (2012). The approach will be to start with small land units and ultimately telescope to regional landscapes. Small areas (e.g., ranches, allotments, grazing districts) for which accurate animal numbers can be estimated will be identified. Comparisons will be made between areas on different ecological sites and with different management regimes in these two MLRAs. Polygons containing perennial grasslands will be tested to determine attributes that allow persistence (e.g., fences, water, past practices, etc.). Regionally, these MLRAs will be assessed in terms of ecological sites and shrub composition to determine the extent to which these ecological sites and current vegetation states may supply forage for red meat production. These analyses will identify ecological sites for which grazing is sustainable and how it will be affected by predicted state changes.

**Contingencies:** Availability and quality of data for livestock numbers at different times in different locations will vary. Accurate histories of management practices will not be available for many areas. We will focus on landscapes with all needed data layers for these analyses.

**Collaborations:** Cooperative Agreements pertaining to Subobjective 4A have been formalized in Project No. 6235-11210-006-62-S and 6235-11210-006-07-S (Appendix Table 2).

- **Subobjective 4B:** Evaluate low-input livestock production strategies in MLRA 42. (Estell, Havstad, Anderson)

  **Hypothesis 4B:** Criollo cattle require fewer inputs of harvested forages to reach marketable weights and are more compatible with low-input sustainable beef production than traditional British breeds on ecological sites and states characteristic of MLRA 42.

  **Rationale Statement:** Environmentally and economically sustainable beef production systems are needed for MLRAs characterized by harsh shrubby ecosystems with low and erratic precipitation. The Jornada is uniquely positioned to compare beef production systems using traditional Angus crossbreds vs. Criollo cattle in MLRA 42. A Criollo herd was established at the Jornada over the past decade with animals obtained from isolated areas of the Sierra Tarahumara in southwestern Chihuahua, Mexico in an effort to exploit the genetics of this desert-adapted breed. These cattle (mean weight ~ 330-360 kg) are smaller framed than the 500+ kg cows now common in the southwest. Anecdotal evidence and preliminary behavior data suggest they require fewer inputs and exhibit travel behaviors (Fig. 9) that allow them to exert less impact on the landscape and be less affected by drought (i.e., reduced forage production) than traditional breeds. Information on diet selection, foraging behavior, and carrying capacity of this specialized breed on ecological sites characteristic of MLRA 42 is needed.

**Research Approach:** The Jornada has approximately 60 Criollo cows and 60 Angus-cross cows. These animals are managed using established husbandry protocols (**light stocking rate, summer calving**), and are maintained in extensive pastures (Fig. 11) and rotated based on forage availability. These pastures vary in size, topography, forage composition, and ecological states, and present the types of management challenges faced by producers operating in conditions representative of MLRA 42. **Herd management (timing of pasture rotation, supplemental feeding, etc.) varies among seasons and years because of the highly variable nature of precipitation (both amount and timing) in this system.** Two lines of research will be conducted that require different types of data and analyses. Production data will be collected on reproductive efficiency (calving rates/intervals), weaning weights, calf growth rate and age at market weight, and external inputs (i.e., supplemental feed) over a 5-year interval to evaluate the two breeds in a standard production setting typical of the region. An economic analysis will be conducted to determine overall profitability of the two beef breeds in this system. Feed and supplement costs and production data will be used to compare average annual net income from the two production systems. Additionally, small-scale replicated studies will be conducted to examine potential differences in foraging behavior between breeds. Dietary habits and species preferences will be measured across seasons. Six mature cows **of similar age** from each breed will be placed in the same pasture and diet scans (Altman 1974) will be used to determine botanical composition during each of four seasons in two consecutive years. Diet selection will be observed on two vegetation types during spring, summer, fall, and winter seasons. Diets will be observed on a predominantly grassland (tobosa) pasture and a predominantly shrubland (mesquite) pasture.

**Contingencies:** Drought and forage availability could alter experimental units available for analyses.

**Collaborations:** Cooperative Agreement pertaining to Subobjective 4B has been formalized in Project No. 6235-11210-006-62-S (Appendix Table 2).

**Objective 5:** Develop mechanistically based predictions of vegetation state changes and site-based wind erosion susceptibilities for landscapes within selected MLRAs under alternative land use-climate change scenarios.

- **Subobjective 5A:** Predict climate-driven vegetation state changes for western landscapes within selected MLRAs. (Peters, Herrick)

  **Research Goal 5A:** Predict vegetation state changes on selected western rangelands under future climate scenarios that include changes in direction (increase, decrease), magnitude, and timing of precipitation.

  **Rationale Statement:** Arid rangeland dynamics are complicated by multiple biotic (plant, animal) and abiotic (soils, elevation, topography, climate) factors and processes interacting across a range of spatial and temporal scales and extreme variability in abiotic conditions characterizing these systems. It is critical to understand how these factors and processes interact in order to manage these systems and to predict changes in system dynamics as climate and other drivers change. A number of tools are available for this synthesis that will improve our understanding and prediction of complex rangeland dynamics. Short-term experiments are useful for isolating and quantifying processes occurring over short time periods and small spatial extents. Long-term experiments are critical for determining the response of these processes to a broad range of environmental conditions. Simulation modeling, in combination with short- and long-term databases, is useful for examining complex ecosystem interactions and predicting responses to environmental drivers and changes in management. There is a critical need to integrate these tools in order to predict long-term consequences of potential climate change on vegetation and state changes.

**Research Approach:** We will build upon an established simulation model of vegetation and soil water dynamics (ECOTONE) linked with a hydrologic-redistribution model (tRIBS; Vivoni et al. 2007) and a wind erosion-deposition model (Okin 2008) for our predictions. We will initially focus our efforts on several areas at the Jornada where long-term data sets exist and where new intensive, coordinated studies will be conducted. Each area will be spatially heterogeneous in vegetation, soils, and topography. One area will be used for model development and the other areas will be used to test model predictions.

*Model development:* ECOTONE is an individual, plant-based gap dynamics model linked with a soil water model developed to simulate arid and semiarid grasslands and shrublands (Peters 2002). The model has been parameterized and tested for black grama-creosotebush communities at the Jornada (Peters and Herrick 2002). We are generalizing ECOTONE for the remaining major plant communities and key plant species, as well as modifying the model to include animal components. We will include additional processes and expand the spatial complexity of ECOTONE in order to examine the relative importance of vegetation-soil-animal feedbacks, resource redistribution, foraging behavior, and patch size to ecosystem dynamics. Key processes and feedbacks identified in Objectives 1-4 will be incorporated into the model either as parameters or additional functional relationships. Transfers of water, seeds, and nutrients among patches or ecological units will be measured through our collaborative efforts with the Jornada Long Term Ecological Research (LTER) program (2012-2018) and included in the development of the model. In particular, parameters for the wind model will be obtained from Objective 5B. The tRIBS model has been used in numerous ecological systems and presently is being tested at the Jornada (Templeton 2011). The model will be tested by comparing output with short- and long-term data from the Jornada that were not used in model development or parameterization.

We will use our integrated simulation model two ways. First, we will conduct historic simulations of our validation areas from 1850 when perennial grasslands were prevalent to 1998 to test the ability of the model to represent shrub invasion processes. Historic vegetation and soils maps and documents will form the basis for initial conditions. We will then run ECOTONE using historic weather data, parameterized for vegetation, soils, and animals, from our experiments and information in the literature. Runs will be conducted both with and without fluxes and flows of materials (seeds, soil, water, nutrients) to determine the relative importance of within- and between-unit processes. We will compare patterns in grasslands and shrublands predicted by the model across multiple spatial scales with current distributions of these vegetation types using ground-based measures and aerial and satellite images. Differences between observed and predicted results will lead to new experiments. Sensitivity analyses on model output will be used to determine the relative importance of separate and interactive processes and factors in shrub invasion for different grassland and soil types and topographic positions within MLRAs 41 and 42.

After the model has been well tested and modified to accurately represent previous dynamics, we will use it to predict future dynamics under different climate and management scenarios. A large number of potential scenarios are possible; only a few are noted here. We will examine potential responses of different vegetation and soil associations to directional changes in climate, as well as to drought cycles. **We will incorporate new data collected as part of Objectives 1 - 4 to parameterize the model.** Long-term consequences of alternative remediation technologies will be investigated. Because our goal is to develop a general problem-solving approach for understanding, managing, and predicting dynamics of arid rangelands, our future plans include testing this approach across a broad range of vegetation, soils, and climatic conditions and management scenarios useful to our customers.

**Contingencies:** Ability of the simulation model to predict future dynamics depends on our ability to identify key processes and to quantitatively represent them.

**Collaborations:** Cooperative Agreement pertaining to Subobjective 5A has been formalized in Project No. 6235-11210-006-62-S (Appendix Table 2).

- **Subobjective 5B:** Develop and implement a wind erosion monitoring network and standardize protocols for measurement and model-based predictions of changes in horizontal and vertical dust flux on western rangelands, including areas undergoing land use change. (Herrick, Vacant Soil Science)

  **Research Goal 5B:** Develop predictive tools for forecasting wind erosion potential in western MLRAs.

  **Rationale Statement:** Wind erosion is an increasing concern for western land managers, transportation planners, and health professionals. Increased wind erosion can be caused by disturbance and vegetation state changes associated with cropland abandonment, climate, development of traditional and alternative energy sources, transportation networks, military training, livestock overgrazing, and urbanization. Assessments of accelerated wind erosion are also part of the Conservation Effects Assessment Program given the importance of wind erosion as a driver in arid and semi-arid systems. A national dataset is needed to evaluate the effects of land use and land cover change across western landscapes on wind erosion, and to calibrate predictive models of erosion (see Objective 5A; Okin 2008). New models and nationally adopted rangeland monitoring protocols developed by the ARS, together with an existing network of ARS research locations, provide a cost-effective opportunity to fill this need.

**Research Approach:** The Jornada will lead development, testing, and implementation of a standard set of soil, vegetation, and wind erosion measurement protocols across a network of ARS locations.

*Protocol development:* Protocols will be selected and adapted based on the following criteria: 1) consistency with existing protocols that are already nationally adopted by the BLM, NRCS, and other federal and state agencies, 2) the ability of these protocols to generate necessary data (i.e., canopy gap size distribution, vegetation height, and soil surface texture; Okin 2008) to parameterize current and potential future wind erosion models, 3) high sensitivity, 4) low cost, and 5) high repeatability. **Parameters include vegetation structure and soil surface characteristics. Vegetation structure parameters must at a minimum characterize horizontal and vertical structure and may also include information about porosity. Soil surface parameters are related to wind erodibility, and may include soil surface texture, roughness, and degree of disturbance.** The protocols will be modular so that they can be applied at multiple scales to address multiple objectives, including studies of vegetation change, land use change, and management system comparisons. The core protocols will be designed to complement and support project-specific objectives. In addition to these core measurements, supplementary protocols will be included that can be applied, as resources allow, to provide more and better data for model calibration.

*Protocol testing:* Protocol sensitivity, cost, and repeatability will be tested across a broad range of land cover conditions on the Jornada and associated with urban and energy developments in the surrounding region. Further testing and refinement will be completed in association with implementation at participating locations.

*Implementation:* A simple decision support system will be developed to assist with project-specific design and implementation. The Jornada will further support implementation through on-line and on-site training. A data management system including tools for data entry, analysis, and generation of standard indicators will also be developed and served from the Jornada.

**Contingencies:** There are no contingencies for protocol development, testing, or implementation. The size of the network will depend on the willingness and ability of other locations to participate. In addition to the Jornada, seven locations have already committed to participating in the network.

**Collaborations:** Cooperative Agreements pertaining to Subobjective 5B have been formalized in Project No. 6235-11210-006-97-R and 6235-11210-006-80-R (Appendix Table 2).

## PHYSICAL AND HUMAN RESOURCES

The Jornada Experimental Range serves as a field station in support of the scientific mission of the ARS rangeland management research unit based in Las Cruces, NM, on the campus of

New Mexico State University (NMSU). The contributions of scientists based in Las Cruces in association with this field station for nearly a century have resulted in a lengthy record of diverse, accessible, and well-documented data sets. The Jornada is, at its core, a long term agricultural research field station. However, in recent decades this long term research nature has been leveraged beyond simple categorization as an agricultural research facility. The involvement of this facility in a broad array of important national science programs and research networks has positioned the Jornada as a multi-dimensional scientific facility of relevance for arid lands, their conservation, and their management. Of particular note is the Jornada's inclusion as one of the original 10 sites as part of the ARS Long-term Agro-ecosystem Research network (LTAR) formally established early in 2012. Of additional note is the Jornada's direct involvement since 1982 as one of the original cohorts of Long-term Ecological Research (LTER) sites (Appendix Table 3) and its inclusion as a relocatable site within the new National Ecological Observation Network (NEON). Our NEON site is slated for construction in 2013.

The Jornada was established from withdrawn public domain by Presidential Executive Order #1526 signed by President William H. Taft five months after New Mexico was granted statehood in early 1912. Originally named the Jornada Range Reserve, this 192,434 acre facility was established within the Bureau of Plant Industry of the USDA, but transferred to the USFS in 1915. The USFS quickly established a research program to address the principle objectives cited in the 1912 Executive Order, including: 1) quantifying carrying capacity of native rangeland for livestock use, 2) establish a system of forage utilization consistent with growth requirements of desert forage plants, and 3) examine the possibility of rangeland improvements by introduction of new plants, seed planting, and conservation of runoff. These objectives were seen as critical to addressing the widespread problems of rangeland degradation that had been documented across the American Southwest at the end of the 19th Century. These objectives have been addressed.

In 1952, the Jornada was transferred to the then newly created ARS. The ARS has been able to expand the research program from its more narrow beginnings to one with national and international significance for land and its conservation and management. The history of research during the past century is effectively categorized into 6 principal themes: plant and landscape ecology, ecosystem sciences, rangeland management, land monitoring and assessment strategies, rangeland improvements, and rangeland livestock production and husbandry (Havstad and Schlesinger 1996). The resulting productivity of over 2700 papers published in the peer-reviewed literature has been a significant contribution to a global understanding of arid ecosystems, their key ecological processes and properties, predictions for future dynamics, and important principles for livestock grazing and arid land management (see searchable bibliography at: **http://jornada.nmsu.edu/biblio**).

In 2012, the Jornada program operates across the western U.S. and has Cooperative Agreements with institutions in 7 other countries. Our formal research collaborations and Specific Cooperative Agreements (SCAs) are listed in Appendix Table 2.

**Staffing:** There are 10 permanent full-time category I ARS scientists, 7 full-time post doctoral research positions (either ARS associates or NMSU equivalent as of June 2012), and 1 collaborating permanent full-time USDA-NRCS scientist housed within this facility for a total of 18 scientists on site. Background and recent accomplishments of federal ARS postdocs directly associated with this project plan appear in Appendix Tables 1A and 1B. These 18 scientists are supported by 15 ARS FTE technical and administrative staff, and 20-25 state technical FTE supported by extramural grants and contracts. The Jornada research program staff of ~60 FTE are housed in Wooton Hall, a modern 29,000 sq. ft. USDA facility constructed in 2002 on the campus of NMSU. This building contains modern laboratory, office and conference facilities that support both ARS and LTER programs based at the Jornada.

In addition, 5 ARS FTE technical staff are assigned to the Jornada field station in support of maintenance, repair, and research assistance activities. These staff are housed at the Jornada field station headquarters (HQ) on a daily basis and provide all needed technical and logistic support for field station activities. In total, the Jornada has a staff of 70-75 scientists, technicians, office and administrative professionals, and graduate and undergraduate students working within the Unit.

**Facility Administration:** An ARS senior scientist serves as location coordinator responsible for all overall administrative and scientific functions and operations of the Jornada research unit and its cooperative research activities. Lead Scientists serve as Principle Investigators for either the ARS or the LTER research programs based at the Jornada. A Station Superintendent is assigned to the Jornada field station facility and directs staff, repair and maintenance activities, and field support functions on site. A research support scientist directs all livestock related activities at the Jornada. Individual technical staff handle specific research projects and field campaigns.

**Headquarters Site:** The Jornada HQ is located in the geographic center of the field station and is approximately 30 mi from the campus of NMSU in Las Cruces. This location provides direct access to hundreds of field sites currently in operation across the Jornada. Currently, at the Jornada HQ the existing infrastructure includes:

- resident housing for an on-site station manager,
- housing for ~20 visitors,
- modern shop, dry lab areas, and storage facilities/buildings,
- modern telecommunications services,
- modern electrical systems and distribution lines,
- an integrated network of 3 domestic water wells providing 50,000g of water storage and a modernized delivery system,
- offices for resident staff and visitors,
- a fire abatement system with appropriately distributed hydrants,
- a T1 fiber optics system providing high speed data communications and wireless internet access service to the HQ and subsequent wireless nodes across the field station,
- a new 2000 $ft^2$ multi-user facility.

**Jornada Field Station Research Sites:** Research sites across the Jornada can be characterized within one of two general categories; 1) long-term, manipulative field studies, and 2) sensor networks (Fig. 11). Metadata are associated with both categories, and both documentation and data sets can be accessed on line. All investigators are required to complete a research authorization request to ensure both metadata requirements are met, and to protect all existing research sites and locations (see: **http://jornada.nmsu.edu/data-catalogs/documentation** for instructions on site access and data documentation requirements). The sensor networks include both local (for example, a dust collector network) and national (for example, climate reference network, U/V network) networks.

**Data Management:** The conceptual framework for providing access to our varied and numerous data sets is presented in Fig. 12. The Jornada has adopted the on-site data management policies established by NSF for the LTER network. The Jornada Basin Information Management System (IMS) provides protocol and services for data collection, verification, organization archives, and distribution in accordance with LTER guidelines, (see: **http://jornada.nmsu.edu/lter/data/data-policies**). All data collected within the Jornada, whether LTER, USDA, or other funding sources, complies with these data management policies.

Associated with data management policies is a data access policy that all data are made publicly available no later than 2 years after submission of the original data, unless a specific extension to this time limit is granted to a principal investigator for a specific reason. Initial documentation for any data set is required of all scientists, collaborators, and their students and field personnel within 90 days of initiation of data collection. All data forms, access requests, and documentation forms are available on-line from **http://jornada.nmsu.edu/lter/data/documentation.**

**Jornada Datasets:** The Jornada maintains a data catalog (Appendix Table 3) comprised of over 150 separate, documented data sets linked to specific field studies or monitoring networks collected for different lengths of time over the course of its research history. Most completed or active data sets, and their metadata, are accessible for open public use. We are actively working towards having all data sets completely available in 2012. These data sets are organized into one of the following seven categories that generally describe their nature or intent: animal, climatic, decomposition, hydrology, inter-site, plant, or soil-related. Lengths of record vary with each specific data set.

Of these, 18 data sets are separated out as truly of a long-term nature. These are data sets with a minimum of 15 years of record, and are data sets that are active, on-going measurements. Many of our other data sets are also on-going, active records, but are not yet a minimum of 15 years of continuous collection. Several of these 18 long-term data sets trace back to the USFS and were initiated in 1915 and are approaching a nearly 100 year record of recorded observations. These data sets (see: **http://jornada.nmsu.edu/data-catalogs/long-term**) include classic climatic records, including daily precipitation and maximum and minimum daily air temperatures, and records of vegetation and soil surface dynamics. Of particular note are the long-term records of vegetation cover dynamics from permanent quadrats established across the Jornada beginning in 1915 (**http://jornada.nmsu.edu/jornadalter/studies/usda/projects/PermQuad.prj**), records of vegetation response to disturbances within plots established in 1938 (**http://jornada.nmsu.edu/jornadalter/studies/usda/projects/vclsusda.prj**), and spatial patterns of net primary productivity established in 1989 (**http://jornada.nmsu.edu/data-catalogs/data#LtNpp**). These records are still generating insights into long term dynamics within this desert, and are published in the peer-reviewed literature (e.g., Havstad et al. 1999, Gibbens et al. 2005, Yao et al. 2006, Peters et al. 2011b). In addition, all of these data are open for public use.

