PROJECT PLAN
NP216 – Sustainable Agricultural Systems Research
February 2019 – January 2024

Old Research Project Number
3050-11210-008-00D

Management Research Unit
Range Management Research Unit

Location
Las Cruces, New Mexico

Title
Science and Technologies for the Sustainable Management of Western Rangeland Systems

Scientists
Richard D. Estell, Lead......... 1.0
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Albert Rango 1.0
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Vacant (Soil Science) 1.0
Vacant (Ecology)……………. 1.0

Total Scientific Staff Years
9.0

Planned Duration
60 months

Post-Peer Review Signature Page

Estell, Richard E., 3050-11210-008D, NP 216
Science and Technologies for the Sustainable Management of Western Rangeland Systems

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.

Richard Estell /s/ 08/20/2018
Research Leader Date

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.

Brandon T. Bestelmeyer /s/ 08/20/2018
Center, Institute or Lab 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

For labs that have a 3-tier organization structure (vs. the 4-tier organization this is implied on the signature page), you may combine the first and second signature block. If you lab uses a different title for the Research Leader or Center Director, you may edit the title lines accordingly.

PrePlan Signature Page for ONP Validation(s)

Pre-Peer Review

Estell, Richard E., 3050-11210-008D, NP 216
Science and Technologies for the Sustainable Management of Western Rangeland Systems

❑ Signature Page completed for Research Leader through Area Director

x 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.

__Ray Bryant /s/______________________________ ___3/15/18_________
Acting National Program Leader Date

Comments:

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PROJECT SUMMARY

The mission of the Range Management Research Unit, based at the Jornada Experimental Range (the Jornada), is to develop and transfer science-based approaches for sustainability of agriculture and other land uses in rangelands of the Western U.S. The core problem we address is: **How to improve agricultural production while simultaneously sustaining or improving the natural resource base and other ecosystem services that this base supports**. Our multidisciplinary group of scientists will develop solutions to this problem that can be applied at different spatial scales, including the Southwest U.S., Western U.S. rangelands, global drylands, or all global agroecosystems. In this 5-year cycle, we will use site-based research, new computational tools, and network leadership to 1) increase the resilience of livestock production systems via a heritage cattle biotype and improved restoration decisions; 2) develop novel approaches to spatial predictive modeling of ecological state change, wind erosion, and disease dynamics; 3) produce new tools and approaches for land assessment, monitoring, and interpretation to support decision-making; and 4) increase availability of science-based knowledge on agricultural options, climate adaptation, and land health via web and mobile applications, stakeholder interactions, and K-12 education programs. Our broad array of customers will have access to alternative cattle genetics, new models and analytical tools, and new site-specific information sources that advance sustainable intensification of agriculture in Western rangelands and beyond.

OBJECTIVES

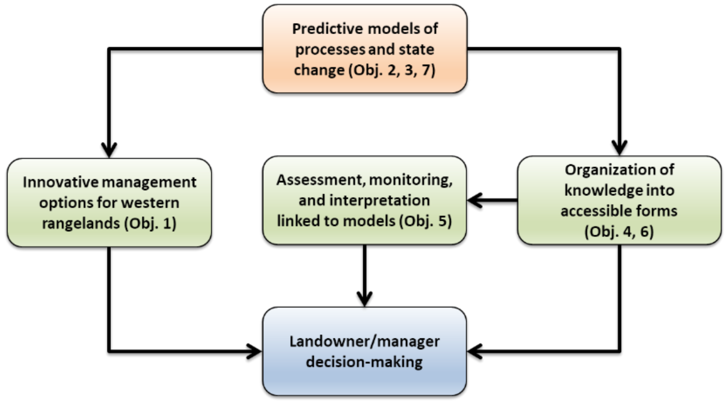

Figure 1. Relationships among key themes and associated objectives. Science and predictive models (orange) lead to new knowledge and tools (green) that can improve decisions (blue)

Our research framework is centered on providing the knowledge needed for decision-making in extensive rangeland agroecosystems, used primarily for beef cattle ranching alongside a variety of other uses (Fig. 1). Such systems occupy 31% (308 million ha) of the land area of the U.S. and occur largely in western arid to semiarid regions (Havstad et al. 2009). Multi-faceted science support and datasets (Fig. 2) are critical in arid rangelands because they are prone to highly uneven "nonlinear" responses to weather and management actions and because management decisions apply to broad spatial scales (100-100,000 ha), encompassing high degrees of spatial heterogeneity (Peters et al. 2006, 2015). Consequently, it is difficult for land managers to perceive important patterns that form the basis for decisions. In order to detect patterns and ascribe causation, sampling and experiments must be conducted over long timeframes, over broad spatial extents, with high attention to spatial and temporal context. Field sampling must be guided by and interpreted with respect to spatial data on climate, soils, and land use; it must be supplemented by models and remotely-sensed data; and advanced statistical approaches are needed to disentangle causation (Peters et al. 2014a). A clear knowledge of causation is needed to avoid decisions that waste limited resources or that place ecosystems onto undesired trajectories of change. Transfer and co-development of knowledge with producers must also be location- and process-specific, necessitating technological innovations to make such interactions possible (Herrick et al. 2016). Finally, ranches in Western rangelands include a mix of privately- and publicly-owned land, such that ranch sustainability relies not only on producer decisions on private land, but also on policies, perceptions, and agency decisions on surrounding public lands (Brunson and Huntsinger 2008). This requires the development and use of collaborative approaches (Wilmer et al. 2017, Allen et al. 2017). Over the past funding periods, we have

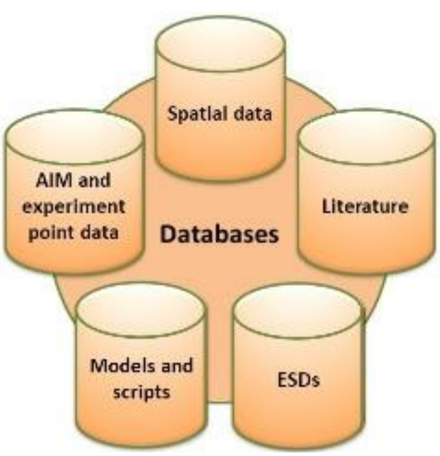

Figure 2. Interlinked databases emphasized in this project plan that create the foundation for decision-support. AIM = assessment, inventory, and monitoring data. ESD = Ecological Site Descriptions.

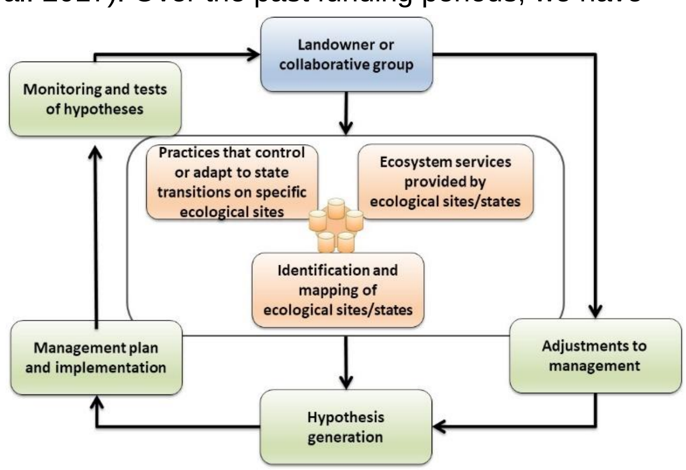

Figure 3. Resilience-based management framework in which our work is applied. The blue and green boxes reflect traditional adaptive management; the orange boxes indicate the data and tools we work with to support adaptive management.

refined strategies for the integration of diverse datasets to address complex science problems (Peters et al. 2014) alongside science-based collaborative adaptive management approaches (Herrick et al. 2006a, Bestelmeyer and Briske 2012). We have sought to improve adaptive management by linking data and information about successful management practices and ecosystem processes/services of interest to specific land areas via maps of land potential (ecological sites) and rangeland condition (ecological states; Fig. 3). We will build upon this framework in the upcoming funding cycle.

Some elements of our research will be most applicable to the desert grassland region surrounding our primary research site, the Jornada Experimental Range (JER). Other elements will be applicable to the Southwest U.S., Western U.S. rangelands, global drylands, or all global agroecosystems (Table 1). Our research program has historically been linked to National Program (NP) #215 (Pasture, Forage, and Rangeland Systems), reflecting our previous exclusive emphasis on rangeland ecology and management. Effective in 2016, our program was transferred to NP #216 (Sustainable Agricultural Systems Research), reflecting a progression of our research toward systems-level approaches that can be applied broadly to U.S. agriculture. In addition, our inclusion as a Long-Term Agroecosystem Research site in 2012 has led to collaborations with research sites involved in cropland, pastureland, and rangeland research. In this regard, our goal is to harness science and technology that not only solve problems in Western rangelands, but can be applied to other agroecosystems.

Subobj.	Topic	Scale of applicability	Principal customers
1A	Criollo production	Western U.S.	Ranchers
1B	Grassland restoration	Southwest U.S.	Action agencies, ranchers
2A	Big data/vesicular stomatitis virus	National/Western U.S.	USDA/APHIS, horse owners
2B	Wind erosion research network	National	Scientists, policymakers
3A	Spatial models of state change	Southwest U.S./global drylands	Scientists, local ranchers and agencies
3B	Phenological monitoring	Southwest U.S./global drylands	Scientists, local ranchers and agencies
4	Ecological Site Description database	National	NRCS and their customers
5A	Assessment/monitoring methods	National/International	NRCS, BLM, rancher cooperatives, foreign governments
5B	Land Potential Knowledge System	National/International	Public, agencies
6	Southwest Climate Hub	Southwest U.S.	Producers, agencies, public
7	LTAR network contributions	National	Scientists, USDA, policymakers

Table 1. Summary of subobjectives, scale(s) of applicability, and customers.

During the next five years we will focus on the following objectives and subobjectives that advance the scientific and technological underpinnings of sustainable management:

Objective 1: Develop or improve livestock management and restoration practices to promote resilience to climate variability and adaptation to increasingly shrub-dominated environments.

- **Subobjective 1A:** Compare productivity and environmental impacts of Raramuri Criollo cattle to conventional livestock production systems in the arid Southwest (part of LTAR Common Experiment; Estell, Vacant Range Specialist, Browning).

- **Subobjective 1B:** Develop collaborative science approaches to test the efficacy of practices to recover and sustain perennial grass cover in the desert grassland region (Bestelmeyer, Vacant Range Specialist, Herrick).

Objective 2: Leveraging temporal and spatial datasets from the Jornada and surrounding region, design and implement big data-model integration approaches to predict and/or resolve disease outbreaks and other regional agricultural problems.

- **Subobjective 2A:** Develop a strategy and operational framework for agricultural Grand Challenges that require big data and trans-disciplinary scientific expertise based on spatio-temporal modeling of cross-scale interactions and interactive machine learning (Peters, Vacant Soil Science, Bestelmeyer).

- **Subobjective 2B:** Develop national wind erosion assessments using big data and models developed through the National Wind Erosion Research Network. (Herrick, Vacant Soil Science)

Objective 3: Improve understanding of ecological state change in the desert grassland region through synthesis and analysis of long-term climate, vegetation, and livestock data, alongside numerous ongoing short- and long-term experiments, including how gradual and abrupt transitions occur in rangeland agroecosystems and how they can be managed.

- **Subobjective 3A:** Predict alternative states in Western rangelands by integrating multiple lines of evidence including spatiotemporal modeling (Peters, Bestelmeyer, Vacant Soil Science).

- **Subobjective 3B**: Formulate phenological indicators of gradual and abrupt changes in primary production using integration of remotely-sensed imagery and ground-based observations (Browning, Peters).

Objective 4: Complete development of a new database to improve quality, accessibility, and utility of Ecological Site Description (ESD) information nationwide, and collaborate with NRCS to complete national population of ESD information (Bestelmeyer, Herrick, Vacant Soil Science, Vacant Ecology).

Objective 5: Develop tools and techniques for managing and integrating ground-based assessment and monitoring data, remotely sensed and digital spatial data, and connect data to interpretive frameworks and models to develop actionable interpretations for land management.

- **Subobjective 5A:** Develop tools and techniques for managing and integrating ground-based assessment and monitoring data, remotely sensed and digital spatial data, and connect data to interpretive frameworks and models to develop actionable interpretations for land management (Herrick, Bestelmeyer, Vacant Ecology).