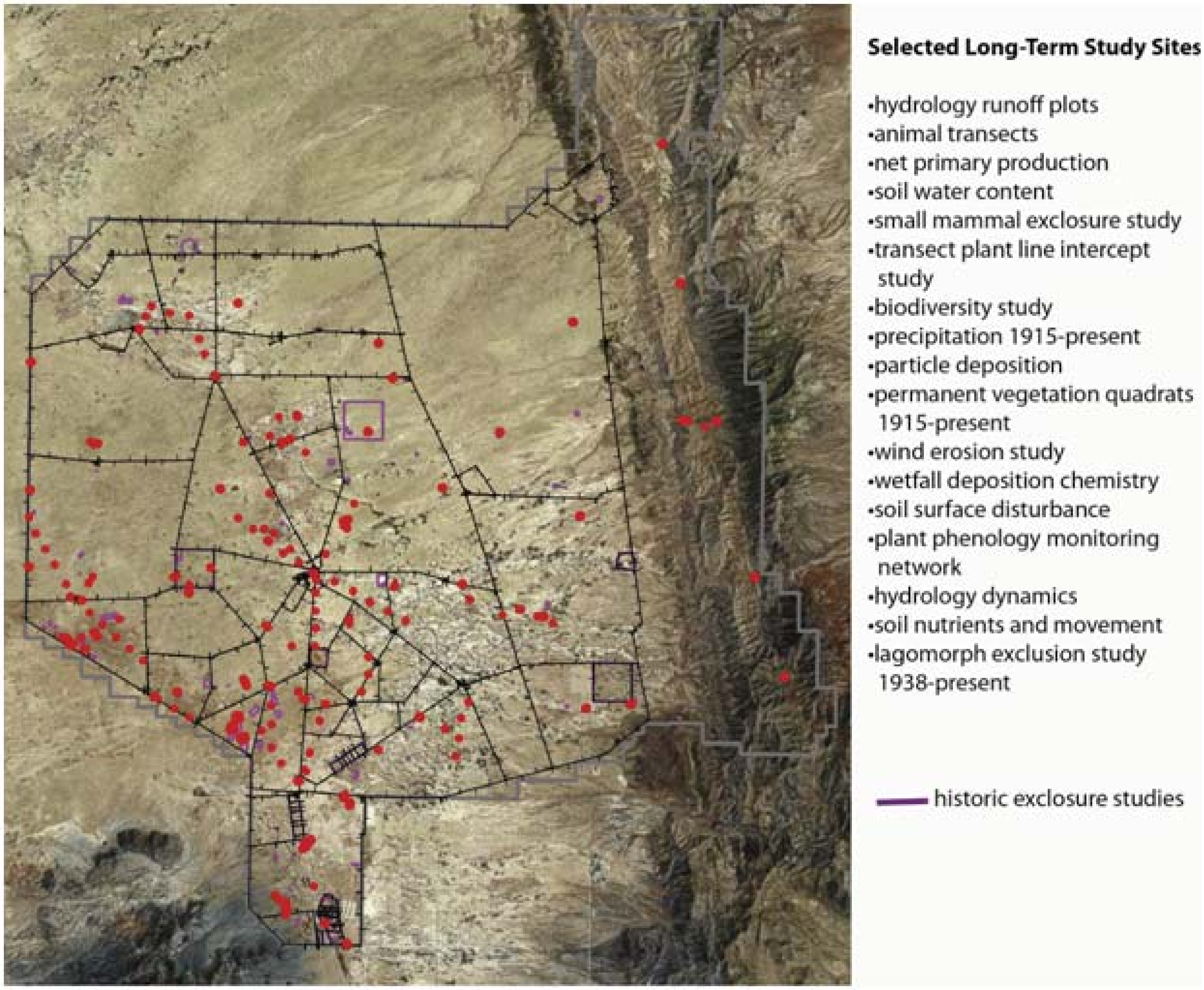



Figure 11. Locations of selected long-term study sites across the Jornada.

The Jornada also maintains an extensive catalog of spatial data. These data include GIS layers detailing boundaries, climatic networks, geographic reference points (e.g., land surveys), cultural features (e.g., roads, livestock watering points, and fences), and land coverage maps. We also provide access to satellite imagery (landsat scenes starting in 1993) as both bit map images and downloadable shape files. The Jornada also has an extensive collection of aerial photographs providing complete coverage of the Experimental Range beginning in 1935. These images have been a recent and rich source of information that has contributed to our scientific efforts (e.g., see Browning et al. 2011). Our spatial data sets are an active area of effort to provide complete and open access via web-based interactive portals, but we have not yet completed this effort. All of these spatial data sets (maps, shape files, GIS coverages) will be available by the end of 2012.

The Jornada also has an extensive collection of historical photographs mostly collected by USDA personnel beginning in the 1920s. All of our original prints and negatives have been archived within the historical special collections within the library system at NMSU to protect the original photographs. All images can be accessed through a searchable data base through the NMSU library system (see: **http://jornada.nmsu.edu/data-catalogs/photos**).

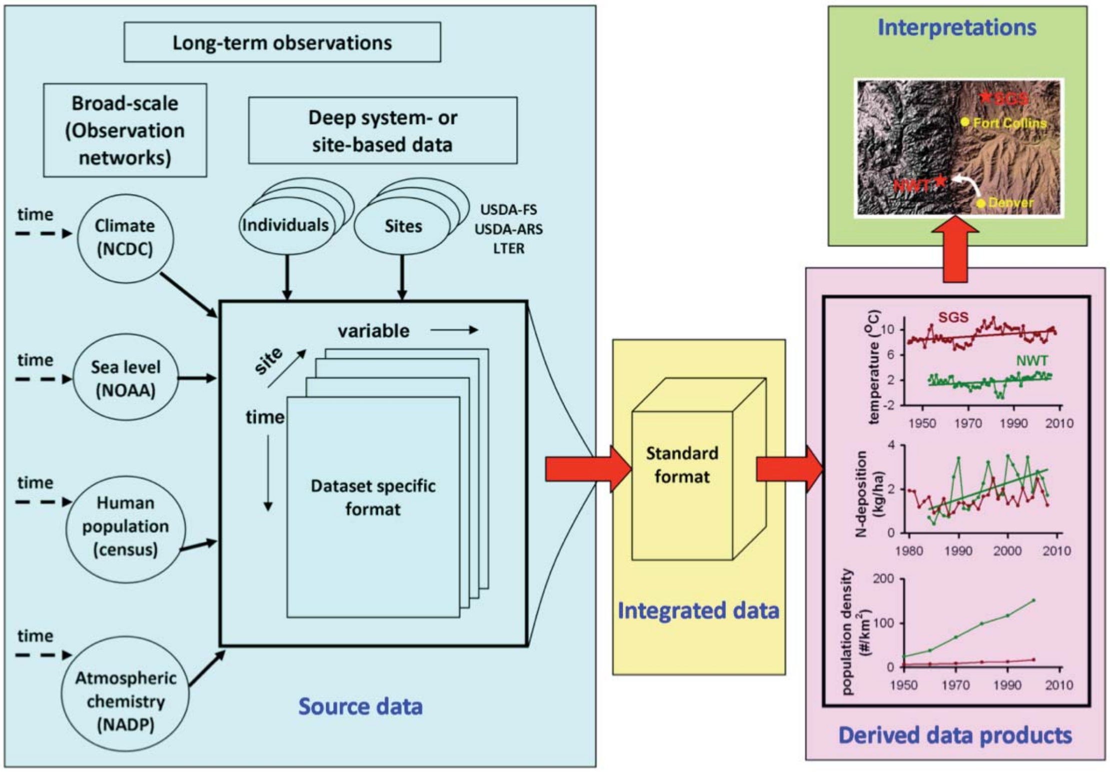



Figure 12. The Jornada data availability strategy is built around the concepts of providing access to source data, integrated data, and derived data products, in order to create increased opportunities for interpretations of these data (From Peters 2010).

**Information Technology/Data Acquisition System**: The Jornada Information Management System (IMS) includes acquisitions and management of spatial data and provision of network and computing systems (see Fig. 13). This system is staffed by 6 full-time personnel funded by both USDA and NSF-LTER programs. These positions include an overall systems manager, 2 GIS specialists, a computer systems manager and 2 network and data system support personnel. The IMS is integrated with a GIS and is composed of a relational database management system and metadata repository.

All metadata can be searched and accessed through the Jornada data web access points. National network sensor data are available on-line through respective network web sites. Data acquisitions within the Jornada are facilitated by a T1 fiber optic system based at the Jornada HQ and associated wireless network data access modes across the range, and a radio based data transmission system for transfer of data from remote instruments to Jornada HQ and subsequent relay to other hosts.

**K-12 Schoolyard Program:** For over a decade, the Jornada program has provided quality, inquiry-based science education opportunities to K-12 students and teachers throughout southern New Mexico and west Texas. Over this time period, program staff have directly worked with >500 teachers who have participated in one-day, five-day, and two-week teacher professional development workshops. These workshops are specifically directed towards development of science based curriculum that can be used by these teachers in their classroom programs. These curricula have been developed through a Cooperative Agreement (Appendix Table 2) with the Asombro Institute for Science Education (see: **http://www.asombro.org**), and specifically address state board of education outcomes for science education in New Mexico. The key to this volume of outreach continues to be this partnership that was established in 1998 among the LTER, the ARS, and the Asombro Institute for Science Education (formerly the Chihuahuan Desert Nature Park), a nonprofit science education organization. Using the combined expertise of these partners, we deliver a multifaceted K-12 education program which includes schoolyard studies, science investigation kits, teacher workshops, field trips, and classroom programs. Over the past 5 years, over 50,000 students have been involved in the Asombro Institute's programs. Approximately 20% of these students participate in field activities conducted on-site at the Jornada as part of their education activities. Annually, Jornada staff devote over 300 hours of time in support of these field programs at the Jornada. Our on-site resident manager at the Jornada HQ provides logistical support for many of these activities.

## PROJECT MANAGEMENT AND EVALUATION

All Category I scientists participating in the proposed project have been with this unit for a minimum of 10 years. Scientists have participated in extensive discussions that developed the previous project plans for the periods of 2002-2007 and 2007-2012. For all scientists, this is their sole ARS research project supported through appropriated funds. The unit Research Leader provides personnel and administrative management, and the Lead Scientist provides overall research management. Each objective of the proposed project has a lead scientist that coordinates activities among scientists working within that objective and its sub-objectives.

Several scientists work on more than one objective, which facilitates communication and interactions. For each scientist, their annual performance plan includes specific goals related to milestones associated with the proposed project. This structure links project outcomes to individual scientist's performance. In addition, the unit operates numerous extramural research agreements that link project research objectives to similar objectives of partner agencies and institutions (Appendix Table 2). These numerous and extensive agreements closely link ARS milestones within the unit project plan with deliverables for partner institutions. These linkages not only provide research synergies and additional staffing resources, but provide a mechanism to promote development of specific useable outcomes from research by the unit.

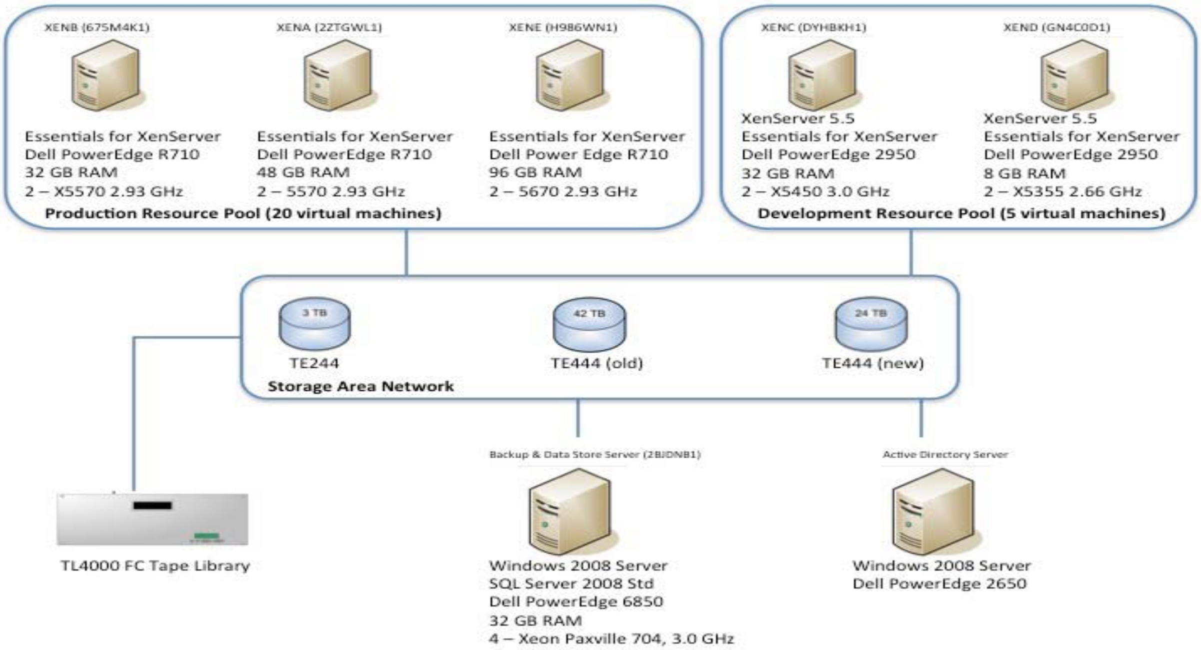



Figure 13. Jornada network server system, including virtual servers established for both data development and data production activities.

## MILESTONE TABLE

SY Team:

| | | |
|---|---|---|
| AR – Al Rango | BB – Brandon Bestelmeyer | DA – Dean Anderson |
| DP – Deb Peters | JH – Jeff Herrick | KH – Kris Havstad |
| ML – Mary Lucero | RE – Richard Estell | V1 – Vacant Rangeland Mgmt |
| V2 – Vacant Soil Science | | |

| | | | |
|---|---|---|---|
| Project Title | Management Technologies for Conservation of Western Rangelands | Project No. | 6235-11210-006-00D |
| National Program | 215 - Pasture, Forage and Rangeland Systems | | |
| Objective | 1: Develop data-driven approaches in the production of ecological site descriptions that guide rangeland conservation and management practices within MLRAs of the western U.S., including New Mexico, Arizona, Oregon, North Dakota, Wyoming, Montana, and Oklahoma. | | |
| Subobjective | 1A: Produce new approaches for and examples of data-driven ecological site description and state-and-transition model development using analysis of inventory, historical, experimental, and monitoring data, augmented by local knowledge. | | |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services | | |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. | | |

| Research Goal | SY Team | Months | Milestones | Progress/Changes | Products |
|---|---|---|---|---|---|
| Systematic approaches for development and use of ESDs/STMs for design and implementation of management actions, assessment, monitoring, modeling, and interpretation. | BB, KH, JH, DP, V1 | 12 | General approach document drafted | | |
| | | 24 | MLRA creation/revision workshops with participating western MLRA groups | | |
| | | 36 | MLRA 42 database assembled | | |
| | | 48 | | | |
| | | 60 | Revised MLRA 42 ESDs within ESIS | | ESDs with management recommendations |

| | |
|---|---|
| Subobjective | 1B: Create and populate a national database of ecological dynamics to be used in guiding national ecological site description development and as a mechanism for stakeholder communication, including specific efforts in major land resource areas of New Mexico, Arizona, Oregon, North Dakota, Wyoming, Montana, and Oklahoma. |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. |

| Research Goal | SY Team | Months | Milestones | Progress/Changes | Products |
|---|---|---|---|---|---|
| To develop a method for representing general models of ecological dynamics in rangelands in a publically accessible database and for specific MLRAs. | BB, KH, JH, V1 | 12 | Draft database structure complete | | |
| | | 24 | | | |
| | | 36 | Complete MLRA questionaires | | |
| | | 48 | | | |
| | | 60 | Database online | | National ESD database |

| | |
|---|---|
| Objective | 2: Improve techniques, including remotely sensed methodologies, for rangeland monitoring and assessment applicable to landscapes within MLRAs, and more broadly for regional and national scales of assessments. |
| Subobjective | 2A: Develop and evaluate innovative approaches for remotely monitoring land surface conditions in order to improve existing and develop new methods for rangeland monitoring. |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. |

| Research Goal | SY Team | Months | Milestones | Progress/Changes | Products |
|---|---|---|---|---|---|
| To inform and support land management decision-making through development | JH, AR, V1, V2 | 12 | Collect images for different study areas | | |
| | | 24 | | | |

| | | | | | |
|---|---|---|---|---|---|
| and use of analytical methods that capitalize on data collected using multiple remote sensing platforms. | | 36 | Compare data from remotely sensed images with ground based measurements | | |
| | | 48 | | | |
| | | 60 | Complete analyses of remotely sensed data | | Remotely sensed indicators for monitoring at landscape scales |
| Subobjective | 2B: Develop innovative, integrated, and flexible inventory, assessment, and monitoring techniques and the decision support tools necessary to implement these approaches at local to national scales. | | | | |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services | | | | |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. | | | | |
| Research Goal | SY Team | Months | Milestones | Progress/Changes | Products |
| To develop inventory, assessment, and monitoring tools relevant at multiple scales within western MLRAs. | JH, BB, KH, V1, V2 | 12 | | | |
| | | 24 | Access regional and national monitoring data sets from partner agencies | | |
| | | 36 | | | |
| | | 48 | Complete analyses of monitoring data | | |
| | | 60 | | | Revised methodologies for monitoring incorporated into Landscape Toolbox web site |
| Objective | 3: Evaluate effectiveness of historic, current, and new grassland restoration practices for dominant ecological sites within specific MLRAs of New Mexico, Arizona, Oregon, and Wyoming. | | | | |
| Subobjective | 3A: Design and implement new studies and analyze experimental data from conservation management practices and grazing management efforts on public and private lands in MLRA 41 and 42 of AZ and NM, MLRA 25 in OR, and MLRAs 58B and 67B in WY with respect to multiple ecosystem services. | | | | |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services | | | | |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. | | | | |
| Hypothesis | SY Team | Months | Milestones | Progress/Changes | Products |
| Restoration treatments will have measureable, positive impacts on rangeland attributes, subject to variations induced by ecological site and initial ecological state. | BB, ME, KH, V2 | 12 | Multi-MLRA coordination complete | | |
| | | 24 | Establish initial monitoring in MLRA 41/42 | | |
| | | 36 | | | |
| | | 48 | | | |
| | | 60 | Initial evaluations of long-term data | | Restoration practices appropriate for specific ecological sites added to ESDs |
| Objective | 4: Evaluate livestock management practices suitable for conserving and restoring rangelands within MLRAs of the southwestern U.S. | | | | |
| Subobjective | 4A: Evaluate grazing management practices and their relationships to ecological state changes within ecological sites in MLRAs 41 and 42 of AZ and NM. | | | | |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services | | | | |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. | | | | |
| Hypothesis | SY Team | Months | Milestones | Progress/Changes | Products |
| Changes in carrying capacity through time are related to management and vary among ecological sites in their responses to grazing management. | RE, KH, DA | 12 | | | |
| | | 24 | Obtain and analyze current and historical livestock records in MLRA 42 across ecological sites | | |
| | | 36 | | | |