- **Subobjective 5B:** Develop, test, and facilitate adoption of a data collection and decision support system that increases land manager ability to monitor their land, and to access, evaluate, integrate and apply local and scientific knowledge (Herrick, Vacant Ecology)

Objective 6: Develop new tools and information to assist agricultural stakeholders in coping with climate variability through: research, science translation and information synthesis; tool development and technology transfer; and stakeholder outreach and education (Southwest Regional Climate Hub; Rango (Elias), Browning, Vacant Soil Science).

Objective 7: Operate and maintain the Jornada Experimental Range LTAR network site using technologies and practices agreed upon by the LTAR leadership. Contribute to the LTAR working groups and common experiments as resources allow. Submit relevant data with appropriate metadata to the LTAR Information Ecosystem. (Bestelmeyer, Estell, Peters, Browning, Herrick, Vacant Range Specialist, Vacant Ecology, Vacant Soil Science, Rango).

NEED FOR RESEARCH

Description of the problem to be solved

Input from our diverse customer base and interactions with National Program staff in 2017 encouraged us to develop new strategies to improve livestock production and rangeland restoration success, improve the accessibility and utility of information about rangeland conditions and climate, and develop new approaches to gain scientific insights from monitoring and big data in agricultural systems. The central problem reflected in these interests is: **How to improve agricultural production while simultaneously sustaining or improving the natural resource base and other ecosystem services that this base supports.** This problem has been codified as the overarching Grand Challenge within ARS, and reflects the preeminent challenge for the sustainable intensification of agriculture globally (Robertson and Swinton 2005, Hunter et al. 2017, Rockström et al. 2017). In extensive rangeland systems, demands for ecosystem services are especially diverse, including livestock production, recreation, wildlife habitat, and regulation of air and water quality (Havstad et al. 2007, Yahdjian et al. 2015). Improvements to production and other ecosystem services are limited, however, by legacies of historical land degradation that have proven difficult to reverse (Estell et al. 2012, DiTomaso et al. 2017) and inherent limitations in land potential due to soils and climate (Liebig et al. 2017). Projected climate change (Havstad et al. 2016) and accelerating conversion of rangelands to other land uses (Bestelmeyer et al. 2015) will limit management options even further. Thus, solving the Grand Challenge problem in rangelands requires a multi-faceted approach including 1) new strategies to increase the profitability of livestock production in altered environments, 2) more effective approaches to restore grass cover in degraded ecological states, 3) a spatially-explicit, predictive understanding of changes in ecosystem processes, and 4) technologies that assist managers in targeting decisions to locations and times where they will be most effective.

Relevance to ARS National Program Action Plan

Objectives of the proposed project plan align with several ARS initiatives. With regard to the NP #216 Action Plan, our proposed research on Criollo cattle and restoration (Objective 1) and predictions to enable management of ecological change in rangelands (Objective 3) link primarily to Problem 1b (Sustainable and resilient grazing land systems). Objective 1, in particular, adopts a full Genetics (G) x Environment (E) x Management (M) perspective (Hatfield and Walthall 2015) in quantifying how distinct cattle biotypes (G) interact with and affect the environment (E) and how sustainable management (M) and its costs vary in different GxE combinations. Proposed work to improve assessment and monitoring technologies (Objective 5) link primarily to Problem 2b (Technologies to enhance efficiency) and 2c (Decision support to enhance efficiency). Big data approaches to agricultural problems (Objective 2), improvements to Ecological Site Descriptions (Objective 4), and Southwest Climate Hub synthesis activities (Objective 6) link primarily to Problem 3b (Enhancing ecosystem services) and 3c (Enabling decision support for sustainability). There are, however, numerous connections among individual objectives and multiple NP 216 problem statements. Our overall approach reflects NP 216's whole-system approach (e.g., livestock, other ecosystem services, environment, and decision-makers) to achieving production, environment, and quality-of-life goals for rural communities.

In addition, Objective 2A (big data analytical frameworks) was designated in 2017 as one of two ARS Grand Challenge projects by the Administrator. Finally, Objective 7 addresses Problem 1d (operation and network activities of the Jornada Long-Term Agroecosystem Research site; LTAR) and Objective 2B (national wind erosion assessments) also contributes to LTAR via network-level contributions.

Potential benefits

There are several specific, long-term benefits of the proposed research. First, ranchers in shrub-dominated, arid environments throughout the Western U.S. will have the option to use an alternative cattle biotype in their operations and the information needed to make this choice. Second, private and public land managers will have new information for targeting grass restoration treatments to maximize efficiency and effectiveness and achieve forage production potential. Third, scientists and policymakers will have new approaches to big data analysis for a wide array of agricultural problems and a capacity to generate wind erosion estimates for a range of spatial scales. Fourth, land managers and policymakers will have new tools to interpret land condition and climate information to inform sustainable, adaptive decision-making. Finally, long-term, standardized data and models from our LTAR site will be available to the science community, including other LTAR sites, and a variety of LTAR network-level products will provide national-level perspectives to policymakers on a range of agricultural issues.

Anticipated products

Products will include 1) published papers that document a) evidence of the effectiveness of management options to the public and b) new approaches for, and insights from, analysis of complex datasets for scientists, 2) an improved and calibrated numerical wind erosion model, 3) a new database to house ecological site information at the national level, 4) new mobile applications to aid in land use decisions at national and global levels, 5) web-based tools and materials to support climate-informed decisions, 6) datasets and improved models available to the scientific community, and 7) derivative scientific materials and strategies for K-12 education.

Customers of research

Because our research program addresses both production and environmental concerns at a variety of spatial scales (Table 1), our customers are highly diverse, including livestock producers and other members of the interested public, federal agency and non-governmental organization staff at local to national levels, other scientists, international aid organizations, foreign governments, and K-12 students and their teachers. We interact with our focal customers via numerous cooperative agreements (Appendix 3) that largely guide our research activities.