| | | | | | |
|---|---|---|---|---|---|
| | | 48 | Determine relationships of livestock numbers and state changes for ecological sites in MLRA 42 | | |
| | | 60 | | | Develop guidelines ecological site-based livestock management |
| Subobjective | 4B: Evaluate low-input livestock production strategies in MLRA 42. | | | | |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services | | | | |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. | | | | |
| Hypothesis | SY Team | Months | Milestones | Progress/Changes | Products |
| Criollo cattle require fewer inputs of harvested forages to reach marketable weight and are more compatible with low-input sustainable beef production on ecological sites in MLRA 42. | RE, KH, DA | 12 | Establish framework for data management and initiate data collection for system inputs/outputs | | |
| | | 24 | | | |
| | | 36 | Conduct diet study | | |
| | | 48 | | | |
| | | 60 | Analyze and summarize breed comparisons | | Assessment of low-input livestock production |
| Objective | 5: Develop mechanistically based predictions of vegetation state changes and site-based wind erosion susceptibilities for landscapes within selected MLRAs under alternative land use-climate change scenarios. | | | | |
| Subobjective | 5A: Predict climate-driven vegetation state changes for western landscapes within selected MLRAs. | | | | |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services | | | | |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. | | | | |
| Research Goal | SY Team | Months | Milestones | Progress/Changes | Products |
| To predict vegetation state changes on selected western rangelands under future climate scenarios (changes in direction, magnitude, and timing of precipitation). | DP, JH | 12 | | | |
| | | 24 | Collect data sets relative to vegetation dynamics under existing and past climate regimes | | |
| | | 36 | | | |
| | | 48 | Complete model runs for vegetation responses under different climate scenarios | | |
| | | 60 | | | Revised state and transitions models including alternative states |
| Subobjective | 5B: Develop and implement a wind erosion monitoring network, and standardize protocols, for measurement and model-based predictions of changes in horizontal and vertical dust flux on western rangelands, including areas undergoing land use change. | | | | |
| NP Action Plan Component | 1: Improved Rangeland Management for Enhanced Livestock Production, Conservation, and Ecological Services | | | | |
| NP Action Plan Problem Statement | C.1. Improve understanding of the fundamental relationships among management practices, ecological processes, and climatic variability to improve rangeland production, conservation and restoration. | | | | |
| Research Goal | SY Team | Months | Milestones | Progress/Changes | Products |
| To develop predictive tools for forecasting wind erosion potential in western MLRAs. | JE, V2 | 12 | | | |
| | | 24 | Establish wind erosion experimental template to be implemented at ARS locations across the western US | | |
| | | 36 | Implement western wide experiment | | |
| | | 48 | | | |
| | | 60 | | | Assessments of accelerated wind erosion |

## ACCOMPLISHMENTS FROM PRIOR PROJECT PERIOD

**1. Terminating ARS research project number:** 6235-11210-006-00D
**2. Title:** Management Technologies for Arid Rangelands
**3. Project period:** 9/25/07 – 9/24/12
**4. Investigators:** Dean M. Anderson, Jerry R. Barrow, Brandon T. Bestelmeyer, Michael C. Duniway, Richard E. Estell, Ed. L. Fredrickson, Kris M. Havstad, Jeffrey E. Herrick, Mary E. Lucero, Debra C. Peters, Albert Rango, Sandy L. Tartowski (Post docs: Dawn Browning, Jason Karl, Andrea Laliberte, Raul Peinetti, Finn Pillsbury, Caiti Steele, Jin Yao)
**5. Project accomplishments and impact:** The following 10 headings capture the key elements of our research program productivity by ARS scientists and our colleagues working at the Jornada field station over the past 5 years.

**Productivity and datasets.** The quantity of our publications has increased through time with a combined average of >44 papers, book chapters, and proceedings papers per year, and a total-to-date for the last 5 years of 198 journal articles, 70 book chapters and proceedings papers, 16 theses and dissertations, and 9 books since 2006 (see full listing at: http://jornada.nmsu.edu). We and our colleagues working at the Jornada published in high visibility/impact journals, including *Trends in Ecology and Evolution* (e.g. Peters 2010), *Science* (e.g., Reynolds et al. 2007), *BioScience* (e.g., Peters et al. 2006, Okin et al. 2009), *Frontiers in Ecology and Evolution* (e.g., Herrick et al. 2010), *Global Change Biology* (Peters et al. 2012b), and *The Journal of Applied Ecology* (e.g., Bestelmeyer et al. 2011b). Our 10 most significant publications (Table 1) were selected based on: impact on Jornada research development, significance to drylands research, contribution to ecological theory and general understanding of ecological systems, and impact on land management. Our database contains > 150 data sets derived from studies representing all core research areas. Core study name abbreviations are shown in italics with accessibility details of datasets (Appendix Table 3; summary at http://jornada.nmsu.edu). On average, one or more of our data sets are accessed more than 238 times per month. Our homepage is accessed an average of 446 times per week by non-Jornada associated computers. 99% of our core long-term datasets are available online and the other 1% require permission of the responsible investigator. We have been awarded, as Principal Investigators, over $8.5M in grants and contracts from 2007-2012, an average of ~$1.4M/yr. These extramural awards have been primarily from the National Science Foundation, the Department of Defense, the NRCS, and the BLM. All of these funds have been used in support of our scientific activities directly related to our ARS research objectives as they apply to the specifics of these awards.

**Conceptual framework.** We continue to test and define our conceptual framework described by Peters et al. (2006) for disentangling complex landscapes such as those in arid regions. Our framework builds on the previous Jornada resource redistribution framework (Schlesinger et al. 1990) at the plant-interspace scale by including multiple scales of interaction and five key components. The framework was expanded to compare connectivity in diverse ecosystems (Okin et al. 2009). This unifying framework is being used to integrate our existing short- and long-term studies and to guide our proposed experiments. This cross-scale framework was used by other sites to explain dynamics in other systems, including temperate and tropical forests, barrier islands, and metapopulations of animals (Peters et al. 2007 and other papers in the *Ecosystems* Special Feature). We also expanded the framework to explain regional and continental-scale dynamics that contributed to the design of NEON (Peters et al. 2008 and other papers in the *Frontiers in Ecology and the Environment* Special Issue).

**Primary technologies.**

**a. Rangeland health.** The Jornada co-developed a qualitative assessment protocol for rangelands (Interpreting Indicators of Rangeland Health), which is being applied globally. In this protocol, evaluators assess three ecosystem attributes by rating 17 indicators tied to the attributes. The ecosystem attributes are: soil and site stability, biotic integrity, and hydrological function. This protocol was used in the first statistically based application for national assessments of rangeland in the U.S. that integrates scientific and local knowledge. Qualitative observations completed at over 10,000 plots in the U.S. showed that while soil degradation remains an issue, loss of biotic integrity is more wide-spread (Herrick et al. 2010). Quantitative soil and vegetation data collected at the same locations support the assessments and serve as a baseline for monitoring the effectiveness of policy and management initiatives, including responses to climate change. These results are providing the information necessary to support strategic decisions by land managers and policy makers.

**b. Landscape toolbox.** The Landscape Toolbox project (see: http://www.landscapetoolbox.org/) began with two concepts:1) many different techniques, tools, methods, data sources, and models are available to aid rangeland management, and 2) for the most part, with a few notable exceptions, these tools are not seeing widespread use. The reasons these tools have not been widely used vary, but two of the main reasons are a lack of general understanding as to what the different tools/methods do and when it is appropriate to use them as well as the absence of a system to integrate different techniques into a workflow to address management or monitoring objectives. As a result, the Jornada and the Idaho Chapter of The Nature Conservancy are working with both public and private land management partners to develop a system, the Landscape Toolbox, for describing and integrating ecological analysis and monitoring tools to enable better rangeland management at landscape scales (Karl 2011). The goal of the Landscape Toolbox is to realize better ecosystem management by integrating existing and emerging field, remote sensing, and ecosystem modeling methods for rangeland assessment, monitoring, and planning.

**c. Ecological site descriptions.** Ecological sites comprise a land classification system that describes ecological potential and ecosystem dynamics of land areas. They are used to stratify the landscape and organize ecological information for purposes of monitoring, assessment, and management. The Jornada has led in development of the scientific principles underlying this concept (Bestelmeyer et al. 2010, Bestelmeyer and Brown 2010). Ecological site descriptions and associated information are used primarily to stratify the landscape for monitoring and assessment, interpretation of resource hazards and opportunities, and to prioritize and select management actions. ESDs are developed and housed by the NRCS and its partners, and used by The Nature Conservancy, the BLM, and many other entities. A recent memorandum of understanding between the NRCS, BLM, and USFS establishes ESD development as an interagency priority and will establish national standards and protocols for ESD development.

**Ecological principles.**

**a. Grassland-to-shrubland transitions.** We focused on resolving the sequence of processes involved in state change from grasslands to shrublands, including the initiation of state change, the mechanisms maintaining the shrubland state and promoting its expansion, and the distribution of state change at broad spatial scales. The initiation and consequences of state transition for black grama production, based on historical data, used an approach for the analysis of abrupt transitions common with other sites (Bestelmeyer et al. 2011a). Feedbacks and shrub adaptations are likely to be responsible for the transition and maintenance of shrubland states (Okin et al. 2009, D'Odorico et al. 2012). Spatial factors mediate the pattern of grasslands and shrublands (Bestelmeyer et al. 2011b), and time series of MODIS Normalized Difference Vegetation Index data was used to detect state changes at landscape scales (Williamson et al. 2012). These results were used to inform management tools and policy interpretations by agencies within the U.S. and internationally (Bestelmeyer et al. 2009; 2011c).

**b. Shrubland-to-grassland transitions.** Initial studies of these reversals using simulation modeling showed that perennial grass recruitment following shrub invasion is dependent on location-specific changes in soil properties and vegetation cover (Peters et al. 2010). These results identified the spatial locations and temporal conditions where remediation efforts are likely to be successful, and guided the design of a pilot study of cross-scale interactions (*ConMod*) that was recently expanded to a full experiment (*Xscale*). Long-term observations of aboveground net primary production (*NPP*) show that 5 consecutive wet years can lead to perennial grass recovery in desertified shrublands (Peters et al. 2012b). Integrating multiple datasets (*Phenology, Jornex, NPP*) showed that a sequence of demographic processes occurred through time to result in grass recovery (Peters et al. submitted).

**c. Plant-animal interactions.** The response of rodent biomass to rainfall is strongly contingent on shrub dominance and is nonlinear: large increases in formerly rare species and population crashes are common (*SMES*). We documented experimentally that black grama seedling establishment may be increasingly limited by rodents as shrubs increase in dominance (*Ecotone*) (Bestelmeyer et al. 2007). This animal-mediated feedback may contribute to grass loss with shrub invasion. By comparing ant communities in areas with different plant composition and ANPP, we found that ant biomass is invariant, but community composition shifts to species capable of accessing homopteran exudates in shrublands (Rios-Casanova and Bestelmeyer 2008).

**d. Soil-plant-water interactions.** Contrary to previous studies, we found that petrocalcic horizons, a rock-like soil horizon common on the Jornada and in desert ecosystems globally, have the capacity to absorb and retain large amounts of plant available water (PAW) (Duniway et al. 2007). Petrocalcic soils are recharged by winter and summer rains, and retain large amounts of PAW for extended time periods (Duniway et al. 2010a). Studies also showed that soil water under mesquite may not limit grass recovery (Duniway et al. 2010c). Long-term (1937-2008) image analysis of neighboring soils with either deep or shallow to petrocalcic horizons revealed that, although both soils had similar initial plant composition, different demographic responses to PAW by depth resulted in a shrub-dominated state on the deep soil and a mixed shrub-grass state on the shallow soil (Browning and Duniway 2011, Browning et al. 2012).

**e. Ecohydrology.** A spatially explicit, integrated field and modeling experiment commenced in 2010 in a watershed within the mixed shrubland bajada geomorphic unit. Initial results showed that horizontal variation in soil moisture measurements improve the characterization of the watershed-scale water balance and ecosystem evapotranspiration compared with traditional approaches. Eddy covariance observations showed that land-atmosphere fluxes during the North American monsoon are linked to soil moisture and vegetation phenology. Spatial variability in soil moisture and runoff correspond to hillslope and channel infiltration properties, and in particular, depth to the calcium carbonate layer. Phenological analyses from field observations (*Phenology*) and UAV imagery showed species-specific responses to seasonal rainfall and soil moisture availability (Browning et al. 2011, Laliberte et al. 2010). Field sampling, sensor network, and remote sensing observations are being integrated with watershed simulations using the Triangulated Irregular Network-based Real-time Integrated Basin Simulator (tRIBS) to explore the spatial organization of ecohydrological systems.

**f. Disturbance.** Results of USDA-LTER collaborative research showed that roads and off-road vehicles commonly impact hydrologic function, and soil and site stability, including susceptibility to wind and water erosion (Duniway et al. 2010b, Duniway and Herrick 2011). We defined elements to systematically predict, assess, and minimize road impacts (Duniway and Herrick 2011). We also presented a framework for quantitative comparisons of disturbance effects across different types of ecosystems and multiple sites (Peters et al. 2011b).

**Livestock management.** Animal management using principles of animal behavior melded with technology to manipulate animal distribution was a major focus of the livestock program. This research showed it is possible to control animal movement and location in real time by integrating electronic signals with GIS technology, creating a "virtual fence" (Anderson 2007, Bishop-Hurley et al. 2007, Schwager et al. 2007, 2008, Anderson et al. 2012b), and a patent was awarded for this technology (Anderson 2010). A manuscript describing research efforts in mixed species stocking was also published (Anderson et al. 2012a). Livestock research focusing on the role of secondary chemistry in plant-animal interactions examined the role of individual and mixtures of terpenes on intake (Estell et al. 2007; 2008). Sesquiterpenes were more strongly related to intake than monoterpenes. Mechanisms were examined to increase shrub consumption by ruminants (Rogosic et al. 2007, Utsumi et al. 2009; 2010). A variety of treatments (supplemental nutrients, medicines, seasonal use, mixed species stocking, manipulating stocking density, diet adaptation/training, and mixing complementary shrub species with varying chemical profiles) were examined. Key findings were that protein supplementation increased juniper intake by small ruminants (Utsumi et al. 2009) and mixing shrubs with different classes of compounds (complementarity) increased shrub intake (Rogosic et al. 2007). These mechanisms were summarized in two review articles (Rogosic et al. 2008, Estell 2010). A procedure was also developed to analyze terpenes in serum and rumen fluid for use in pharmacokinetic studies of terpene metabolism in ruminants (Estell et al. 2010). A manuscript was published outlining the need for new technologies and mechanisms for utilizing shrubs in the wake of growing demand for red meat and waning grasslands (Estell et al. 2012).

**Simulation modeling.** We used a multi-layer model of soil water dynamics to simulate effects of transitions from grasslands to shrublands on black grama recruitment across the Jornada (Peters et al. 2010). We used resource selection functions to compare foraging behavior of a heritage breed of cattle from Mexico (Criollo) with a commonly used introduced European breed (Angus) as a first step in adding cattle as transport vectors to our ENSEMBLE model (Peinetti et al. 2011).

**Socio-ecological systems.** We initiated studies of coupled human-natural systems through data acquisition and mapping of socioeconomic variables in selected areas of southern NM where we documented: changes in land cover classes and land fragmentation through time, trends in land ownership, and historical linkages among climatic drivers, management decisions, and transitions from grasslands to shrublands (Skaggs et al. 2011).

**Synthesis activities.** We tested a variety of sensors at both the Sevietta and Jornada as part of twice yearly Jornex campaigns since 1996 (*Jornex*) (e.g., Rango et al. 2009). We continued our research on grassland-shrubland ecotones at the Sevietta LTER that started in 1995 with direct connections, both conceptually and experimentally, to Jornada research (e.g., Peters and Yao 2012). The small mammal exclosure study (*SMES*), now in its 16$^{th}$ year, being conducted at 3 sites in the Chihuahuan Desert, is providing information on regional variation in plant-animal interactions. We are leading the collection and synthesis of long-term data from LTER, USDA-ARS, and USFS sites through the EcoTrends Project that is resulting in synthesis publications (Moran et al. 2008, Peters 2010, Bestelmeyer et al. 2011a, Peters et al. 2011b), a book to be published by the USDA (Peters et al. 2012a), and a web page for data access, analysis, and synthesis (www.ecotrends.info).

**Sensor development.** Jornada researchers have made great progress in developing, using, and making accessible UAV-based remote sensing technology (Rango et al. 2009, Laliberte et al. 2011a,b). UAV imagery has very fine resolution (5-15 cm pixel size) making it highly suitable for mapping fine-scale vegetation and soil features. Because the Jornada currently owns 2 UASs, missions can be flown on ca. 1-2 weeks notice. Efficient workflows for image acquisition, orthorectification, mosaic-ing and vegetation classification procedures have been released to the public (Laliberte et al. 2010; 2011a). Image mosaics provide high-resolution shrub, grass, and soil percentage cover, species composition, patch size and distribution, and shrub density. Terrain models from the imagery provide detailed digital elevation and surface models.

**Broader impacts.** More than 102,000 people participated in hands-on programs of the Jornada K-12 science education program through the Asombro Institute for Science Education since 1999. The majority of participants were from underserved populations from southern New Mexico and west Texas: ca. 80% are classified as “economically disadvantaged,” and 75% are Hispanic. In the last six years, highlights include: (a) the program is a model used by regional school districts (El Paso Independent School District), afterschool and summer programs (e.g., Gen M summer program for middle school students), other NSF-funded programs (e.g., GK12 program at the University of Texas El Paso), and statewide initiatives (New Mexico’s NSF EPSCoR), (b) staff worked with educational researchers to develop assessment tools for both formative and summative evaluation, (c) 57,256 students participated in field trips and schoolyard activities, and (d) 3,229 K-12 teachers attended programs and workshops. We also actively conducted monitoring and research activities throughout the Chihuahuan Desert and the western U.S., primarily through our collaborations with state and federal agencies, including the BLM, NRCS, and the U.S. Geological Survey (Herrick et al. 2010). Our monitoring manual and qualitative assessment protocol for grasslands and savannas is in use by the BLM and NRCS. Monitoring methods are being applied nationally at over 2000 locations per year. The qualitative assessment protocol is also being applied nationally, and both protocols have been translated into Spanish, Mongolian, and Chinese.