SCIENTIFIC BACKGROUND

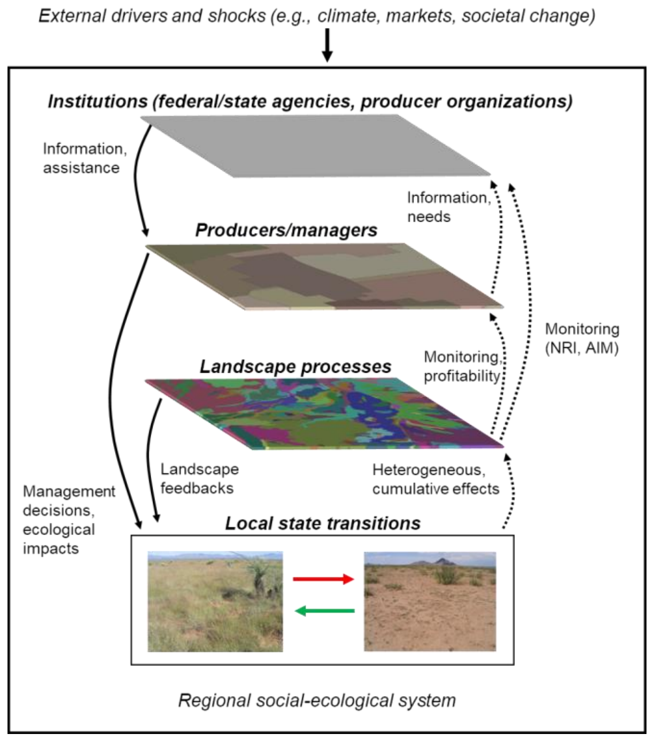

Figure 4. Cross-scale interactions in a social-ecological model. Effects from broader scales of the hierarchy (solid arrows) elicit consequences and feedbacks from finer scales and back again from broad scales (dashed arrows). Global drivers (top) come from outside of the social-ecological system and can affect any level of the hierarchy.

The primary focus of agroecosystem science (and NP #216) is to promote the sustainability of agricultural systems. In this context, sustainability refers to the long-term ability of agroecosystems to meet production, environmental, and human welfare goals simultaneously. The emerging science of resilience emphasizes four concepts that indicate the knowledge, strategies, and tools needed to achieve sustainability (Walker and Salt 2006). The first concept is ***an expansive view of agricultural systems as "social-ecological systems"*** (SESs) comprising social and biophysical elements of a landscape and the feedbacks among them (Fischer et al. 2015; Fig. 4). Science cannot promote sustainability if explicit attention is not paid to these feedbacks. Second is the recognition that ***SESs can undergo relatively abrupt transitions*** in response to changing external drivers and shocks due to amplifying feedbacks within the SES. Such transitions are cross-scale phenomena, involving the interactions of fine-scale ecological transitions in vegetation and soils, landscape processes affecting the rate of vegetation transitions, and broad-scale social processes such as agricultural profitability, manager and government perceptions of change, and management and policy responses (Peters et al. 2007). In order to sustain a desired SES, it must be resilient to inevitable changes in external drivers and shocks, including novel disturbances, climate change and associated extreme events, and societal change. Third, ***resilience can be promoted via adaptation and transformation***. Adaptation refers to the ability of an SES to make adjustments to prevent a transition and enhance adaptive capacity (i.e., the ability to sustain the essential features of the SES). In contrast, transformation refers to the necessity for radical changes in SES structure in order to achieve sustainability goals (Moore et al. 2014). Finally, ***co-development of science with stakeholders and accessibility of locally-relevant information*** (i.e. translational science) is increasingly recognized as a prerequisite for the effective use of science in implementing adaptation or transformation strategies (Enquist et al. 2017).

In the light of these concepts, our strategy to promote sustainability in Western rangelands involves four interlinked approaches for managing resilience (Fig. 1):

1) Develop a mechanistic and predictive understanding of how transitions occur in ecological and social-ecological systems, including transitions that are undesirable (degradation, community collapse) and desirable (restoration, sustainability transformations; Objectives 2, 3, 7).

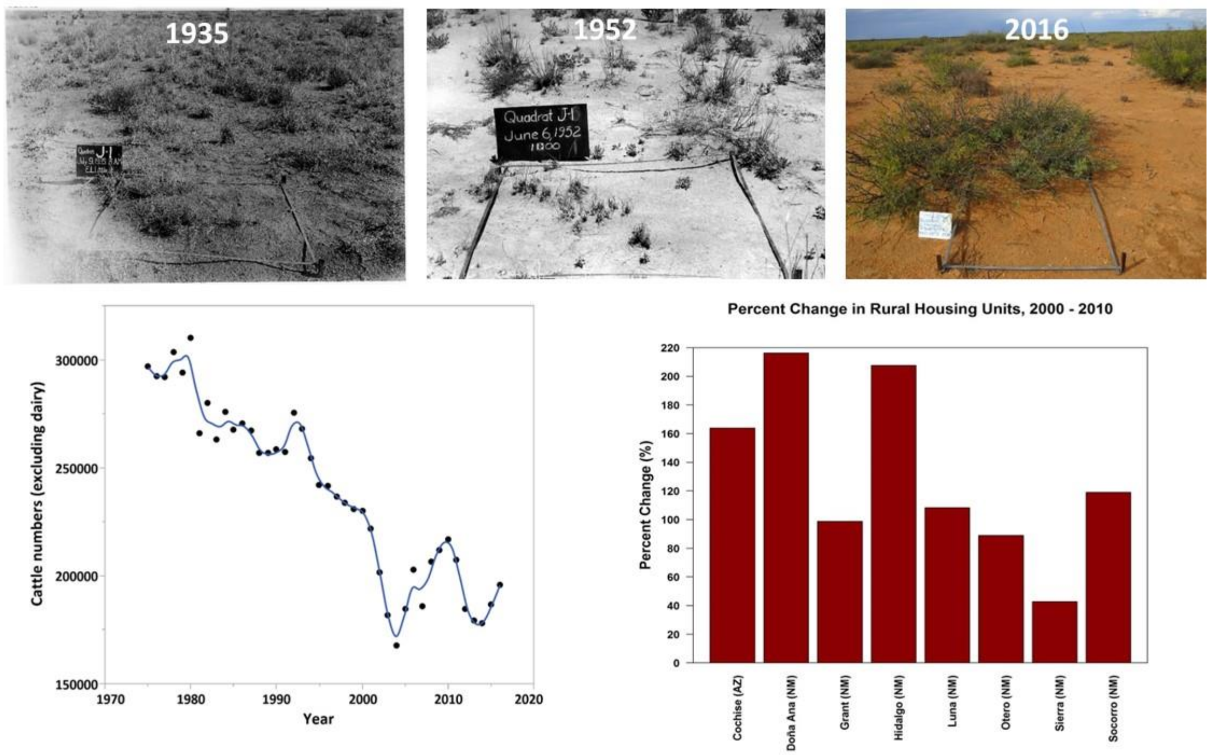

Figure 5. Top: changes in vegetation from *Bouteloua eriopoda* grassland to *Prosopis glandulosa* shrubland recorded in long-term quadrat data. Bottom left: Cattle numbers in southwest NM counties over time, fit with a smoother. Bottom right; Changes in rural housing units in southwest NM counties and SE Arizona.