**Table 1. Ten most significant publications from 2007-2012.**

| Authors | Journal citation | Impact or significance |
|---|---|---|
| Browning, D.M., Duniway, M.C., Laliberte, A., Rango, A. | 2012. Hierarchical analysis of vegetation dynamics over 71 years: Soil-rainfall interactions in a Chihuahuan desert ecosystem. Ecological Applications (In Press). | Linking vegetation dynamics to specific soil properties captured within ecological site framework |
| Estell, R.E., Havstad, K.M., Cibils, A.F., Fredrickson, E.L., Anderson, D.M., Schrader, T.S., James, D.K. | 2012. Increasing shrub use by livestock in a world with less grass. Rangeland Ecology and Management (In Press). | New paradigm for livestock production on arid rangelands |
| Bestelmeyer, B.T., Ellison, A.M., Fraser, W.R., Gorman, K.B., Holbrook, S.J., Laney, C.M., Ohman, M.D., Peters, D.P.C., Pillsbury, F.C., Rassweiler, A., et al. | 2011a. Analysis of abrupt transitions in ecological systems. Ecosphere 2: art 129. | Framework for state changes that links research across diverse LTER sites |
| Karl, J. | 2011. Turning information into knowledge for rangeland management. Rangelands 33:3-5. | Conceptual basis for our knowledge systems model |
| Peters, D.P.C. | 2010. Accessible ecology: synthesis of the long, deep, and broad. Trends in Ecology and Evolution 25:592-601. | Framework to integrate accessible data from individuals, sites, and networks |
| Herrick, J.E., Lessard, V.C., Spaeth, K.E., Shaver, P.L., Dayton, R.S., Pyke, D.A., Jolley, L., Goebel, J.J. | 2010. National ecosystem assessments supported by local and scientific knowledge. Frontiers in Ecology and the Environment 8:403–408. | First use of National Resources Inventory data for regional assessments |
| Bestelmeyer, B.T., Tugel, A.J., Peacock, G.L. Jr, Robinett, D.G., Shaver, P.L., Brown, J.R., Herrick, J.E., Sanchez, H., Havstad, K.M. | 2009. State-and-transition models for heterogeneous landscapes: A strategy for development and application. Rangeland Ecology and Management 62:1-15. | Application of ecological principles to land management |
| Rango, A., Laliberte, A.S., Herrick, J.E., Winters, C., Havstad, K.M., Steele, C., Browning, D.M. | 2009. UAV-based remote sensing for rangeland assessment, monitoring, and management. Journal of Applied Remote Sensing 3:033542. | First illustration of the application of UAS to rangeland monitoring |
| Peters, D.P.C., Groffman, P.M., Nadelhoffer, K.J., Grimm, N.B., Collins, S.L., Michener, W.K., Huston, M.A. | 2008. Living in an increasingly connected world: a framework for continental-scale environmental science. Frontiers in Ecology and the Environment 5:229-237. | Framework for continental scale ecology; intro paper to special issue; instrumental in NEON design |
| Havstad, K.M., Peters, D.P.C., Skaggs, R., Brown, J., Bestelmeyer, B.T., Fredrickson, E., Herrick, J.E., Wright, J. | 2007. Ecosystem services to and from rangelands of the western United States. Ecological Economics 64:261-268. | Linking services to vegetation states and ecological sites |

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**PAST ACCOMPLISHMENTS**
**RICHARD E. ESTELL, RESEARCH ANIMAL SCIENTIST LEAD**

**Education**

| | |
|---|---|
| 1984 | New Mexico State University, Animal Science, Ph.D. |
| 1979 | University of Tennessee, Animal Science, M.S. |
| 1976 | Purdue University, Agriculture, B.S. |

**Work Experience**

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|---|---|
| 2011-Present | Lead Scientist, Animal Scientist, USDA, Range Management Research Unit, USDA, ARS, Las Cruces, NM |
| 1989-2011 | Research Animal Scientist, USDA, Range Management Research Unit, USDA, ARS, Las Cruces, NM |
| 1984-1989 | Research Assistant II, Animal Science Department, New Mexico State University, Las Cruces, NM |

**Accomplishments**

The scientist developed a program to examine the biochemical basis of diet selection. The scientist identified tarbush as a shrub model for exploring phytochemistry-herbivore relationships, characterized its nutritional and toxicological attributes and secondary chemistry profile, and demonstrated that livestock discriminate between individual plants when forced to consume tarbush. Removal of chemicals from tarbush with organic solvents increased consumption by sheep, and crude fractions isolated from sequential extractions with hexanes, ether, and ethanol all dramatically decreased consumption of alfalfa pellets, suggesting several compounds and classes are involved in intake suppression. The scientist established a protocol for a bioassay to test effects of specific chemicals on intake by sheep. The scientist tested a series of terpenes and showed camphor, α-pinene, camphene, and caroyphyllene oxide reduced intake when applied individually to alfalfa pellets, but conditioning lambs to terpene odors did not alter subsequent intake. The scientist collaborated with others to study the role of secondary chemistry in shrub consumption by ruminants and mechanisms to increase intake of unpalatable shrubs. Numerous treatments (supplemental nutrients, medicines, seasonal use, mixed species stocking, manipulating stocking density, diet adaptation/training, and mixing complementary shrub species with varying chemical profiles) were examined. Protein supplementation was shown to increase juniper intake by sheep and goats. Mixing classes shrubs with different classes of compounds (complementarity) increased intake by goats.

**Selected Peer-reviewed Publications (from 68 total)**


1. **Estell, R.E.**, Fredrickson, E.L., Anderson, D.M., Havstad, K.M., Remmenga, M.D. 2002. Effects of four mono- and sesquiterpenes on consumption of alfalfa pellets by sheep. Journal of Animal Science 80:3301-3306.
2. Animut, G., Goetsch, A.L., **Estell, R.E.**, Merkel, R.C., Dawson, L.J., Sahlu, T., Puchala, R. 2004. Effects of methods of exposure to Eastern red cedar foliage on cedar consumption by Boer crossbred wether goats. Small Ruminant Research 54:197-212.
3. **Estell, R.E.**, Fredrickson, E.L., Anderson, D.M., Havstad, K.M., Remmenga, M.D. 2005. Effect of previous exposure of sheep to monoterpene odors on intake of alfalfa pellets treated with camphor or α-pinene. Small Ruminant Research 58:33-38.
4. **Estell, R.E.**, Fredrickson, E.L., Anderson, D.M., Remmenga, M.D. 2005. Effects of γ-terpinene, terpinolene, α-copaene, and α-terpinene on consumption of alfalfa pellets by sheep. Journal of Animal Science 83:1967-1971.
5. **Estell, R.E.**, Fredrickson, E.L., Peters, D.P.C. 2006. Introduction to Special Issue - Landscape linkages and cross-scale interactions in arid and semi-arid ecosystems. Journal

of Arid Environments 65:193-195.
6. Rogosic, J., **Estell, R.E.**, Skobic, D., Martinovic, A., Maric, S. 2006. Role of species diversity and secondary compound complementarity on diet selection of Mediterranean shrubs by goats. Journal of Chemical Ecology 32:1279-1287.
7. Rogosic, J., **Estell, R.E.**, Skobic, D., Stanic, S. 2007. Influence of secondary compound complementarity and species diversity on consumption of Mediterranean shrubs by sheep. Applied Animal Behavior 107:58-65.
8. **Estell, R.E.**, Fredrickson, E.L., Anderson, D.M., Remmenga, M.D. 2007. Effects of eugenol, α-terpineol, terpin-4-ol, and methyl eugenol on consumption of alfalfa pellets by sheep. Small Ruminant Research 73:272-276.
9. Fredrickson, E.L., **Estell, R.E.**, Remmenga, M.D. 2007. Volatile compounds on the leaf surface of intact and regrowth tarbush (Flourensia cernua DC) canopies. Journal of Chemical Ecology 33:1867-1875.
10. **Estell, R.E.**, Fredrickson, E.L., Anderson, D.M., Remmenga, M.D. 2008. Effects of cis-β-ocimene, cis-sabinene hydrate, and monoterpene and sesquiterpene mixtures on alfalfa pellet intake by lambs. Journal of Animal Science 86:1478-1484.
11. Rogosic, J., **Estell, R.E.**, Ivankovic, S., Kezic, J., Razov, J. 2008. Potential mechanisms to increase shrub intake and performance of small ruminants in Mediterranean shrubby ecosystems. Small Ruminant Research 74:1-15.
12. Lucero, M.E., **Estell, R.E.**, Tellez, M.R., Fredrickson, E.L. 2009. A retention index calculator simplifies identification of plant volatile organic compounds. Phytochemical Analysis 20:378-384.
13. Utsumi, S.A., Cibils, A.F., **Estell, R.E.**, Soto-Navarro, S.A., Van Leeuwen, D.M. 2009. Seasonal changes in one seed juniper intake by sheep and goats in relation to protein and plant secondary metabolites. Small Ruminant Research 81:152-162.
14. **Estell, R.E.** 2010. Coping with shrub secondary metabolites by ruminants. Small Ruminant Research 94:1-9.
15. **Estell, R.E.**, Utsumi, S.A., Cibils, A.F. 2010. Measurement of monoterpenes and sesquiterpenes in serum, plasma, and rumen fluid from sheep. Animal Feed Science and Technology 158:104-109.
16. Lucero, M.E., **Estell, R.E.**, Fredrickson, E.L. 2010. Composition of Ceanothus gregii oil as determined by steam distillation and solid-phase microextraction. Journal of Essential Oil Research 22:140-142.
17. Lujan, A.L., Utsumi, S.A., Smallidge, S.T., Baker, T.T., **Estell, R.E.**, Cibils, A.F., Ivey, S.L. 2010. Manipulating sheep browsing levels on coyote willow (Salix exigua) with supplements. Sheep and Goat Research Journal 25:32-38.
18. Utsumi, S.A., Cibils, A.F., **Estell, R.E.**, Baker, T.T., Walker, J.W. 2010. One-seed juniper sapling use by goats in relation to stocking density and mixed grazing with sheep. Rangeland Ecology and Management 63:373-386.
19. Rango, A., Havstad, K.M., **Estell, R.E.** 2011. The utilization of historical data and geospatial technology advances at the Jornada Experimental Range to support western America ranching culture. Remote Sensing 3:2089-2109.
20. **Estell, R.E.**, Havstad, K.M., Cibils, A.F., Fredrickson, E.L., Anderson, D.M., Schrader, T.S., James, D.K. Increasing shrub use by livestock in a world with less grass. Rangeland Ecology and Management (In Press).

## PAST ACCOMPLISHMENTS
## DEAN M. ANDERSON, RESEARCH ANIMAL SCIENTIST

### Education

| | |
|---|---|
| 1977 | Texas A&M University, Range Science, Ph.D. |
| 1972 | Colorado State University, Agronomy, M.S. |
| 1970 | University of Southern Colorado, Biology, B.S**.** |

### Work Experience

| | |
|---|---|
| 1977-Present | Research Animal Scientist, USDA, Range Management Research Unit, USDA, ARS, Las Cruces, NM |
| 1973-77 | Graduate Research Assistant, Texas A&M University, College Station, TX. |
| 1969-73 | Graduate Research Assistant, Colorado State University, Fort Collins, CO. |

### Accomplishments

The scientist demonstrated originality and creativity by improving existing devices and designing and creating new devices to implement innovative, economically efficient, ecologically based approaches to free-ranging animal management. The scientist's research focuses on low-stress, humane approaches to handling animals. The research based protocols developed can be adopted by producers to reduce labor and associated expenses, while lowering production risks. The scientist developed the concept, assembled and orchestrated the team and established proof-of-concept through field testing of an autonomous methodology for controlling free-ranging animal distribution. Directional Virtual Fencing (DVF™) eliminates the need for internal conventional fencing while providing near real-time management. Another example includes development of the first completely autonomous animal weighing system for obtaining individual liveweights from free-ranging cattle at a remote location by combining several electromechanical technologies. A novel approach was conceived by the incumbent to socialize small ruminants (sheep and goats) with cattle to form a cohesive group termed a “flerd,” that consistently remains together under free-ranging conditions. A flerd provides small ruminants protection from canine predation, reduces time required to check livestock groups, eliminates the need for internal sheep/goat fencing, and improves the distribution of small ruminants over a landscape. Applying a previously untried optical technology, a team directed by the incumbent was able to identify the botanical composition of pre- and post-digested plant material using Laser-Induced Fluorescence and fluorometry. By combining two previously unrelated disciplines (animal behavior and optical identification) it is now possible to efficiently manage free-ranging livestock on landscapes in near real-time by manipulating animal distribution to optimize plant and animal growth and nutrition.

### Selected Peer-reviewed Publications (from 63 total)

1. Estell, R.E., Fredrickson, E.L., **Anderson, D.M.,** Havstad, K.M., Remmenga, M.D. 2002. Effects of four mono- and sesquiterpenes on the consumption of alfalfa pellets by sheep. Journal of Animal Science 80:3301-3306.
2. Hyder, P.W., Fredrickson, E.L., Remmenga, M.D., Estell, R.E., Pieper, R.D., **Anderson, D.M.** 2003. A digital photographic technique for assessing forage utilization. Journal of Range Management. 56:140-145.
3. Danielson, T.L., Rayson, G.D., **Anderson, D.M.**, Estell, R.E., Fredrickson, E.L., Green, B.S. 2003. Impact of filter paper on fluorescence measurements of buffered saline filtrates. Talanta 59:601-604.
4. Estell, R.E., Fredrickson, E.L., **Anderson, D.M.,** Havstad, K.M., Remmenga, M.D. 2005. Effect of previous exposure of sheep to monoterpene odors on intake of alfalfa pellets treated with camphor or α-pinene. Small Ruminant Research 58:33-38.

5. Estell, R.E., Fredrickson, E.L., **Anderson, D. M.**, Remmenga, M.D. 2005. Effects of γ-terpinene, terpinolene, α-copaene, and α-terpinene on consumption of alfalfa pellets by sheep. Journal of Animal Science 83:1967-1971.
6. Fredrickson, E.L., Estell, R.E., Laliberte, A.S. and **Anderson, D.M.** 2005. Mesquite recruitment in the Chihuahuan Desert: Historic and prehistoric patterns with long-term impacts. Journal of Arid Environments 65:285-295.
7. Danielson, T.L., Obeidat, S., Rayson, G.D., **Anderson, D.M.**, Fredrickson, E.L., Estell, R.E. 2006. Photoluminescent distinction among plant life forms using phosphate buffered saline extract solutions. Appl. Spectroscopy. 60:800-807.
8. **Anderson, D.M.**, Rayson, G.D., Obeidat, S.M., Ralphs, M., Estell, R., Fredrickson, E.L., Parker, E., Gray, P. 2006. Use of fluorometry to differentiate among clipped species in the genera Astragalus,Oxytropis and Pleuraphis. Rangeland Ecology and Management. 59:557-563.
9. Schwager, M., **Anderson, D.M.,** Butler, Z., Rus, D. 2007. Robust classification of animal tracking data. Computers and Electronics in Agriculture. 56:46-59.
10. Obeidat, S.M., Glasser, T., Landau, S.Y., **Anderson, D.M.,** Rayson, G.D. 2007. Application of multi-way data analysis on excitation-emission spectra for plant identification. Talanta. 72:682-690.
11. Bishop-Hurley, G.J., Swain, D.L., **Anderson, D.M.**, Sikka, P., Crossman, D., Corke, P. 2007. Virtual fencing applications: Implementing and testing an automated cattle control system. Computers and Electronics in Agriculture. 56:14-22.
12. **Anderson, D.M.** 2007. Virtual fencing – past, present and future. The Rangeland Journal. 29:65-78.
13. Estell, R.E., Fredrickson, E.L., **Anderson, D.M.**, Remmenga, M.D. 2007. Effects of eugenol, α-terpineol, terpin-4-ol, and methyl eugenol on consumption of alfalfa pellets by sheep. Small Ruminant Research. 73:272-276.
14. Estell, R.E., Fredrickson, E.L., **Anderson, D.M**., Remmenga, M.D. 2008. Effects of cis-ß-ocimene, cis-sabinene hydrate, and monoterpene and sesquiterpene mixtures on alfalfa pellet intake by lambs. Journal of Animal Science. 86:1478-1484.
15. Obeidat, S., Bai, B., Rayson, G.D., **Anderson, D.M**., Puscheck, A.D., Landau, S.Y., Glasser, T. 2008. A multi-source portable light emitting diode spectrofluorometer. Applied Spectroscopy. 62:327-332..
16. Schwager, M., Detweiler, C., Vasilescu, I., **Anderson, D.M.**, Rus, D. 2008. Data-driven identification of group dynamics for motion prediction and control; Journal of Filed Robotics. 25(6-7);305-324.
17. **Anderson, D.M**. inventor. 2010. Ear-A-Round equipment platform for animals. U.S. Patent 7,753,007B1. Jul. 13. 16p. Int. Cl. A01K 15/02. 2010.
18. **Anderson, D.M**., Danielson, T.L., Obeidat, S.M., Rayson, G.D., Estell, R.E., Bai, B., Fredrickson, E.L. 2011. Differentiating among plant spectra by combining pH dependent photoluminescence spectroscopy with multi-way principal component analysis (MPCA). The Open Agriculture Journal 5:1-9.
19. **Anderson, D.M**., Fredrickson, E.L., Estell, R.E. 2012. Managing livestock using animal behavior: mixed-species stocking and flerds. Animal. 1-11.

**PAST ACCOMPLISHMENTS**
**BRANDON T. BESTELMEYER, RESEARCH ECOLOGIST**

**Education**

| | |
|---|---|
| 2000 | Colorado State University, Ecology, Ph.D. |
| 1994 | Colorado State University, Zoology, M.S. |
| 1990 | University of California, Irvine, Applied Ecology, B.A. |
| 1990 | University of California, Irvine, Biological Sciences, B.S. |

**Work Experience**

| | |
|---|---|
| 2003- Present | Research Ecology, Range Management Research Unit<br>USDA, ARS, Las Cruces, NM |
| 2000-2003 | Postdoctoral Ecologist, Range Management Research Unit<br>USDA, ARS, Las Cruces, NM |

**Accomplishments**

The scientist developed protocols, guidance, and scientific studies for development and use of state-and-transition models and ecological site descriptions. These efforts have provided national guidance to federal agencies (Natural Resources Conservation Service, Bureau of Land Management) and local guidance to agency offices and non-governmental organizations for the use of landscape ecology and alternative state concepts in the development of assessment, monitoring, and management strategies. The concepts are also being applied internationally in China, Mongolia, and Argentina. Basic research to inform ecological site descriptions has focused on how the occurrence of vegetation states is related to management, soil, climate, and spatial properties across landscape and regional scales. This work has contributed to the idea that the occurrence of ecological thresholds can be detected and predicted using basic measurements and carefully selected sampling designs. The scientist also contributes research on the effects of state-transitions on biodiversity patterns, a topic which is poorly understood but drives many management decisions. The biodiversity work has focused on how coupled changes in landscape pattern and energy flux associated with transitions reorganize animal communities as well as animal feedbacks to ecosystems.

**Selected Peer-reviewed Publications (from 53 total)**


1. **Bestelmeyer, B.T.**, Brown, J.R., Havstad, K.M., Chavez, G., Alexander, R., Herrick, J.E. 2003. Development and use of state-and-transition models for rangelands. Journal of Range Management 56:114-126.
2. **Bestelmeyer, B.T.**, Miller, J.R., Wiens, J.A. 2003. Applying species diversity theory to land management. Ecological Applications 13:1750–1761.
3. **Bestelmeyer, B.T.**, Herrick, J.E., Brown, J.R., Trujillo, D.A., Havstad, K.M. 2004. Land management in the American Southwest: a state-and-transition approach to ecosystem complexity. Environmental Management 34:38-51.
4. **Bestelmeyer, B.T.** 2005. Does desertification diminish biodiversity? Enhancement of ant diversity by shrub invasion in southwestern USA. Diversity and Distributions 11:45-55.
5. **Bestelmeyer, B.T.**, Trujillo, D.A., Tugel, A.J., Havstad, K. M. 2006. A multi-scale classification of vegetation dynamics in arid lands: what is the right scale for models, monitoring, and restoration? Journal of Arid Environments 65:296-318.
6. Herrick, J.E., **Bestelmeyer, B.T.**, Archer, S.R., Tugel, A.J., Brown, J.R. 2006. An integrated framework for science-based arid land management. Journal of Arid Environments 65: 319-335.
7. **Bestelmeyer, B.T.**, Ward, J.P., Havstad, K.M. 2006. Soil-geomorphic heterogeneity governs patchy vegetation dynamics at an arid ecotone. Ecology 87:963-973.

8. **Bestelmeyer, B.T.** 2006. Threshold concepts and their use in rangeland management and restoration: the good, the bad, and the insidious. Restoration Ecology 14:325-329.
9. Peters, D., **Bestelmeyer, B.**, Fredrickson, E., Herrick, J., Monger, C., Havstad, K. 2006. Disentangling complex landscapes: new insights to forecasting arid and semiarid system dynamics. Bioscience 56:491-501.
10. **Bestelmeyer, B.**, Ward, J., Herrick, J. Tugel, A. 2006. Fragmentation effects on soil aggregate stability in a patchy arid grassland. Rangeland Ecology and Management. 59:406-415.
11. Peters, D.C., **Bestelmeyer, B**., Turner, M.G. 2007. Cross-scale interactions and changing pattern-process relationships: Consequences for system dynamics. Ecosystems 10:790-796.
12. **Bestelmeyer, B. T.**, Khalil, N.I., Peters, D.P.C. 2007. Does shrub invasion indirectly limit grass establishment via seedling herbivory? A test at grassland-shrubland ecotones. Journal of Vegetation Science. 18:363-370.
13. Briske, D., **Bestelmeyer, B.T.**, Stringham, T.K., Shaver, P.L. 2008. State-and-transition models: recommendations for resilience-based application. Rangeland Ecology and Management 61:359-367.
14. **Bestelmeyer, B.T.**, Tugel, A., Peacock, G.L., Robinett, D., Shaver, P.L., Brown, J., Herrick, J.E., Sanchez, H., Havstad, K.M. 2009. State-and-transition models for heterogeneous landscapes: A strategy for development and application. Rangeland Ecology and Management 62:1-15.
15. Moseley, K., Shaver, P., Sanchez, H., **Bestelmeyer, B**. 2010. Ecological site development: A gentle introduction. Rangelands 32:16-22.
16. **Bestelmeyer, B**., Moseley, K., Shaver, P., Sanchez, H., Briske, D., Fernandez-Gimenez, M. 2010. Practical advice for developing state-and-transition models. Rangelands 32:23-30.
17. Schwilch, G., **Bestelmeyer, B.**, Bunning, S., Critchley, W., Herrick, J., Kellner, K., Liniger, H. P., Nachtergaele, F., Ritsema, C.J., Schuster, B., Tabo, van Lynden, R.G., Winslow, M. 2011. Experiences in monitoring and assessment of sustainable land management. Land Degradation and Development 22: 214–225.
18. **Bestelmeyer, B.T.,** Goolsby, D.P., Archer, S.R. 2011. Spatial patterns in state-and-transition models: a missing link to land management? Journal of Applied Ecology 48:746–757.
19. **Bestelmeyer, B.T**., A.M. Ellison, W.R. Fraser, K.B. Gorman, S.J. Holbrook, C.M. Laney, M.D. Ohman, D.P.C. Peters, F.C. Pillsbury, A. Rassweiler, R.J. Schmitt, S. Sharma. 2011. Analysis of abrupt transitions in ecological systems. Ecosphere 2:129. doi:10.1890/ES11-00216.1.
20. Williamson, J.C., **B.T. Bestelmeyer**, D.P.Peters. 2012. Spatiotemporal patterns of production can be used to detect state change across an arid landscape. Ecosystems 15: 34-47.

**PAST ACCOMPLISHMENTS**
**KRIS M. HAVSTAD, SUPERVISORY RESEARCH RANGELAND MANAGEMENT SCIENTIST**

**Education**

| | |
|---|---|
| 1981 | Utah State University, Range Science, Ph.D. |
| 1977 | New Mexico State University, Range Science, M.S. |
| 1975 | Oregon State University, Range Science, B.A. |

**Work Experience**

| | |
|---|---|
| 1989- Present | Supervisory Range Scientist, Range Management Research Unit<br>USDA, ARS, Las Cruces, NM |
| 1987- Present | Adjunct Professor, New Mexico State University, Las Cruces, NM |
| 1985-1988 | Associate Professor, Montana State University, Bozeman, MT |
| 1981-1985 | Assistant Professor, Montana State University, Bozeman, |

**Accomplishments**

The scientist has quantified influences of cattle genetic and rangeland environment interactions on forage intake and production efficiencies. The scientist has characterized winter grazing behaviors of rangeland cattle in northern latitudes in response to cold temperatures and revised characterization of lower critical ambient temperatures. The scientist has co-developed a new conceptual model for revegetation of degraded arid rangelands. The scientist was a member of a team that was engaged in quantifying long term ecological dynamics in arid environments and applying that knowledge to management technologies applicable for desert rangelands. The scientist was a member of a team that applied knowledge of basic ecological processes to the development of indicators for monitoring and assessing rangelands.

**Selected Peer-reviewed Publications (from 105 total)**

1. Peters, D.C., Pielke, R.A., Bestelmeyer, B.T., Allen, C.D., Munson-McGee, S. and **Havstad, K.M.** 2004. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. Proceedings of the National Academy of Sciences. 101:15130-15135.
2. Gibbens, R.P., McNeely, R.P., **Havstad, K.M.**, Beck, R.F. and Nolen, B. 2005. Vegetation changes in the Jornada basin from 1858 to 1998. Journal of Arid Environments. 61:651-668.
3. Bestelmeyer, B.T. Ward, J.P. and **Havstad, K.M.** 2006. Soil-geomorphic heterogeneity governs patchy vegetation dynamics at an arid ecotone. Ecology. 87:963-973.
4. Bestelmeyer, B.T., Trujillo, D.A., Tugel, A.J. and **Havstad, K.M.** 2006. A multi-scale classification of vegetation dynamics in arid lands: What is the right scale of models, monitoring, and restoration? Journal of Arid Environments. 65:296-318.
5. Drewa, P.B., Peters, D.C. and **Havstad, K.M.** 2006. Population and clonal level responses of a perennial grass following fire in the northern Chihuahuan Desert. Oecologia. 150:29-39.
6. Peters, D.C. and **Havstad, K.M.** 2006. Nonlinear dynamics in arid and semi-arid systems: Interactions among drivers and processes across scales. Journal of Arid Environments. 65:196-206.
7. Peters, D.P.C., Mariotto, I., **Havstad, K.M.** and Murray, L.W. 2006. Spatial variation in remnant grasses after a grassland-to-shrubland state change: Implications for restoration. Rangeland Ecology and Management. 59:343-350.
8. Yao, J., Peters, D.C., **Havstad, K.M.** Gibbens, R.P. and Herrick, J.E. 2006. Multi-scale factors and long-term responses of Chihuahuan desert grasses to drought. Landscape Ecology. 21:1217-1231.
9. **Havstad, K.M.**, Peters, D.P.C., Skaggs, R., Brown, J., Bestelmeyer, B., Fredrickson, E., Herrick, J., and Wright, J. 2007. Ecological Services to and from rangelands of the United States. Ecology Economics. 64:261-268.

10. Briske, D.D., Derner, J.D., Brown, J.R., Fuhlendorf, S.D., Teague, W.R., **Havstad, K.M.**, Gillen, R.L., Ash, A.J., and Wilms, W.D. 2008. Rotational grazing on rangelands: Reconciliation of perception of experimental evidence. Rangeland Ecology and Management. 61:3-17.
11. Angerer, J., Han, G., Fujisaki, I., **Havstad, K.M.** 2008. Climate change and ecosystems of Asia with emphasis on Inner Mongolia and Mongolia. Rangelands. 30: (3):46-51.
12. **Havstad, K.M.**, Herrick, J.E., Tseelei, E.A. 2008. Mongolia's rangelands: Is livestock production the key to the future? Frontiers in Ecology and the Environment. 6:386-391.
13. Bestelmeyer, B.T., **Havstad, K.M**, Damindsuren, B., Han, G., Brown, J.R., Herrick, J.E., Steele, C., and Peters, D.C. 2009. Resilience theory in models of rangeland ecology and restoration: the evolution and application of a paradigm. In: Hobbs, J.J and Suding, K.N. (eds). New Models for Ecosystem Dynamics and Restoration.
14. Peters, D. C. P., Bestelmeyer, B. T., Knapp, A. K., Herrick, J. E., Monger, H. C., and **Havstad, K.M** 2009. Approaches to predicting broad-scale regime shifts using changing pattern-process relationships across scales. In: Miao, S., Carstenn, S., Nungesser, M. (eds). Real World Ecology: Large-scale and long-term case studies and methods.
15. Svejcar, T., **Havstad, K**., 2009. Improving Field-Based Experimental Research to Compliment Contemporary Management. Rangelands 31:26-30.
16. Rango, A., **Havstad, K.M.**, 2009. Water-harvesting applications for rangelands revisited. Environmental Practice 11, 84-94.
17. Liang, Y., Han, G., Zhou, H. Zhao, M., Snyman, H.A., Shan, D. **Havstad, K.M.** 2009. Grazing intensity on vegetation dynamics of a typical steppe in Northeast Inner Mongolia. Rangeland Ecology and Management 62:328-336.
18. **Havstad, K.**, James, D., Romig, K. 2010. Prescribed Burning as an Infrequent Tool to Affect a Vegetation State Transition in Black Grama (Bouteloua eriopida Torr.) Dominated Ecological Sites. Journal of Arid Environments 74:1324-1328.
19. Wang, Z., Jiao, S., Han, G., Zhao, M., Willms, W.D., Hao, X., Wang, J.A., Din, H., **Havstad, K.M.**, 2011. Impact of stocking rate and rainfall on sheep performance in a desert steppe. Rangeland Ecology and Management 64:249-256.
20. Rango, A., **Havstad, K.M.**, Estell, R.E., 2011. The utilization of historical data and geospatial technology advances at the Jornada Experimental Range to support western America ranching culture. Remote Sensing 3:2089-2109.

## PAST ACCOMPLISHMENTS
## JEFFREY E. HERRICK, RESEARCH SOIL SCIENTIST

### Education

| | |
|---|---|
| 1993 | Ohio State University, Agronomy, Ph.D. |
| 1987 | Lincoln College, New Zealand; Agricultural Science; Diploma |
| 1985 | Swarthmore College, PA; Biology, B.A. B.A. |

### Work Experience

| | |
|---|---|
| 1998- Present | Soil Scientist, Range Management Research Unit<br>USDA, ARS, Las Cruces, NM |
| 1994 - 1998 | Postdoctoral Research Associate, New Mexico State University, Las Cruces, NM |
| 1987 - 1993 | National Science Foundation Graduate Research Fellow and Graduate Research Assistant, Ohio State University, Columbus, OH |

### Accomplishments

The scientist has developed in a diverse, highly integrated research program on basic soil and ecosystem processes that has resulted in the generation and international adoption of a number of rangeland assessment, monitoring, and remediation tools. The scientist wrote the first review paper on the role of soil biota in rangeland soil hydrology and organized the first international workshop to address the challenge of quantifying changes in soil aggregation in poorly structured rangeland soils. The scientist developed and implemented the first long-term, landscape-level experiment to define the relationship between soil surface disturbance, soil properties, and vegetation change; co-led the development of an internationally applied rangeland assessment protocol; developed the first rangeland monitoring manual which effectively integrates plant community dynamics and dynamic soil properties to address basic ecosystem functions rather than a single, use-dependent value; and developed innovative approaches to rangeland remediation. The assessment and monitoring protocols are being applied nationally through the NRCS National Resource Inventory program and have been independently translated into Spanish and Chinese. Several of the associated tools have been commercialized. The scientist has fostered greater communication among ecologists, managers and policymakers by initiating collaborative research projects and by organizing conferences, workshops, and symposia, including an international conference on ecology and globalization.

### Selected Peer-reviewed Publications (from 93 total)

1. Okin, G.S., Gillette, D.A., **Herrick, J.E.** 2006. Multiscale controls on and consequences of aeolian processes in landscape change in arid and semiarid environments. Journal of Arid Environments. 65:253-275.
2. **Herrick, J.E.**, Bestelmeyer, B.T., Archer, S., Tugel, A., Brown, J.R. 2006. An integrated framework for science-based arid land management. Journal of Arid Environments. 65:319-335.
3. **Herrick, J.E.**, Garcia-Moya, E., Willms, W., Bestelmeyer, B., Sundt, P. and Barnes, W. 2006. Arid and semi arid rangeland monitoring in North America. Science et Changements Planétaires Sécheresse. 17:235-241.
4. Beever, E. A. and **Herrick**, **J.E.** 2006. Effects of feral horses in Great Basin landscapes on soils and ants: Direct and indirect mechanisms. Journal of Arid Environments. 66:96-112.
5. **Herrick, J.E**., Schuman, G.E. and Rango, A. 2006. Monitoring ecological processes for restoration projects. Journal of Nature Conservation. 14:161-171.
6. Duniway, M., **Herrick, J.E.** and Monger, H.C. 2007. The high water-holding capacity of petrocalcic horizons. Soil Science Society of America Journal. 71:812-819.

7. **Herrick, J.E.** and Sarukhan, J. 2007. A strategy for ecology in an era of globalization. Frontiers in Ecology and the Environment 5:172-181.
8. **Herrick, J.E.**, Bestelmeyer, B.T. and Crossland, K. 2008. Simplifying ecological site verification, rangeland health assessments, and monitoring. Rangelands. 30:24-26.
9. Duniway, M.C., Snyder, K.A. and **Herrick, J.E**. 2010. Spatial and temporal patterns of water availability in a grass-shrub ecotone and implications for grassland recovery in arid environments. Ecohydrology. 3:55-67.
10. Duniway, M.C., **Herrick, J.E.**, and Monger, H.C. 2010. Spatial and temporal variability of plant-available soil water in arid ecosystems and consequences for resilience. Oecologia. 163:215-226.
11. **Herrick, J.E.**, Lessard, V.M., Spaeth, K.E., Shaver, P.L., Dayton, R.S., Pyke, D.A., Jolley, L., Goebel, J.J. National ecosystem assessments supported by scientific and local knowledge. Frontiers in Ecology and the Environment. 8:403-408. 2010.
12. **Herrick, J.E.,** Van Zee, J.W., Belnap, J., Johansen, J.R., Remmenga, M., 2010. Fine gravel controls hydrologic and erodibility responses to trampling disturbance for coarse-textured soils with weak cyanobacterial crusts. CATENA 83, 119-126.
13. Karl, J., **Herrick, J.E.,** 2010. Monitoring and assessment based on ecological sites. Rangelands 32, 60-64.
14. Laliberte, A.S., Browning, D.M., **Herrick, J.E.,** Gronemeyer, P. 2010. Hierarchical object-based classification of ultra high resolution Digital Mapping Camera (DMC) imagery for rangeland monitoring and assessment. Journal of Spatial Science 55, 101-115.
15. Laliberte, A.S., **Herrick, J.E.,** Rango, A. 2010. Acquisition, orthorectification, and classification of unmanned aerial vehicle (UAV) imagery for rangeland monitoring. Photogrammetric Engineering and Remote Sensing 76, 661-672.
16. Li, J., Okin, G.S., **Herrick, J.E.,** Munson, S.M., Miller, M.E., Belnap, J., 2010. A simple method to estimate threshold friction velocity in the field. Geophysical Research Letters 37, 1-5.
17. Duniway, M., **Herrick, J.E.,** 2011. Disentangling road network impacts: the need for a holistic approach. Journal of Soil and Water Conservation 62, 31A-36A.
18. Riginos, C., **Herrick, J.E.,** Sundaresan, S.R., Farley, C., Belnap, J. 2011. A simple graphical approach to quantitative monitoring of rangelands. Rangelands 33, 6-13.
19. Toevs, G.R., Karl, J.W., Taylor, J.J., Spurrier, C.S., Karl, M., Bobo, M.R., **Herrick, J.E.** 2011. Consistent indicators and methods and a scalable sample design to meet assessment, inventory, and monitoring information needs across scales. Rangelands 33:14-20.

**PAST ACCOMPLISHMENTS**
**MARY LUCERO, RESEARCH MOLECULAR BIOLOGIST**

**Education**

| | |
|---|---|
| 1997 | New Mexico State University, Molecular Biology, PhD |
| 1988 | New Mexico State University, Curriculum & Instruction, M.A. |
| 1986 | New Mexico State University, Agricultural & Extension Education, B.S. |

**Work Experience**

| | |
|---|---|
| 2005-Present | Research Molecular Biologist, Range Management Research Unit, USDA-ARS, Las Cruces, NM |
| 1999-2005 | Postdoctoral Research Chemist, Range Management Research Unit, USDA-ARS, Las Cruces, NM |
| 1997-1999 | Postdoctoral Research Associate, New Mexico State University, Las Cruces, NM |
| 1992-1997 | Graduate Research Assistant, New Mexico State University, Las Cruces, NM |
| 1987-1992 | Science Teacher, Picacho Middle School, Las Cruces, NM. |

**Accomplishments**

The scientist co-authored and filed a patent for the transfer of uncultured endophytes to non-native hosts, and has worked with local growers and educators to demonstrate the impact of co-cultivating crops with endophyte-laden native plant species. The scientist has isolated and identified three previously undescribed microorganisms from in-vitro propagated plants, raising questions about the purity of plant genetic information, and has demonstrated the inefficiency of standard PCR methods for detection of uncultured fungi in plant systems. The scientist has demonstrated the potential of co-cultivated desert shrubs to enhance vigor of crops from eleven botanical families, and demonstrated the utility of co-cultivation as a mechanism for enhancing native grass establishment. The scientist has published novel essential oil profiles from four previously undescribed desert plant species.

**Peer-reviewed Publications**


1. Hyder, P.W., Fredrickson, E.L., Estell, R.E., **Lucero, M.E.** 2002. Transport of phenolic compounds from leaf surface of creosotebush and tarbush to soil surface by precipitation. Journal of Chemical Ecology 28, 2469-2476.
2. **Lucero, M.E.,** Estell, R.E., Fredrickson, E.L. 2003. The essential oil composition of *Psorothamnus scoparius* (A. Gray) Rydb. Journal of Essential Oil Research 15, 108-111.
3. Hyder, P.W., Fredrickson, E.L., Estell, R.E., **Lucero, M.E.,** Remmenga, M.D. 2005. Loss of phenolic compounds from leaf litter of creosotebush *[Larrea tridentata* (Sess. & Moc. ex DC.) Cov] and tarbush (*Flourensia cernua* DC.). Journal of Arid Environments 61, 79-91.
4. **Lucero, M.E.,** Estell, R.E., Sedillo, R.L. 2005. The composition of *Dalea formosa* oil determined by steam distillation and solid-phase microextraction. Journal of Essential Oil Research 17, 645-647.
5. Medina, A., **Lucero, M.E.,** Holguin, F.O., Estell, R.E., Posakony, J.J., Simon, J., O'Connell, M. 2005. Composition and antimicrobial activity of *Anemposis californica* leaf oil. Journal of Agricultural and Food Chemistry 53, 8694-8698.
6. Barrow, J.R., **Lucero, M.E.** 2006. "Transfer and Incorporation of heritable Symbiotic Fungi Into Non-Host Plants". Patent Application filed U.S. Patent Office, 8/08/06.
7. **Lucero, M.E.,** Barrow, J.R., Osuna, P., Reyes, I. 2006. Plant-fungal interactions in Arid and Semi-arid Ecosystems: Large-scale impacts from microscale processes. Journal of Arid Environments 65, 276-284.