2) Develop tools for measuring progress toward or away from particular transitions (i.e. changes in resilience; Objective 5).

3) Develop and test innovative strategies for adaptation and transformation (Objective 1).

4) Organize knowledge to assist stakeholders in understanding and executing adaptation/transformation strategies of interest (Objectives 4, 6).

Efforts to promote the sustainability of Western rangelands began over a century ago and continually evolve alongside social and ecological change. The JER was established in 1912 in order to develop approaches to remedy widespread rangeland degradation across the American Southwest at the end of the 19th century. The research that followed, conducted within the U.S. Forest Service (USFS) beginning in 1915, then within ARS upon its founding in 1952, and then in collaboration with the National Science Foundation-funded Jornada Basin Long-Term Ecological Research (LTER) Program starting in 1982, improved livestock management practices and our understanding of ecosystem change. A key discovery is that arid to semiarid agroecosystems of the Southwestern U.S. are undergoing substantial and irreversible changes, under control of several interacting drivers at multiple scales of space and time (Peters et al., 2015). Following early episodes of severe overgrazing and drought, the once predominant perennial grasslands have been replaced by shrublands in most areas (Fig. 5). Landscape-level positive feedbacks cause the continued expansion of shrublands even when grazing is well managed. Spatial heterogeneity in soils and climate, however, strongly mediate ecosystem trajectories, such that the rate of shrub expansion and grass loss varies substantially across the landscape, pointing to potential restoration priorities (Browning et al. 2012). Nonetheless, increasing inter-annual variation in precipitation has been demonstrated to promote increasing shrub dominance at the regional scale (Gherardi and Sala 2015). Transitions from grassland to shrubland, paralleled by societal and technological changes, have caused shifts in agricultural production, other ecosystem services, and rural communities (Peters et al. 2015). Regional beef production has declined, and continues to decline in recent decades (Fig. 5). The value of ranches, and the incomes of people managing them, are increasingly decoupled from livestock production (Torell et al. 2005). Alternative uses of rangelands are increasing, particularly exurban/energy development and recreation (Yahdjian et al. 2015). Even though stocking rates have declined compared with the beginning of the 20th century, grassland recovery has been limited or absent in many areas. Where grass recovery has been limited, ongoing shrub encroachment, soil erosion, and biodiversity loss affect a variety of ecosystem services including forage provision, air quality, hunting, and other recreational opportunities (Estell et al. 2012). Rural livelihoods are becoming more challenging in Southwestern rangelands, as they are in most U.S. agroecosystems. Below, we describe how our next phase of research will provide solutions to these challenges.

Objective 1. Livestock management and restoration practices for altered landscapes. Our first objective focuses on two complementary subobjectives to improve rural sustainability in arid rangelands: a) increase resilience of livestock production systems via alternative genetics, specifically the Raramuri Criollo biotype and b) develop new options for restoration and improve the outcomes of ongoing restoration strategies. This objective comprises our contribution to the Common Experiment of the LTAR network (see Objective 7 below).

Criollo cattle were introduced to the New World from the Andalusia region of southern Spain by Christopher Columbus (Rodero et al. 1992) before 1500, and to New Mexico before 1600 (Rouse 1977). Although many of these original genetics have been diluted through crossbreeding with other breeds, a few pockets of Criollo have remained isolated in specific areas of Mexico without the influence of crossbreeding (Ulloa-Arvizu et al. 2008). In some cases, these geographically isolated groups of cattle evolved for nearly 500 years under natural selection that resulted in unique biotypes (McTavish et al. 2013). One such isolated group of Criollo that has undergone many generations of adaptation to harsh conditions and poor nutrition with minimal intervention is the Raramuri biotype from the Copper Canyon in Mexico (D. Anderson et al. 2015).

Although Raramuri Criollo (RC) are considered to be well adapted to areas with scarce forage and water resources, research on this biotype is extremely limited. The Jornada established a research herd to characterize the attributes of this biotype and their productivity on extensive shrub-dominated arid rangelands. These small framed cows purportedly have a number of attributes that may make them more suited to desert conditions and a better fit for these fragile landscapes than larger breeds of mixed European ancestry introduced in the last 100 years that are typically raised in the southwestern U.S. Anecdotal reports and preliminary findings suggest that in comparison to conventional beef breeds, RC may require fewer inputs (e.g. supplemental feed; Diaz et al. 2015), and exhibit different diet selection patterns and use of vegetation types (Nyamuryekung'e et al. 2016; Spiegal et al. 2017b) and distribution patterns (e.g. travel per day and distance from water; Peinetti et al. 2011; Spiegal et al. 2017a) under extensive management. Preliminary data from an ongoing three-year diet study suggest that Hereford x Angus crossbreds (HA) and RC cows not only use the landscape differently but also consume different plant species (Fig. 6). Criollo also foraged in a much larger area and travelled further from water than HA in periods when forage availability was low and not uniformly distributed. Also, preliminary observations suggest RC cows are more heat tolerant than their HA counterparts; during the hottest hours of the day, Criollo cows moved farther and faster and spent less time near water than HA (Nyamuryekung'e et al. 2017).