8. **Lucero, M.E.,** Morrison, A., Fredrickson, E.L., Estell, R.E., Richman, D. 2006. Volatile composition of *Guiterrizia sarothrae* (broom snakeweed) as determined by steam distillation and solid phase microextraction. Journal of Essential Oil Research 18, 121-125.
9. Barrow, J.R., **Lucero, M.E.,** Reyes-Vera, I., Havstad, K.M. 2007. Endosymbiotic fungi structually integrated with leaves reveals a lichenous condition of C4 grasses. In Vitro Cellular and Development Biology - Plants 43, 65-70.
10. Barrow, J.R., **Lucero, M.E.,** Reyes-Vera, K., Havstad, K.M. 2008. Do symbiotic microbes have a role in plant evolution, performance and 2response to stress? Communicative and Integrative Biology 1, 69-73.
11. **Lucero, M.E.,** Barrow, J.R., Osuna, P., Reyes-Vera, I. 2008. Enhancing native grass productivity by cocultivating with endophyte-laden calli. Rangeland Ecology and Management 61, 124-130.
12. **Lucero, M.E.,** Barrow, J.R., Osuna-Avila, P., Reyes-Vera, I. 2008. A cryptic microbial community persists within micropropagated *Bouteloua eriopods* (Torr.) Torr. cultures. Plant Science 174, 570-575.
13. **Lucero, M.E.,** Estell, R.E., Tellez, M., Fredrickson, E.L. 2009. A retention index calculator simplifies identification of plant volatile organic compounds. Phytochemical Analysis 20, 378-384.
14. **Lucero, M.**, Dreesen, D.R., VanLeeuwen, D. 2010. Using hydrogel filled, embedded tubes to sustain grass transplants for arid land restoration. Journal of Arid Enviornments 74, 987-990.
15. **Lucero, M.E.**, Estell, R.E., Fredrickson, E.L. 2010. Composition of *Ceanothus gregii* oil as determined by steam distillation and solid-phase microextraction. Journal of Essential Oil Research 22, 140-142.
16. Reyes-Vera, I., **Lucero, M.E.,** Barrow, J.E. 2010. An improved protocol for micropropagation of saltbush *(Atriplex)* species. Native Plant Journal 11, 53-56.
17. **Lucero, M.,** Unc, A., Cooke, P., Shulei, S. 2011. Endophyte microbiome diversity in micropropagated Atriplex canescens and Atriplex torreyi var griffithsii. PLoS One 6, e17693.

**PAST ACCOMPLISHMENTS**
**DEBRA C. PETERS, RESEARCH ECOLOGIST (formerly Debra P. Coffin)**

**Education**

| | |
|---|---|
| 1988 | Colorado State University, CO; Range Science, Ph.D. |
| 1983 | San Diego State University, CA; Biology, M.S. |
| 1981 | Iowa State University, IA; Biology; B.S. |

**Work Experience**

| | |
|---|---|
| 2011-Present | Rangeland Ecologist, Range Management Research Unit, USDA, ARS, Las Cruces, NM |
| 2002-2011 | Lead Scientist and Rangeland Ecologist, Range Management Research Unit, USDA, ARS, Las Cruces, NM |
| 1998-2002 | Rangeland Ecologist, Range Management Research Unit, USDA, ARS, Las Cruces, NM |
| 1994-1997 | Research Scientist, Colorado State University, Fort Collins, CO |
| 1989-1993 | Research Associate, Colorado State University, Fort Collins, CO |
| 1988-1989 | Postdoctoral Associate, Colorado State University, Fort Collins, CO |
| 1984-1987 | Graduate Research Assistant, Colorado State University, Fort Collins, CO |

**Accomplishments**
The scientist developed a spatially explicit gap dynamics simulation model of interactions between woody and herbaceous species for arid and semiarid ecosystems. The scientist has been instrumental in generalizing this simulation model for other rangeland types within the US and abroad, and for making ecosystem simulation models readily available and easy to use by non-modelers and experienced modelers. The scientist's work on connecting pattern and process across multiple scales has lead to new studies by other investigators within the NSF supported Long Term Ecological Research (LTER) program. The scientist's explicit consideration of the role of spatial processes, such as seed dispersal and water redistribution, on generating patterns across landscapes has been adopted as a general conceptual model of rangeland dynamics by scientists at the Jornada and collaborating locations. The scientist initiated and conducted comparative experiments and simulation analyses among arid and semiarid LTER sites in the US and Hungary as part of a collaborative project.

**Selected Peer-reviewed Publications (from 89 total)**
1. **Peters, D.C**. 2004. Selection of models of invasive species dynamics. Weed Technology. 18:1236-1239.
2. **Peters, D.C.,** Pielke, R.A., Bestelmeyer, B.T., Allen, C.D., Munson-Mcgee, S., Havstad, K.M. 2004. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. Proceedings of the National Academy of Sciences. 101(42):15130-15135.
3. **Peters, D.C.,** Urban, D.L., Gardner, R.H., Breshears, D.D., Herrick, J.E. 2004. Strategies for ecological extrapolation. Oikos. 106(3):627-636.
4. **Peters, D.C**., Yao, J., Havstad, K.M. 2004. Insights to invasive species dynamics from desertification studies. Weed Technology. 18:1221-1225.
5. Estell, R.E., Fredrickson, E.L., **Peters, D.P.C.** 2006. Introduction to special issue - Landscape linkages and cross-scale interactions in arid and semi-arid ecosystems. Journal of Arid Environments. 65:193-195.
6. Goslee, S.C., **Peters, D.P.C**., Beck, K.G. 2006. Spatial prediction of invasion success across heterogeneous landscapes using an individual-based model. Biological Invasions. 8:193-200.

7. **Peters, D.P.C.,** Bestelmeyer, B.T., Herrick, J.E., Fredrickson, E.L., Monger, H.C., Havstad, K.M. 2006. Disentangling complex landscapes: New insights into arid and semiarid system dynamics. BioScience. 56:491-501.
8. **Peters, D.P.C.,** Gosz, J.R., Pockman, W.T., Small, E.E., Parmenter, R.R., Collins, S.L. and Muldavin, E. 2006. Integrating patch and boundary dynamics to understand and predict biotic transitions at multiple scales. Landscape Ecology 21:19-33.
9. **Peters, D.P.C.,** Havstad, K.M. 2006. Nonlinear dynamics in arid and semi-arid systems: Interactions during drivers and processes across scales. Journal of Arid Environments. 65:196-206.
10. **Peters, D.P.C**., Mariotto, I., Havstad, K.M., Murray, L.W. 2006. Spatial variation in remnant grasses after a grassland-to-shrubland state change: Implications for restoration. Rangeland Ecology & Management. 59:343-350.
11. **Peters, D.P.C.,** Yao, J., Gosz, J.R. 2006. Woody plant invasion at a semi-arid/arid transition zone: importance of ecosystem type to colonization and patch expansion. Journal of Vegetation Science. 17:389-396.
12. **Peters, D.P.C.,** Bestelmeyer, B.T., Turner, M.G. 2007. Cross-scale interactions and changing pattern-process relationships: consequences for system dynamics. Ecosystems. 10:790-796.
13. **Peters, D.P.C.,** Sala, O.E., Allen, C.D., Covich, A., Brunson, M. 2007. Cascading events in linked ecological and socio-economic systems: predicting change in an uncertain world. Frontiers in Ecology and the Environment. 5:221-224.
14. **Peters, D.C.,** Groffman, P.M., Nadelhoffer, K.J., Grimm, N.B., Collins, S.L., Michener, W.K., Huston, M.A. 2008. Living in an increasingly connected world: a framework for continental-scale environmental science. Frontiers in Ecology and the Environment 6, 229-237.
15. **Peters, D.C.** 2008. Ecology in a connected world: A vision for a "network of networks". Frontiers in Ecology and the Environment 6, 227-284.
16. **Peters, D.P.C.,** Herrick, J.E., Monger, H.C., Huang, H. 2010. Soil-vegetation-climate interactions in arid landscapes: Effects of the North American monsoon on grass recruitment. Journal of Arid Environments 74, 618-623.
17. **Peters, D.,** 2010. Accessible ecology: Synthesis of the long, deep, and broad. Trends in Ecology and Evolution 25, 592-601.
18. **Peters, D.P.C.,** Lugo, A.E., Chapin, F.S., Pickett, S.T.A., Duniway, M., Rocha, A.V., Swanson, F.J., Laney, C., Jones, J., 2011. Cross-system comparisons elucidate disturbance complexities and generalities. Ecosphere 2, art81.
19. **Peters, D.P.C.,** Yao, J., Sala, O.E., Anderson, J.P. 2012. Directional climate change and potential reversal of desertification in arid and semiarid ecosystems. Global Change Biology 18, 151-163.
20. **Peters, D.P.C.,** J. Yao. 2012. Long-term experimental loss of foundation species: consequences for dynamics at ecotones across heterogeneous landscapes. Ecosphere (In Press).

**PAST ACCOMPLISHMENTS**
**ALBERT RANGO, RESEARCH HYDROLOGIST**

**Education**
1969 Colorado State University; Watershed Management; Ph.D.
1966 Pennsylvania State University; Meteorology; M.S.
1965 Pennsylvania State University; Meteorology; B.S.

**Work Experience**

| | |
|---|---|
| 2001-Present | Research Hydrologist, Supergrade ST(SL-1), USDA/ARS/SPA/Jornada Experimental Range, Las Cruces, NM |
| 1997-2003 | President, International Commission on Remote Sensing, International Association of Hydrological Sciences |
| 1994-Present | Principal Investigator, JORNEX Project, Jornada Experimental Range, Las Cruces, NM |
| 1994-2001 | Research Hydrologist, USDA, ARS, HL, Beltsville, Maryland |
| 1993-1997 | Principal Investigator, CRADA, Regional Watershed Modeling under Conditions of Change, Electric Power Research Institute, Palo Alto, California |
| 1991-1996 | U.S. National Representative to the International Association of Hydrological Sciences |
| 1990-1992 | President and General Chairman, Western Snow Conference |
| 1989-1995 | Rapporteur on Remote Sensing for Hydrology, World Meteorological Organization, Geneva, Switzerland |
| 1986 | President, American Water Resources Association |
| 1983-1994 | Hydrologist and Research Leader, USDA/ARS/BA/NRI/HL, Beltsville, Maryland |
| 1972-1983 | Hydrologist and Branch Head, Hydrological Sciences Branch |
| 1969-1972 | Assistant Professor of Meteorology, Pennsylvania State University |

**Accomplishments**
The scientist led development of visual and digital methods for extracting snow covered area from a variety of satellite sensors. The scientist conceived and designed the satellite snow cover version of the Snowmelt Runoff Model (SRM), which is used for simulations, forecasts, and climate change evaluations. SRM is currently being adapted to the Rio Grande basin for operational forecasts. The scientist developed the first techniques for analyzing satellite microwave data over large areas and developed a means for estimating snow water equivalent and depth on flat, high prairies and in large mountain basins. The scientist developed a formalized algorithm as part of SRM for evaluating hydrologic response to climate change and has used it to evaluate river basin responses under varying conditions of climate change. The scientist is the principal investigator for the JORNEX project (now a formalized part of the Jornada Basin LTER) and in the role directs the field experiments, integrates the various data being collected, and coordinates the joint cooperative investigations under the JORNEX umbrella. The scientist has assembled historic research records along with historic aerial photography of rangeland remediation treatments in the Jornada Basin to assess their effects on rangeland condition and ecosystem stability. The scientist has developed hyperspatial remote sensing (5-10 cm resolution) using both simple digital and 6-band multispectral cameras mounted on autonomous Unmanned Aerial Vehicles (UAVs), which have found extensive use in rangeland science, ecology, and hydrology.

**Selected Peer-reviewed Publications (from 183 total)**

1. Foster, J., Kelly, R., **Rango, A.,** Armstrong, R., Erbe, E.F., Pooley, C.D., P., 2006. Use of low-temperature scanning electron microscopy to compare and characterize three classes of snow cover. Scanning 28, 191-203.
2. **Rango, A.** 2006. Snow: The Real Water Supply for the Rio Grande Basin. New Mexico Journal of Science 44, 99-118.
3. **Rango, A**., Laliberte, A.S., Steele, C., Herrick, J.E., Bestelmeyer, B.T., Schmugge, T.J., Roanhorse, A., Jenkins, V. 2006. Using unmanned aerial vehicles for rangelands: Current applications and future potentials. Environmental Practice 8, 159-168.
4. Su, L., Chopping, M.J., **Rango, A**., Martonchik, J.V., Peters, D.C. 2007. Differentiation of semi-arid vegetation types based on multi-angular observations from MISR and MODIS. International Journal of Remote Sensing 28, 1419-1424.
5. Chopping, M., Moisen, G., Su, L., Laliberte, A., **Rango, A.,** Martonchik, J., Peters, D.C. 2008. Large area mapping of southwestern forest crown cover, canopy height, and biomass using MISR. Remote Sensing of Environment 112, 2051-2063.
6. Chopping, M., Su, L., **Rango, A.,** Martonchik, J.V., Peters, D.C., Laliberte, A., 2008. Remote sensing of woody shrub cover in desert grasslands using MISR with a geometric-optical canopy reflectance model. Remote Sensing of Environment 112, 19-34.
7. **Rango, A.,** Laliberte, A., Winters, C. 2008. Role of aerial photos in compiling a long-term remote sensing data set. Journal of Applied Remote Sensing 2, 023541.
8. **Rango, A.,** Martinec, J., Roberts, R.T. 2008. Relative importance of glacier contributions to water supply in a changing climate. World Resource Review 20, 487-503.
9. Laliberte, A., **Rango, A.** 2009. Texture and scale in object-based analysis of subdecimeter resolution unmanned aerial vehicle (UAV) imagery. IEEE Transactions on Geoscience and Remote Sensing 47, 761-770.
10. **Rango, A.,** Havstad, K.M., 2009. Water-harvesting applications for rangelands revisited. Environmental Practice 11, 84-94.
11. **Rango, A.,** Laliberte, A., Herrick, J.E., Winters, C., Havstad, K.M., Steele, C., Browning, D.M. 2009. Unmanned aerial vehicle-based remote sensing for rangeland assessment, monitoring, and management. Journal of Applied Remote Sensing 3, 033542.
12. Laliberte, A.S., Herrick, J.E., **Rango, A.** 2010. Acquisition, orthorectification, and classification of unmanned aerial vehicle (UAV) imagery for rangeland monitoring. Photogrammetric Engineering and Remote Sensing 76, 661-672.
13. **Rango, A.,** Laliberte, A. 2010. Impact of flight regulations on effective use of unmanned aircraft systems for natural resources applications. Journal of Applied Remote Sensing 4.
14. Browning, D.M., Laliberte, A.S., **Rango, A.** 2011. Temporal dynamics of shrub proliferation: Linking patches to landscapes. International Journal of Geographical Information Science 25, 913-930.
15. Laliberte, A.S., Goforth, M.A., Steele, C.M., **Rango, A.** 2011. Multispectral remote sensing from unmanned aircraft: image processing workflows and applications for rangeland environments. Remote Sensing 3, 2529-2551.
16. Laliberte, A.S., **Rango,** A. 2011. Image processing and classification procedures for analysis of sub-decimeter imagery acquired with an unmanned aircraft over arid rangelands. GIScience & Remote Sensing 48, 4-23.
17. Laliberte, A.S., Winters, C., **Rango, A.** 2011. UAS remote sensing missions for rangeland applications. Geocarto International 26, 141-156.
18. **Rango, A.,** Havstad, K.M., Estell, R.E. 2011. The utilization of historical data and geospatial technology advances at the Jornada Experimental Range to support western America ranching culture. Remote Sensing 3, 2089-2109.

**ISSUES OF CONCERN STATEMENT**

**Animal Care:** Animal Care: All research projects involving livestock are reviewed and approved by the Institutional Animal Care and Use Committee at New Mexico State University prior to initiation.

**Endangered Species:** Not Relevant

**Environmental Impact Statement:** On the basis that this federal project is being conducted for the sole purpose of conducting research, this project is categorically excluded in accordance with regulations for the National Environmental Policy Act.

**Human Study Procedure:** Not Relevant

**Laboratory Hazards:** Although no serious laboratory hazards are anticipated relative to this project proposal, employees receive safety training prior to using laboratories. Under the direction of the Location Collateral Duty Safety Officer, the research unit has an active safety committee, safety manual, chemical hygiene plan, and hazardous waste disposal plan. All laboratory safety training requirements are augmented through an agreement with the Safety Officer at NMSU to provide routine training to employees through on line testing and evaluations.

**Occupational Safety & Health:** Although no serious safety and health issues are expected regarding this proposal, employees review safety and health manual and receive training on issues such as “right to know” and how to read Material Safety Data Sheets.

**Recombinant DNA Procedures:** Not Relevant

**Homeland Security:** Not Relevant

**Intellectual Property:** Patents developed in accord with ARS policies. Intellectual property collaborations are covered under guidelines in established Specific Cooperative Agreements (Appendix Table 2).

While preparing the Project Plan, I (Richard E. Estell) have carefully examined all aspects of the planned research to ensure that appropriate safety concerns are addressed, all necessary permits have been identified, and that environmental issues have been considered in making the National Environmental Policy Act (NEPA) decision documented in the statement. All permits are in hand or have been requested. Documentation supporting NEPA decision is in the MU project file and available for review upon request.

I (John P. McMurtry) certify that the proposed research conforms to current regulations and guidelines regarding the above issues and concerns.

____________________________________ ____________

John P. McMurtry, Associate Area Director Date

**EXISTING SPECIFIC COOPERATIVE AGREEMENTS (SCAs):** see Appendix Table 2

## APPENDIX

**Appendix Table 1A: PAST ACCOMPLISHMENTS OF DAWN M. BROWNING, POST DOCTORAL RESEARCH ASSOCIATE - 2013-2014**

**Education**

| | |
|---|---|
| 2008 | University of Arizona, AZ; Natural Resource Studies, Ph.D. |
| 2000 | University of Arkansas, AR; Biological Sciences, M.S. |
| 1996 | Mississippi State University, MS; Biological Sciences; B.S. |

**Work Experience**

| | |
|---|---|
| 2009-Present | Physical Research Scientist, Range Management Research Unit, USDA, ARS, Las Cruces, NM |
| 2007-2009 | Instructor, University of Arizona, Tucson, AZ |
| 2004-2007 | EPA STAR Graduate Fellow, University of Arizona, Tucson, AZ |
| 2003-2004 | Graduate Research Assistant, University of Arizona, Tucson, AZ |
| 2000-2002 | Research Specialist, New Mexico State University, Las Cruces, NM |

**Accomplishments**

The scientist has devised an approach to quantify vegetation dynamics in a hierarchical patch dynamics framework using time series aerial photography. The scientist bridges the fields of ecology and remote sensing to seek a mechanistic understanding of the ecological processes that yield spatial patterns discerned with spatial analyses and remotely sensed imagery. Published studies have focused on shrub-encroached ecosystems in the Sonoran and Chihuahuan Deserts of the southwestern U.S. and development of predictive models of species requirements for reptilian and avian species of concern. The scientist has mentored four undergraduate students to devise tangible research projects based in ecology that incorporate geographical information science.