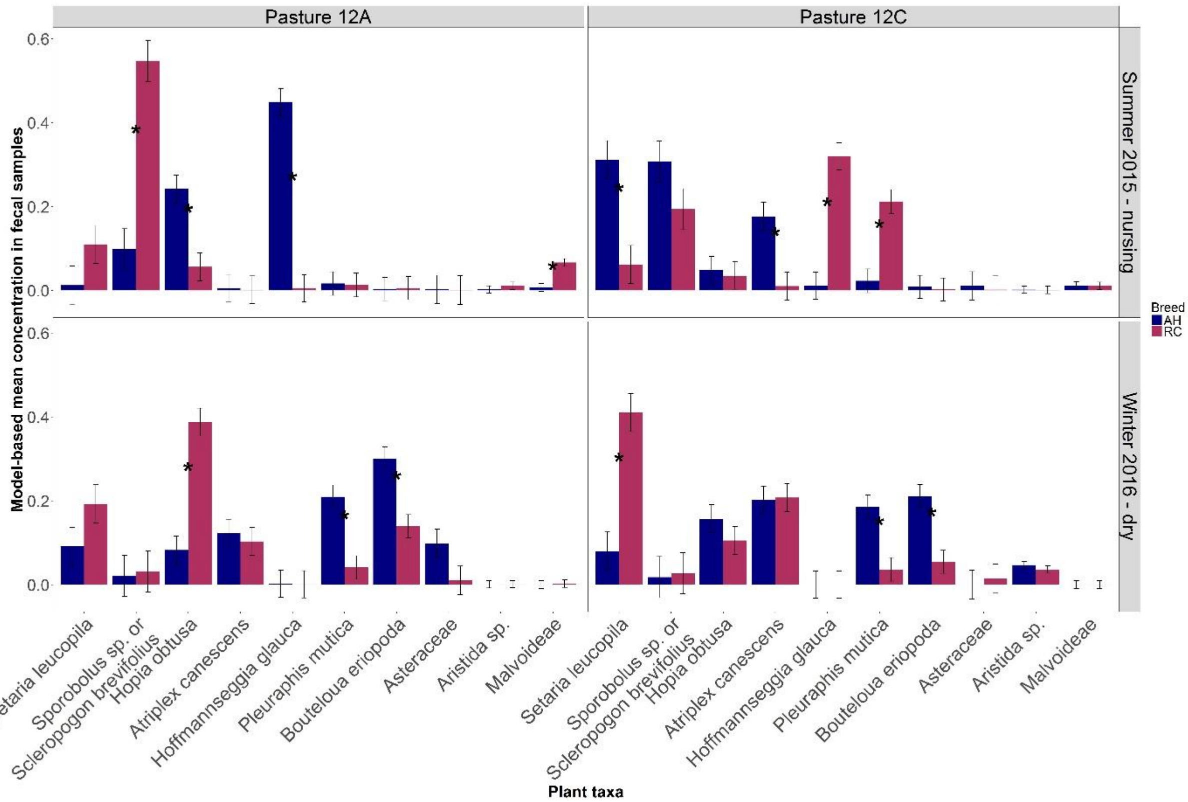

Figure 6. Fecal DNA concentrations in diets of Angus x Hereford crossbred (AH) and Raramuri Criollo (RC) cows grazing Chihuahuan Desert pastures in summer (nursing) and winter (dry) of the 2015/16 season.

Collectively, these results suggest RC may be a better fit for harsh shrubby environments than conventional beef breeds because they exhibit behaviors and traits (use larger areas, travel greater distances, spend less time in a given area, move further from water, have a smaller frame size) that result in lower impact on a given area, particularly during drought periods when vegetation and soils are most vulnerable. Although our preliminary results suggest reduced input costs and a lower environmental footprint for desert beef production with this biotype, the impacts of this biotype on the landscape have not yet been evaluated.

A second approach for adapting to shrub-dominated environments is to use restoration actions to increase the cover of perennial grasses. Increasing perennial grass cover in arid rangelands positively affects numerous ecosystem services, including forage production, species habitat, and soil stabilization. We will conduct continuing and new research to maximize the benefits of grass restoration investments and discover new restoration approaches. For decades, brush (shrub) management with targeted herbicides (e.g. tebuthiuron, clopyralid, triclopyr) has been the primary means to increase grass cover, and these treatments have been applied to over 800,000 ha of public and private rangelands surrounding in southwestern NM (Bureau of Land Management data). Modern herbicides are highly effective in killing certain widespread shrub species. Shrub death reduces competition with grasses for surface soil water, thus potentially enabling increased grass recruitment and production (Archer et al. 2017). There are, however, instances in which grasses do not recover following brush management, potentially resulting in additional losses of ecosystem services and increased wind erosion (Brock et al. 2014). Lack of grass response is may be due to surface soil degradation, an absence of source plants/seeds,

Figure 7. An eroding *P. glandulosa* duneland area in 2006 and in 2009 after a rare grass establishment event.

and post-treatment grazing practices. The circumstances leading to restoration success or failure have not been systematically examined. Our goal is to identify climatic, soil profiles, and initial ecological characteristics (e.g., remnant plant cover, soil crusts), that are associated with restoration success in order to more efficiently target brush management actions.

Range seeding is often ineffective in arid (< 250 mm mean annual rainfall) rangelands, and can be of limited effectiveness even in semi-arid climates (James et al. 2011). Past Jornada research highlights the limitations of this restoration approach, often associated with soil degradation (Herrick et al. 2006b). In spite of these failures, our long-term monitoring revealed that natural, extreme climate events can catalyze rapid and sustained restoration of perennial grass cover (Peters et al. 2014b; Fig. 7). A sequence of high precipitation years beginning in 2006 led to widespread (but spatially variable) recruitment of perennial grasses in areas that were devoid of grasses for decades and that were, therefore, not used for grazing. These new grass populations have persisted until the present time and appear to be self-sustaining under average and dry rainfall conditions, even with grazing use (that is now possible due to grass recovery). Therefore, this event constitutes a classical state change, but in this case a desirable one. Although forecast long-term increases in interannual climate variability may favor shrubs over grasses (Gherardi and Sala 2015), we hypothesize that it is possible to take advantage of extreme rainfall years for grass restoration within shrublands. We will initiate a new project to 1) understand the causes of spatial variation in grass recruitment, 2) quantify the consequences of the recruitment for ecosystem services (including cover, soil health, and effects on wind erosion), and 3) develop restoration strategies to increase the range of environments where recruitment occurs.

Objective 2. Big data-model integration. A mechanistic, predictive understanding of agroecosystem change at landscape to regional scales—in Western rangelands and all other US agroecosystems—will require transdisciplinary research that exploits “big data”. Such approaches integrate multiple disciplines and capitalize on advances in sensors, software, and other infrastructure. Data on biological and physical processes, environmental properties, locations, and time steps are now more available than at any time in history (e.g. Hampton et al. 2013, Michener 2015). Data are available from individual research sites, organized networks of sites (e.g. U.S. Long Term Ecological Research Program, Robertson et al. 2012; U.S. Long Term Agroecosystem Research Program, Moran et al. 2008), from online data repositories (summarized in Michener 2015), and directly from many government and non-governmental sources. In addition, advances in software, hardware, and mindsets are allowing researchers access to big data through sharing and analytics (Hampton et al. 2015; White et al. 2015).

An operational framework for transdisciplinary science is critically needed to allow integration of these large sources and diverse types of data and knowledge (Peters 2010). Conceptual frameworks for model-data fusion have been proposed for complex systems, such as vector-borne diseases (LaDeau et al. 2011), but there is an urgent need for a general operational approach to integrate existing data and understanding about processes to inform the strategic collection of new data, to develop testable hypotheses, and to make predictions about future conditions (NASEM 2016; LaDeau et al. 2017).

As part of the ARS Grand Challenge theme, we will develop a systematic approach to big data-model integration that can be applied to an array of multi-scale, complex agroecological problems. Our strategy and operational approach will first be applied and refined via a collaborative study on vesicular stomatitis (VS), a vector-borne, zoonotic RNA virus (VSV) that commonly affects livestock. Explanations for VSV occurrence patterns, however, remain unknown. Because the disease is clinically indistinguishable from Foot-and-Mouth Disease (FMD), one of the most devastating exotic diseases in livestock that was eradicated from the U.S. in 1926, VS infections in the US lead to animal quarantines at the county level with subsequent effects on the livestock, horse show, and horse racing industry, and trade embargos resulting in economic losses (Bridges et al. 1997). VSV is endemic to southern Mexico (Rodriguez et al. 2000) where outbreaks occur yearly that are caused by multiple viral genetic lineages (Arroyo et al. 2011). Spatial patterns of disease in the Western U.S. have been related to one or a few biophysical and climatic factors (Rodriguez et al. 1996, McCluskey et al. 2003); however an analysis of all possible factors across the spatial extent and temporal domain of the disease has not been conducted. VS is the most commonly reported vesicular disease in livestock in the Americas (Rodriguez 2002), and occurred over >1.1 M km^2 of the Western U.S. from 2004-2016. VS occurrence is expected to be a function of the biology and genetics of multiple vectors and hosts as well as effects of climate, soil, hydrology, and vegetation, each operating at different spatio-temporal scales. Thus, the VS system requires an approach that integrates: a) trans-disciplinary scientific expertise, b) very large, heterogeneous databases, and c) technical expertise for data harmonization and analysis.

We will also apply a big data-model integration approach to another problem: modelling wind erosion and dust emissions at regional to national levels. Wind erosion associated with loss of vegetation cover is one of the most important consequences of state transitions in Western rangelands and other drylands, contributing to soil degradation that reduces productivity and increases air quality-associated health problems in adjacent urban areas (Field et al. 2010). Nonetheless, there is large uncertainty about where, when, and how much wind erosion is occurring across the U.S. Managing and planning for the impacts of wind erosion requires an understanding of fundamental sediment transport processes and their interactions within agroecosystems. A scientific foundation has been developed from experimental research (Zobeck et al. 2013), and through models of dust interactions with biogeochemical cycles and the climate system (Shao et al. 2011). Application of this understanding requires that knowledge of aeolian processes can be reliably up-scaled to represent the many dynamic interactions within fields, across regions, and nationally. Yet, integrating observations and modeling to inform management and policy has been limited by a number of factors. Experiments and monitoring have typically been conducted using non-standard methods and sampling designs that lack statistical rigor. This has limited the utility of data to be compared across scales and systems. Numerical models have been developed to overcome these measurement challenges; however, available models have had limited spatial application in the U.S., have been unable to predict the impacts of land use change, particularly in rangelands, and their uncertainties have not been quantified (Webb et al. 2016). New models, and data to support their development, are needed to support wind erosion management and policy options.

In 2014, the Jornada led the establishment of a multi-partner National Wind Erosion Research Network (Webb et al. 2016; see https://winderosionnetwork.org). The objectives of the Network are to: 1) produce big data to support research into wind erosion processes across agroecosystems; 2) support development and application of wind erosion models to inform management of public and private lands; and 3) facilitate collaboration among existing rangeland, pastureland, and air quality monitoring networks operated by several government agencies to further the science and its application to management (Webb et al. 2017). This research fills a key information gap by developing a more accurate and generalizable, process-based wind erosion model and linking it to widely-available vegetation and soil surface monitoring data to produce scalable estimates of wind erosion rates and sediment flux as affected by land management. The Network currently consists of 15 sites (10 operational as of December 2017), including seven LTAR network sites and an additional three ARS units. Network data are collected following a standard methods protocol developed by the Jornada and are consistent with established protocols adopted nationally by the Bureau of Land Management (BLM) and Natural Resources Conservation Service (NRCS). The data consistency ensures that Network research products are compatible with data collected by existing monitoring programs to assess land health and land potential, currently estimated to include 50,000 sites (Toevs et al. 2011; see Objective 5A), and wind erosion models produced by the Network will have direct and scalable applications across U.S. public and private lands. This subobjective will support expansion of the National Wind Erosion Research Network and implementation of its standardized data collection protocols to support basic research into wind erosion processes across U.S. agroecosystems and apply numerical wind erosion models to improve understanding of national wind erosion rates and the impacts of land use and land cover change.