**Peer-reviewed Publications**

1. Taylor, E., M. Malawy, **D.M. Browning**, S. Lamar, and D. DeNardo. 2005. Effects of food supplementation on the physiological ecology of female Western diamond-backed rattlesnakes (*Crotalus atrox*). Oecologia 144:206-213.
2. **Browning, D.M.**, S.J. Beaupre, and L. Duncan. 2005. Using Partitioned Mahalanobis $D^2(k)$ to formulate a GIS-based model of timber rattlesnake hibernacula. Journal of Wildlife Management 69:33-44.
3. **Browning, D.M.**, S.R. Archer, G.P. Asner, M.P. McClaran, and C.A. Wessman. 2008. Woody plants in grasslands: Post-encroachment dynamics. Ecological Applications 18(4):928-944.
4. **Browning, D.M.**, S.R. Archer, and A.T. Byrne. 2009. Field validation of historic aerial photography: How much are we missing? Journal of Arid Environments 73:844-853.
5. Rango, A., A. Laliberte, J. Herrick, C. Winters, K. Havstad, C. Steele and **D. Browning**. 2009. UAV-based remote sensing for rangeland assessment, monitoring, and management. Journal of Applied Remote Sensing 3(1):033542.
6. McClaran, M.P., **D.M. Browning**, and C. Huang. 2010. Temporal Dynamics and Spatial Variability in Desert Grassland Vegetation. *In* Repeat Photography: Methods and Applications in the Natural Sciences. R.H. Webb, D.E. Boyer, and R.M. Turner, editors. Island Press. Pp. 145-166.
7. Laliberte, A.S., **D.M. Browning**, J.E. Herrick, and P. Gronemeyer. 2010. Hierarchical object-based classification of ultra high resolution digital mapping camera (DMC) imagery for rangeland monitoring and assessment. Journal of Spatial Science 55:1, 101-115.

8. **Browning, D.M.**, A.S. Laliberte and A. Rango. 2011. Temporal dynamics of shrub proliferation: Linking patches to landscapes. International Journal of Geographical Information Science 25:6, 913-930. doi: 10.1080/13658816.2010.498789.
9. **Browning, D.M.** and S.R. Archer. 2011. Protection for livestock fails to deter shrub proliferation in a desert landscape with a history of heavy grazing. Ecological Applications 21:5, 1629-1642. doi: 10.1890/10-0542.1.
10. **Browning, D.M.** and M.C. Duniway. 2011. Digital Soil Mapping in the Absence of Field Training Data: A Case Study Using Terrain Attributes and Semiautomated Soil Signature Derivation to Distinguish Ecological Potential. Applied and Environmental Soil Science. doi:10.1155/2011/421904.
11. Laliberte, A.S., **D.M. Browning**, A. Rango. 2012. A comparison of three feature selection methods for object-based classification of sub-decimeter resolution UltraCam-L imagery. International Journal of Applied Earth Observation and Geoinformation. 15:70-78. doi: 10.1016/j.jag.2011.05.011.
12. **Browning, D.M.** M.C. Duniway, A.S. Laliberte, and A. Rango. Hierarchical analysis of vegetation dynamics over 71 years: Soil-rainfall interactions in a Chihuahuan desert ecosystem. Ecological Applications (In Press).
13. D.C. Peters, J. Yao, **D.M. Browning,** and A. Rango. Regime shift reversal: the role of sequential processes and early indicators. Ecology (In Review).
14. J.W. Karl, J.E. Herrick, and **D.M. Browning**. A vision for rangeland management based on best available knowledge and information. Rangeland Ecology and Management (In Review).
15. **Browning, D.M.** J. Franklin, S.R. Archer, and D.P. Guertin. Spatial patterns of grassland-shrubland state transitions: a 74 year record on grazed and protected areas. Landscape Ecology (In Review).

**Appendix Table 1B: PAST ACCOMPLISHMENTS OF JASON KARL, POST DOCTORAL RESEARCH ASSOCIATE - 2013-2014**

**Education**

| | |
|---|---|
| 2009 | Michigan State University, Fisheries and Wildlife, Ph.D. |
| 1998 | University of Idaho, Environmental Science, M.S. |
| 1996 | University of Idaho, Wildlife Biology, B.S. |

**Work Experience**

| | |
|---|---|
| 2009 - Present | Post-doctoral Research Ecologist, USDA-ARS, Jornada Experimental Range, Las Cruces, New Mexico |
| 2002 - 2009 | Spatial Ecologist, Idaho Chapter of The Nature Conservancy, Hailey, Idaho |
| 1999 - 2002 | Senior GIS Analyst, Pacific Biodiversity Institute, Winthrop, Washington |
| 1998 - 1999 | Senior GIS Analyst, Landscape Dynamics Lab, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho |
| 1996 - 1999 | Graduate Research Assistant, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho |

**Accomplishments**

Research expertise is in spatial ecology and how the ecological elements and processes are arrayed in space and time. The implications of spatial and temporal scaling to natural resource management are important aspects of the ecological research and conservation projects. Current areas of research include: 1) Use of object-based image analysis of satellite and aerial imagery to detect ecologically relevant scales in arid rangelands, 2) Development of rangeland assessment and monitoring methods using object-based image analysis techniques, 3) Development of multi-scale sample design methods and tools for application across large landscapes, 4) Frameworks for integrating field and remote sensing methods for rangeland assessment, monitoring, and management planning.

**Peer-reviewed Publications**


1. **Karl, J.,** Herrick, J.E. 2010. Monitoring and assessment based on ecological sites. Rangelands 32, 60-64.
2. **Karl, J.W.,** and Maurer, B.A. 2010. Multivariate correlations between imagery and field measurements across scales: comparing pixel aggregation and image segmentation. Landscape Ecology 24, 591-605.
3. **Karl, J.,** Maurer, B.A. 2010. Spatial dependence of predictions from image segmentation: A variogram-based method to determine appropriate scales for producing land-management information. Ecological Informatics 5, 194-202.
4. **Karl, J.W.** 2010. Spatial Predictions of Cover Attributes of Rangeland Ecosystems Using Regression Kriging and Remote Sensing. Rangeland Ecology and Management 63, 335-349.
5. **Karl, J.W**. 2011. Turning information into knowledge for rangeland management. Rangelands 33, 3-5.
6. **Karl, J.W**., Colson, K., Swartz, H. 2011. Rangeland assessment and monitoring methods guide. Rangelands 33, 48-54.
7. Toevs, G.R., **Karl, J.W.,** Taylor, J.J., Spurrier, C.S., Karl, M., Bobo, M.R., Herrick, J.E. 2011. Consistent indicators and methods and a scalable sample design to meet assessment, inventory, and monitoring information needs across scales. Rangelands 33, 14-20.
8. Duniway, M., **Karl, J.W.,** Schrader, T.S., Baquera, N., Herrick, J.E. 2011. Rangeland and pasture monitoring: an approach to interpretation of high-resolution imagery focused on

observer calibration for repeatability. Environmental Monitoring and Assessment. 10.1007/s10661-011-2224-2.

9. **Karl, J.W.,** Opsomer, J., Nusser, S., Laliberte, A.S., Duniway, M.C., and Unnasch, R.S. Using VHR imagery for rangeland monitoring and assessment: some statistical considerations. Rangeland Ecology and Management (In Press).
10. **Karl, J.W.,** Duniway, M.C., and Schrader, T.S. A technique for estimating canopy-gap size distributions from very-high-resolution digital imagery. Rangeland Ecology and Management (In Press).
11. Unnasch, R.S., and **Karl, J.W**. Scale and conservation planning. in Craighead, L. (ed). Conservation Planning. ESRI Press. Redlands, CA (In Press).

**Appendix Table 2. Existing Cooperative Agreements and Specific Cooperative Agreements[1]**

| Project Number | Accession # | Start Date | Term Date | Agreement # | Title | Cooperating Agency |
|---|---|---|---|---|---|---|
| 6235-11210-006-94-S | 420918 | 3/1/11 | 9/30/12 | 58-6235-1-94F | Development Of Evidence-Based Management Practices For Rangelands In The Americas | National institute of Agricultural Technology (INTA) Argentina |
| 6235-11210-006-02-R | 421886 | 6/27/11 | 6/30/15 | 60-6235-1-83 | Using National And Field Collected Information To Report On The Condition Of Public Lands | Bureau of Land Management Washington, D.C. |
| 6235-11210-006-83-N | 418908 | 1/1/10 | 12/31/14 | 58-6235-0-027FN | Technologies And Their Transfer For Monitoring, Assessment As Management Of Mongolian & Us Rangelands' | Mongolian Society for Range Management UlaanBaatar, Mongolia |
| 6235-11210-006-96-S | 420845 | 3/1/11 | 9/30/15 | 58-6235-1-078 | Distribution And Habitat Selection/Space Use Of Migratory And Resident Golden Eagles (Aquila Chrysaetos)… | Bureau of Land Management Santa Fe, New Mexico |
| 6235-11210-006-74-S | 416461 | 2/16/09 | 2/15/14 | 58-6235-9-057 | Monitoring And Assessment Database Enhancement | Barry Lavine (Computer Software Contractor) Portland, Oregon |
| 6235-11210-006-98-R | 421203 | 3/8/11 | 9/30/12 | 60-6235-1-080 | Rangeland Assessment And Monitoring In Mongolia For Mcc/Mca | Millennium Challenge Corporation Washington, D.C. |
| 6235-11210-006-03-R | 421955 | 8/1/11 | 9/30/12 | 60-6235-1-084 | Monitoring For Natural Resource Planning (Sike) | Department of Defense Ft. Bliss, Texas |
| 6235-11210-006-93-R | 420464 | 8/23/10 | 8/22/15 | 60-6235-0-075 | Technologies For Managment And Restoration Of Bureau Of Land Management Administered Rangelands In | Bureau of Land Management Santa Fe, New Mexico |

| Project Number | Accession # | Start Date | Term Date | Agreement # | Title | Cooperating Agency |
|---|---|---|---|---|---|---|
| | | | | | New Mexico | |
| 6235-11210-006-99-R | 421333 | 3/18/11 | 9/30/12 | 60-6235-1-078 | Management, Habitat, Chihuahuan Desert-Phase Ii | Bureau of Land Management Santa Fe, New Mexico |
| 6235-11210-006-97-R | 421187 | 10/1/10 | 9/30/12 | 60-0179-1-917 | Conservation Effects Assessment Project - Grazinglands (2011) | Natural Resource Conservation Service Washington, D.C. |
| 6235-11210-006-07-S | 422615 | 2/1/12 | 1/31/17 | 58-6235-2-084 | Field Testing Of Monitoring And Assessment Technologies Across Large Ranch Landscapes In The Southwestern U.S. | Malpai Borderlands Group Douglas, Arizona |
| 6235-11210-006-06-R | 422612 | 10/1/11 | 9/30/12 | 60-6235-2-087 | Rangeland Assessment And Monitoring In Mongolia For Mcc/Mca, Fy12 | Millennium Challenge Corporation Washington, D.C. |
| 6235-11210-006-04-G | 422450 | 12/15/11 | 12/14/16 | 59-6235-2-082 | Web-Based Monitoring Tool Enhancement And Development | The Other Firm, LLC (Mobile Applications) Athens, Alabama |
| 6235-11210-006-95-M | 420993 | 1/12/11 | 1/11/16 | 58-6235-1-075M | Landscape Monitoring | Bureau of Land Management Washington, D.C. |
| 6235-11210-006-08-R | 422724 | 10/1/11 | 9/30/12 | 60-6235-2-088 | Support To Develop Simple Indicators To Monitor Changes In Rangeland Health In Namibia | Millennium Challenge Corporation Washington, D.C. |
| 6235-11210-006-05-N | 422444 | 1/1/12 | 12/31/16 | 58-6235-2-081N | Integrated Rangeland Monitoring And Assessment Across Scales | The Nature Conservancy Santa Fe, New Mexico |
| 6235-11210-006-84-M | 418833 | 2/1/10 | 1/31/15 | 58-6235-0-065M | Mutual Requirements And Agreements Pertaining To The Jornada Experimental Range (Jer) And | Department of Defense, Department of the Army, White Sands Missile Range, New Mexico |

| Project Number | Accession # | Start Date | Term Date | Agreement # | Title | Cooperating Agency |
|---|---|---|---|---|---|---|
| | | | | | White Sands Missile Range (Wsmr) Co-Use Land Area | |
| 6235-11210-006-62-S | 413041 | 3/13/08 | 3/12/13 | 58-6235-8-044 | Rangeland Management Practices And Technologies | New Mexico State University Las Cruces, New Mexico |
| 6235-11210-006-88-R | 419667 | 5/1/10 | 4/30/15 | 60-6235-0-072 | Taking Aim To The Field: Development, Testing, And Initial Implementation Of A Scalable Sampling Framework For Monitoring ... | Bureau of Land Management Washington, D.C. |
| 6235-11210-006-71-R | 414850 | 10/1/08 | 9/30/12 | 60-6235-8-056 | Lake Mead National Recreation Area Ecosystem Health Monitoring | Bureau of Land Management Washington, D.C. |
| 6235-11210-006-76-N | 416799 | 5/1/09 | 4/30/14 | 58-6235-9-119FN | New Methodologies For Assessing Dynamics Of Arid And Semi-Arid Rangelands In South And North America | Universidad Nacional La Pampa, Argentina |
| 6235-11210-006-75-S | 416719 | 4/16/09 | 4/15/14 | 58-6235-9-059 | Science Education Curricula Development And Outreach Programs | Asombro Institute for Science Education Las Cruces, New Mexico |
| 6235-11210-006-80-R | 418105 | 8/1/09 | 9/30/12 | 60-6235-9-061 | National Resource Inventory & Conservation Effects Assessment Program | Natural Resource Conservation Service Washington, D.C. |
| 6235-11210-006-86-N | 418960 | 3/1/10 | 2/28/15 | 58-6235-0-072FN | Technologies For Management Of Arid And Semi-Arid Rangelands | Agricultural University of Inner Mongolia Hohhot, China |

[1]Project numbers for Specific Cooperative Agreements end in "S"

**Appendix Table 3: Core long-term and short-term Jornada-LTER studies and associated datasets.****

| Study name[1] | Study | Responsible PI | Duration | Core areas [2] | Dataset name[3] (Variables measured) | Number of hits online[4] (requests[5]) |
|---|---|---|---|---|---|---|
| CORE (SIGNATURE) LONG-TERM STUDIES AND ASSOCIATED DATASETS | | | | | | |
| VEGETATION DYNAMICS | | | | | | |
| *VegMaps* | Vegetation maps | Havstad (Gibbens) | 1858, 1915, 1928, 1998 | 1 | Vegetation maps (Dominant species or functional groups) | * |
| *PermQuad* | Permanent Chart Quadrat Data | Havstad | 1915- | 3,5 | Cover of individual shrubs & perennial grasses (Basal/canopy area, perimeter of individuals) | USDA |
| | | | 1915- | 3,5 | Density of perennial forbs | |
| *LTER1_tran* | Transect Plant Line Intercepts | Anderson (Cunningham) | 1982- | 1 | Transect plant line intercepts - LT series (% cover) by species | 143 (1) |
| *LTER1_bound* | East & West Boundary Fence Plant Line Intercepts | Anderson (Cunningham) | 1982-1992 | 1 | East & west boundary fence plant line intercepts - % cover for 9 species | 47 (1) |
| | | | 1986- | 1,3 | East & west boundary fence plant line intercepts - % cover for all species | 32 (1) |
| *NPP* | Spatial and Temporal Patterns of Net Primary Production in Chihuahuan Desert Ecosystems (15 locations) | Peters (Huenneke) | 1989- | 1 | Net primary production quadrat data (Cover, height by plant or plant part) | 737 (2) |
| | | | 1989- | 1 | Net primary production quadrat biomass data by species | 529 (5) |
| | | | 1989- | 1 | Annual ANPP, SUMMARY | 40 (9) |
| | | | 1989- | 1 | Net primary production reference harvest data (Height, cover, and dry weight by species) | 525 |
| | | Anderson | 1996- | 5 | Annual ground-based photos of 15 NPP locations | |
| *Phenology* | Perennial Plant Phenology on NPP Locations | Peters (Huenneke) | 1992- | 1 | Plant phenology transect at NPP locations (Monthly phenological stage of select species) | 152 (3) |
| *CCE* | Climate Change Experiment | Sala (Reichmann) | 2006- | 1,4 | Soil water content in precipitation & nitrogren treatment plots at 2 depth profiles | |
| | | | 2007 | 1,4 | Plant cover in precipitation and nitrogen treatment plots by species | |
| | Climate Change Experiment: Response of mesquite and black grama to precipitation change | Throop | 2007-2008 | 1,4 | Photosynthetic rates for leaves from 5 precipitation treatments | |
| | | | 2007-2008 | 1,4 | Pre-dawn water potential for leaves from 5 precipitation treatments | |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Xscale ConMod* | Cross-scale study | Peters | 2008- | 4 | Conmod Pilot Study: Plant cover from plant line intercepts (Cover by species) | |
| | | | 2008- | 4 | Conmod Pilot Study: Biannual repeat photography of conmod plots | |
| | | | 2008- | 4 | Conmod Pilot Study: Quarterly BSNE sediment collection (Sediment weight collected at 2 heights) | |
| | | | 2008- | 4 | Conmod Pilot Study: Monthly bedload (Total dry weight, % ash weight) | |
| CARBON AND NITROGEN | | | | | | |
| *TermBaits* | Termite Baits | Anderson (Whitford) | 1988-2000 | 2 | Termite bait data (Loss of OM to termites) | 69 |
| *LIDET* | LTER Fine Litter Decomposition Experiment (LIDET): Above- and belowground decomposition of litter and roots over time (cross-site study) | Harmon | 1990-2002 | 2 | LTER Fine Litter Decomposition Experiment (LIDET) (Mass loss & nutrient concentrations of leaf litter, roots, & dowels) | Oregon State U |
| PLANT-ANIMAL INTERACTIONS | | | | | | |
| *StockRate* | Livestock stocking rate | Havstad | 1916- | 3 | Livestock abundance by pasture totaled for the Jornada (Animal unit months for cattle, horses, & sheep) | * |
| *CLC* | Valentines Creosotebush Lagomorph Study: perennial grass response to shrub removal, and lagomorph and cattle exclusion through time | Havstad (Valentine) | 1938- | 3 | Line intercept data of long-term vegetation responses to shrub removal and lagomorph exclusion in a creosotebush community (Cover by species) | 309 |
| *MSE* | Multiple Stressor Experiment: to examine effects of one-time pulse of seasonal livestock overgrazing and shrub removal on grass:shrub transitions | Havstad (Whitford) | 1996- | 3 | Line-Point Intercept data on grazed & shrub removal plots (Cover by plant species) | USDA |
| | | Okin (Virginia) | 1996- | 3 | Annual small scale soil movement associated with mesquite shrubs & following shrub removal (Soil height at increasing distances from shrub center) | USDA |
| | | Anderson | 1997- | 3 | Annual ground-based photos of ungrazed/grazed and shrub-removal/unremoved plots | USDA |
| *SMES* | Small Mammal Exclosure Study: To examine effects of exclusion of small mammals on plant species abundance through time | Schooley (Lightfoot) | 1995- | 5 | SMES rabbit survey data (Species abundance) | 27 |
| | | | 1995- | 3 | SMES vegetation quadrat data (Cover and height by species) | 5 |
| | | | 1995- | 3 | SMES Cryptogam Crust Data (Cover of crusts) | 16 |
| | | | 1995- | 3 | SMES Leaf Litter Data (Cover of | 16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | litter) | |
| | | | 1995- | 5 | SMES Rabbit Feces Data (Number of feces) | 16 |
| | | | 1995- | 3 | SMES Soil Surface Disturbance (Type, % cover, and vertical dimension of small mammal disturbance) | 32 |
| | | | 1995- | 5 | SMES termite casing data (Dimensions of casing ) | 14 |
| | | | 1995-2005 | 3 | SMES vegetation line intercept data (Species abundance & cover) | 20 |
| | | | 1995-2007 | 5 | SMES rodent trapping data (Species abundance) | 51 (2) |
| *Ecotone* | Ecotone study: to examine effects of small mammals on black grama recovery after disturbance across ecotones between black grama and mesquite | Bestelmeyer (Campanella) | 2003- | 5 | Ecotone rodent trapping data (Species abundance) | * |
| | | | 2003- | 1 | Ecotone plant biomass by functional group | * |
| | | | 2003- | 5 | Ecotone rodent metrics (Species abundance, biomass, & energy) | * |
| | | | AEOLIAN | | | |
| *SoilMove* | Soil movement study across black grama-mesquite ecotones | Havstad (Gibbens) | 1933- | 3 | Height of soil surface along grassland-shrubland ecotones | USDA |
| *SCRAPE* | Crust Evolution | Okin (Gillette) | 1995- | 3 | Abrasion of crust at Scrape Location (Soil height & hardness) | * |
| | | | 1996- | 3 | Monthly photos of soil surface at 3 Scrape Site tower locations (3 soil surface closeups & 1 site overview photo) | * |
| *DustFlux* | Sediment collectors (BSNEs) at NPP locations and other locations | Okin (Gillette) | 1998- | 3 | Quarterly horizontal sand mass flux data (BSNEs) at 15 NPP locations and Geomet location (Dust weights at 5 heights) | * |
| *NEAT* | Nutrient and Ecosystem impacts of Aeolian Transport (NEAT) experiment | Okin | 2004- | 3 | Horizontal sediment mass flux before & after the windy season from vegetation removal plots (Sediment weight at various heights) | * |
| | | Throop/ Archer (Hewins) | 2008-2012 | 2,4 | Effect of soil deposition on litter decomposition (mass loss & litter ash weight) | * |
| | | | HYDROLOGY | | | |
| *Runoff* | Hydrology Natural Runoff Plots | Anderson (Ward) | 1982-1994 | 4 | Hydrology natural runoff plots - runoff (Runoff depth, suspended sediment concentration, precipitation, deposited sediment, and % organic carbon) | 73 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 1989-1990 | 3 | Hydrology natural runoff plots plant cover by species | 51 |
| | | | 1988-1990 | 4 | Hydrology plot surface runoff water chemistry (Concentration of dissolved ions) | 61 |
| *Ponds* | Stock ponds | Vivoni | 2001- | 4 | Monthly surface water at instrumented stock ponds (Water height) | * |
| | | | 2001- | 4 | Monthly repeat photography of instrumented stock ponds | * |
| *TW* | Hydrometeorological Characterization of the Tromble Weir Watershed | Vivoni (Templeton) | 2010- | 3 | Channel network flow at four locations in the Tromble Watershed (Water height & flow rate) | * |
| | | | 2010- | 3 | Hydrological and energy surface and atmospheric fluxes in the Tromble Watershed (Wind speed, air temperature, atmospheric pressure, $CO_2$ & $H_2O$ concentrations, & heat fluxes) | * |
| | | | 2010- | 3 | Precipitation measured at four locations in the Tromble Watershed | * |
| | | | 2010- | 3 | Soil moisture in the Tromble Watershed at 3 depths | * |
| | | | 2010- | 3 | Soil temperature in the Tromble Watershed at 3 depths | * |
| CLIMATE, SOILS, AND ATMOSPHERE | | | | | | |
| *USDA_met* | USDA Jornada Experimental Range Climate Data | Rango | 1914- | 3 | USDA-NOAA Daily Climatological Data (Precipitation, max/min air temperature) | 605 (1) |
| | | | 1914- | 3 | USDA Monthly Summary Climatological Data (Precipitation, max/min air temperature) | 122 |
| | | | 1953-1979 | 3 | USDA Monthly Total Pan Evaporation Data | 96 |
| *PPT_net* | JER Standard Gauge Precipitation Data | Rango | 1915- | 3 | JER standard gauge precipitation data | 50 (2) |
| *LTER1_swc* | Transect Soil Water Content | Herrick (Wierenga) | 1982- | 4 | Transect soil water content at 5 depths to 150 cm | 356 (2) |
| | | | 1982- | 4 | Transect soil water content as neutron count data at 5 depths to 150 cm | 5 |
| *LTER_met* | LTER Weather Station Climate Data | Rango | 1983- | 3 | Daily summary climate data from LTER Weather Station (Wind Speed & direction, solar radiation, relative humidity, precipitation, air & soil temperature) | 581 (6) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 1983- | 3 | Hourly summary climate data from LTER Weather Station (Wind Speed & direction, solar radiation, relative humidity, precipitation, air and soil temperature) | 552 (6) |
| | | | 1983- | 3 | Evaporation pan data (Jornada LTER) | 98 |
| | | | 1992- | 3 | Dipstick rain gauge data - LTER Weather Station (Precipitation) | 48 |
| *AtmDep* | Atmospheric Deposition | Rango (Schlesinger) | 1983- | 4 | Wetfall deposition chemistry data (Jornada LTER Weather Station) (NO3, NH4, Cl, SO4, Ca, Mg, Na, K, total N, & total P) | 50 (5) |
| | | | 1983- | 4 | Dryfall deposition chemistry data (Jornada LTER Weather Station) (NO3, NH4, Cl, SO4, Ca, Mg, Na, K, total N, & total P) | 81 (5) |
| *NPP_ppt* | Monthly graduated rain gauge (GRG) precipitation at 15 NPP locations (LTER-II) | Rango | 1989- | 3 | Monthly graduated rain gauge (GRG) precipitation at 15 NPP locations (LTER-II) | 56 (7) |
| | Tipping bucket rain gauge precipitation - NPP locations | Rango | 1999- | 3 | Precipitation: Tipping bucket rain gauge precipitation - NPP locations (LTER-III) (Timestamp for each 0.1 mm) | 8 |
| *NPP_swc* | NPP Soil Water Content | Duniway (Virginia) | 1989- | 4 | NPP soil water content to 3m depth | 252 (1) |
| | | | 1989- | 4 | NPP soil water content as neutron count data to 3m depth | 23 (1) |
| *Biodiv_ppt* | Biodiversity precipitation | Rango | 1996- | 3 | Precipitation: Biodiversity tipping bucket rain gauge data - By Event (LTER-III) (Timestamp for each 0.1 mm) | 39 |
| | | | 1996- | 3 | Biodiversity tipping bucket rain gauge data - Daily Summary (Precipitation) | 53 |
| GEOMORPHOLOGY | | | | | | |
| *SoilMaps* | Maps of soil units | Monger | 1918, 1963, 1980 | 6 | Soil units | * |
| *DesertSoils* | Desert Soils Project | Monger (Gile) | 1957-1972 | 6 | Soils maps | * |
| *DEM* | Elevation maps | Monger | | 6 | Elevation | * |
| *Landform* | Landform and geomorphology maps | Monger | | 6 | Landform and geomorphology | * |
| LAND-ATMOSPHERE INTERACTIONS | | | | | | |
| *Jornex* | Energy Balance | Rango | 1995- | 1,2 | JORNEX vegetation transects (species & canopy height) | USDA |

| | | | | | | |
|---|---|---|---|---|---|---|
| *BowenRatio* | Carbon fluxes on eight US rangeland sites | Havstad | 1996-2006 | 3 | Jornada Bowen ratio data (Annual and monthly net ecosystem exchange of carbon; air temperature, concentrations of water vapor & CO2 in air; soil temperature, water content, bulk density, & heat flux) | USDA |
| *CBC (EddyFlux)* | Eddy flux tower data on creosotebush bajada location | Tweedie | 2010- | 4 | Meteorological data from eddy flux tower (Pressure, air temp, relative humidity, precip, wind speed & direction) | U Texas-El Paso |
| | | | 2010- | 1 | Hourly phenology photos for determination of greenness (Digital photo) | |
| MANAGEMENT PRACTICES | | | | | | |
| *ShrubControl* | Shrub control treatments | Havstad | 1912- | 3,5 | Shrub control treatments | USDA |
| *Exclosures* | Livestock exclosures | Havstad | 1912- | 3,5 | Livestock exclosures | USDA |
| *Regional LandCover* | Social-ecological dynamics of rangelands of the Chihuahuan Desert | Skaggs | 1936-1940 | 3 | Historical vegetation maps of public grazing lands in southwestern New Mexico | BLM |
| *County LandCover* | Remote sensing assessment of land cover change in the Mesilla Valley, NM | Buenemann (Hestir) | 1985-2009 | 3 | Land cover classification | * |
| IMAGERY | | | | | | |
| | Ground-based photos | Rango | 1912- | 1-5 | Ground-based photos | USDA |
| | Aerial photos | Rango | 1936- | 1,3,5 | Aerial photos | USDA |
| | Landsat & NOAA AVHRR | Rango | 1972- | 1,3,5 | Landsat & NOAA AVHRR | USDA |
| | UAV photos | Rango | 2004- | 1,3,5 | UAV photos | USDA |
| Study name[6] | Study | Responsible PI | Duration | Core areas | Dataset name (Variables measured) | Number of hits online (requests) |
| SHORT-TERM STUDIES AND ASSOCIATED DATASETS | | | | | | |
| VEGETATION DYNAMICS | | | | | | |
| | Mesquite Phenology Study | Anderson (Virginia) | 1986 | 4 | Mesquite Phenology Study: Mesquite Tissue Nutrients - 1986 (N & P) | 46 |
| | | | 1987 | 4 | Mesquite Phenology Study: Mesquite Tissue Nutrients - 1987 (N & P) | 50 |
| | | | 1987 | 5 | Mesquite Phenology Study: Mesquite Soil Mites (Abundance) | 91 |
| | | | 1987 | 4 | Mesquite Phenology Study: Mesquite Root Tube Soil Nutrients (NO3 & NH4, %H2O) | 49 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 1988 | 5 | Mesquite Phenology Study: Soil Nematodes (Abundance) | 59 |
| | | | 1988 | 5 | Mesquite Phenology Study: Mesquite foliar arthropods (Abundance) | 47 |
| | | | 1988 | 5 | Mesquite Phenology Study: Mesquite Phenology (Phenology componenets) | 44 |
| | | | 1988-1989 | 5 | Mesquite Phenology Study: Surface soil microarthropods (Abundance) | 68 |
| | | | 1988-1989 | 4 | Mesquite Phenology Study: Plant nutrient analysis (Concentrations of N, P, Zn, Cu, Fe, & Mn) | 85 |
| | | | 1988-1989 | 5 | Mesquite Phenology Study: Mesquite nodulating rhizobia (Abundance) | 73 |
| | | | 1988-1989 | 4 | Mesquite Phenology Study: Soil Nutrients (Concentrations of N, PO4, Zn, Cu, Fe, & Mn) | 89 |
| | Transect Creosote Leaf Area Study | Anderson (Whitford) | 1986 | 5 | Transect Larrea Leaf Area (Leaf weight-per-unit area) | |
| | Transect Vegetation Biomass | Anderson (Whitford) | 1989 | 5 | Transect Vegetation Biomass of herbaceous | 58 |
| | | | 1989 | 2,4 | Transect Soil Mineralization Potential (Field) (N-mineralization potential ) | 52 |
| | | | 1989 | 2,4 | Transect Soil Mineralization Potential (Initial) (N-mineralization potential) | 60 |
| | Ecosystem Effects of Plant Diversity (Biodiversity Experiment) | Anderson (Huenneke) | 1995 | 3,5 | Biodiversity study: Biomass removal, initiation of experiment (Dry mass removed by plant growth form) | 52 |
| | | | 1996-1999 | 2,3 | Biodiversity study: Soil erosion pan (Weight of surface sediments by category) | 32 |
| | | | 1997 | 5 | The effects of changing vegetative composition on the abundance, species diversity and activity of birds in the Chihuahuan Desert (LTER-III) (Bird species and activity type) | 58 |
| | | | 1997-2004 | 5 | Biodiversity study: Vegetation transects (Diameters and height by species) | 250 |
| | | | 1998 | 2,3,5 | Biodiversity study: Erosion zone vegetation (Plant cover and volume) | 79 |
| | | | 1999 | 5 | Biodiversity study: Biodiversity plant response, Summer 1999 (Diameters and height by species) | 28 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Drought recovery of Larrea tridentata | Anderson (Gutschick) | 1996-2000 | 4 | Drought recovery gas-exchange (Leaf stomatal conductance, internal CO2 concentration, & temperature) | 97 |
| | Arson burn on LTER-I Transect Plant Line Intercepts | Anderson (Huenneke) | 2000 | 5 | Arson burn on LTER-I Transect plant line intercepts - LT series (% cover) (Average by species) | 38 |
| | | | 2000 | 5 | Arson burn on LTER-I Transect plant line intercepts - field data (tape format) (Cover by species) | |
| CARBON, NITROGEN, MICRONUTRIENTS | | | | | | |
| | Transect Soil Physics | Anderson (Nash) | 1982-84 | 4 | Transect soil particle size analysis | 46 |
| | | Anderson (Fisher) | 1985 | 4 | Transect soil cations (Concentrations) | 26 |
| | | | 1985-86 | 4 | Transect soil phosphate (Concentration) | 38 |
| | | | 1985-86 | 4 | Transect total nitrogen in soil | 39 |
| | Transect Soil Nitrogen | Anderson (Fisher) | 1983-86 | 4 | Transect Soil Nitrogen (N concentrations in NO3, NO2, and NH4) | 17 |
| | Transect Litter Collection Study | Anderson (Whitford) | 1985-1988 | 2 | Transect creosote litterfall (Biomass) | 44 |
| | | | 1985-1988 | 2 | Transect mesquite litterfall (Biomass) | 45 |
| | Fluffgrass: Microarthropod effects on nitrogen availability | Anderson (Silva) | 1986 | 4 | Fluffgrass plant total nitrogen and biomass | 44 |
| | | | 1986 | 5 | Fluffgrass plant growth (Growth responses to treatments) | 33 |
| | | | 1986-1987 | 4,5 | Fluffgrass mesocosm: mites and nematodes (Total & microbial N availability) | 46 |
| | | | 1986-1987 | 5 | Mesocosm microarthropod numbers | 40 |
| | | | 1986-1987 | 4 | Fluffgrass anion exchange resins bags for NO3 (NO3 availability) | 36 |
| | | | 1986-1987 | 4 | Fluffgrass cation exchange resin bags for NH4 (NH4 availability) | 27 |
| | | | 1986-1987 | 5 | Fluffgrass plant dynamics (Plant diameter; mite & nematode soil weight; root weight, root total N, nematode abundance) | 26 |
| | | | 1986-1987 | 4 | Fluffgrass soil total nitrogen in rhizosphere | 39 |
| | Grama/Mesquite Leaching Mineralization Potential Survey | Anderson (Fisher) | 1986 | 4 | Grama/Mesquite Leaching Mineralization Potential Survey (Soil inorganic N) | 34 |
| | Mesquite Soil Cores | Anderson (Virginia) | 1986 | 5 | Mesquite Soil Cores: Deep Soil Microarthropods (Abundance) | 41 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 1986 | 4 | Mesquite Soil Cores: Deep Soil Core Micronutrients (Zn, Cu, Fe, & Mn concentrations) | 45 |
| | | | 1986 | 4 | Mesquite Soil Cores: Deep Soil Core N-Mineralization (N-mineralization potential) | 40 |
| | | | 1986 | 4 | Mesquite Soil Cores: Deep Soil Core Nutrients (P & N concentrations; root biomass; VAM, & rhizobia abundance) | 46 |
| | | | 1986 | 4 | Mesquite Soil Cores: Deep Core Soil Saturation Extracts (Cations, carbon, & sulfate concentrations) | 39 |
| | | | 1986 | 5 | Mesquite Soil Cores: Surface Soil Microarthropods (Taxonomy and abundance at 2 depths) | 72 |
| | | | 1986 | 4 | Mesquite Soil Cores: Surface Soil Nematodes (Abundance by guild) | 62 |
| | | | 1986 | 4 | Mesquite Soil Cores: Surface Soil Nutrients (Soil nutrients, root biomass, & minteralization potential) | 43 |
| | | | 1986 | 4 | Mesquite Soil Cores: Surface Soil Canopy Position Nutrients (Soil N concentrations under shrubs) | 47 |
| | Transect Root Decomposition | Anderson (Mun) | 1986-1990 | 2,4 | Root chemistry (Concentrations of tannin, lignin, carbohydrates, N, H2O & acid solubles, non-polar substance) | 32 |
| | | | 1986-1990 | 2,4 | Root chemistry raw data (Concentrations of tannin, lignin, carbohydrates, N, H2O & acid solubles, non-polar substance) | 38 |
| | | | 1986-1990 | 2 | Root weight (Initial and remaining weight) | 42 |
| | Ammonia Volatilization | Anderson (Schlesinger) | 1988 | 4 | Nitrogen volatilized as ammonia -- 1988 | 88 |
| | | | 1989 | 4 | Nitrogen volatilized as ammonia -- 1989 | 43 |
| | Plant Nutrient Distribution In Long-Term NPP Plots | Anderson (Virginia) | 1989-1990 | 1,4 | Plant nutrient distribution beneath and between plant canopies in mesquite, grassland, playa, creosotebush, and tarbush communities (Total N & P) | 43 |
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[1] Study name.

[2] Core Areas: 1) primary production; 2) organic matter accumulation in surface layers; 3) disturbances; 4) inorganic inputs and movements of nutrients through soils; 5) populations selected to represent trophic structure

[3] Datasets continue to be added to online catalog

[4] Number of times a data file associated with a dataset was accessed online from Jan 2007 – Dec 2011.

There is an approximately 13 month gap (21.6%) in access logs (07/2010 - 08/2011) resulting from server migration in 2010. Numbers have been adjusted to excluded website crawlers (autoharvesting robots), which usually increased numbers 10 fold.
Link to Data web access statistics by domain, data type, and core area

[5] Number of times a data file associated with a dataset was requested from the information management team from 11/01/2006 - 1/31/2012.

[6] Short-term studies are not cited.

* Access via PI is not tracked by the JRN information management team.

** Table with hotlinks available at http://jornada-www.nmsu.edu/renewal_2012/A-Suppl_TableA1.pdf