Objective 3. Predictive models of rangeland change. Ecological state transitions in rangeland vegetation are prevalent throughout the Western U.S. Although most studies focus on transitions from grasslands to dominance by woody plants (Archer et al. 2017) recent observations (e.g. Fig. 7) indicate that grasses can recover under some conditions (Peters et al. 2012). Shrublands can also exhibit shifts in dominance of shrub species. Grasslands or shrublands can transition to novel ecosystems dominated by exotic annual or perennial invasive species (Yu et al. 2016). Past Jornada research has demonstrated that spatial and temporal variation in state transitions are the result of 1) patch structure and spatial and temporal context interacting with 2) transport vectors (wind, water, animals) and 3) interacting environmental drivers that vary strongly over time (e.g. precipitation, temperature, human activities) that 4) influence resource redistribution across a range of scales, as mediated or constrained by 5) geomorphic and topo-edaphic features (Peters et al. 2006) with 6) significant effects on ecosystem goods and services (Havstad et al. 2007, Yahdjian et al. 2015). As yet, these factors have not been successfully integrated into a unified analytical approach. Such an approach would enhance our ability to predict and extrapolate state change dynamics across spatial and temporal scales up to and including those relevant to land management and policy.

Much of what we have learned emerges from dozens of individual long-term monitoring or experimental studies in relatively small plots or from remote sensing and repeat aerial photography studies over specific time periods within the JER and adjacent sites. While these studies indicate the operation of specific ecological processes that can be generalized to regions and, when combined with data from other sites, continental scales (e.g., Petrie et al. 2018), they are not able to generate specific predictions for unsampled areas of a landscape or unsampled time periods, which is critical for land management decisions in heterogeneous and dynamic environments (Bestelmeyer et al. 2011). In addition, similar types of experimental manipulations conducted in different locations have sometimes yielded contradictory results (e.g. Alvarez et al. 2012, Bestelmeyer et al. 2013). We will develop novel approaches to data integration in order to develop a predictive, spatially-explicit model of state change across the 78,000 ha JER by linking plot-scale data involving long-term monitoring, high-resolution spatial data on soils and topography, maps of historical management records, high resolution, long-term climate data, and remotely-sensed imagery. This modelling approach will be applicable in other research sites and in agricultural landscapes where data have been assembled for management purposes, such as ranching collaboratives (e.g. the Malpai Borderlands Group) and LTAR sites.

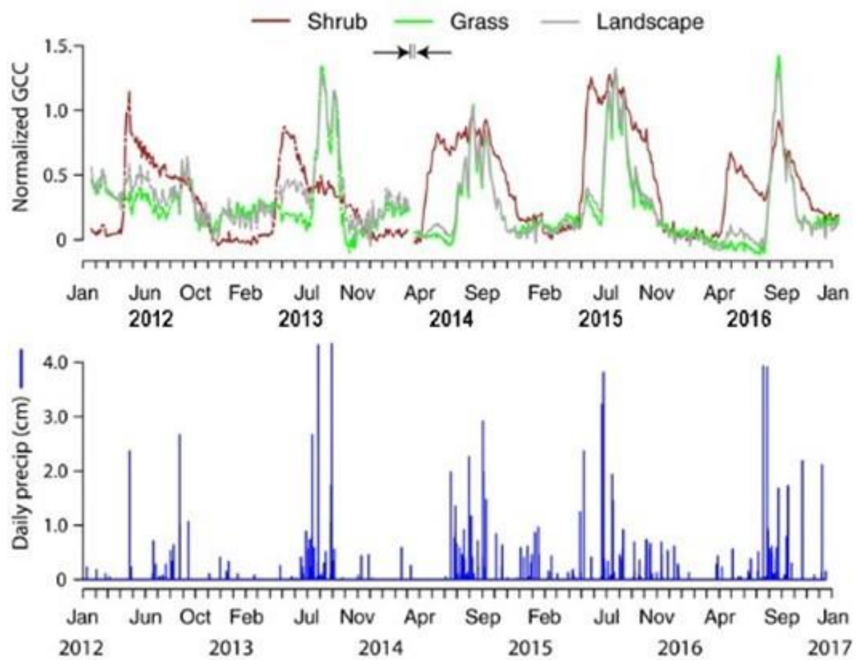

Figure 8. Top panel: Greenness curves derived from image objects identified on daily phenocam images for *B. eriopoda* (a C4 grass) and *P. glandulosa* (a C3 shrub), and a landscape containing several plant species, GCC =Green Chromatic Coordinate; Bottom panel: daily rainfall at the phenocam site.

We will also begin new research on the use of vegetation phenology to predict vegetation responses to changes in climate and soil health. Vegetation phenology is widely acknowledged as a sensitive indicator of responses to environmental conditions such as drought (that can be exacerbated by soil degradation) and temperature extremes (Cleland et al. 2007; Sherry et al. 2007; Walther et al. 2002). Phenology serves as a modulator of feedbacks between vegetation and the climate system through seasonality of albedo and fluxes of water, energy, and CO_2 (see Richardson et al. 2013). The influence of phenology on primary production via growing season dynamics (Hufkens et al. 2016), potential spread of invasive species (Morellato et al. 2016), and land-surface interactions via surface roughness and soil erosion potential (Chappell and Webb 2016) offers untapped potential for incorporating phenological metrics in management decision-making.

Much of the effort in the rapidly-growing field of phenology research has focused on identifying conditions that drive seasonal phenomena (see review in Donnelly and Yu 2017). Despite these advances, a mechanistic understanding of factors driving phenological responses of plants in water-limited ecosystems remains a knowledge gap (Primack and Miller-Rushing 2011). For example, average temperature or accumulated warming is a clear driver in the timing of first leaf and flower in a meta-analysis of 50 warming experiments in predominantly temperate regions (Wolkovich et al. 2012). In contrast, field observations of timing of first leaf from a 6-year study on the JER indicate that severe drought can stall first leaf production in perennial C4 grasses, and that interactions between rainfall and temperature may be important in rangeland agroecosystems (Browning et al. 2017b).

The development and evaluation of phenological metrics require a multi-scale approach. At the finest spatial scale, seasonal metrics include the date of start, end, and peak of growing season that offer species specificity and are based on repeated field observations of individual plants (Fig. 8). At a broader spatial scale, digital cameras mounted on towers (hereafter "phenocams") offer image data reflecting canopy development for species and functional groups. At an even broader spatial scale, moderate resolution satellite imagery offers a repeated consistent measure of land surface greenness for ecological states or communities. In order to devise informative phenological indicators for decision-making, we need to evaluate metrics across field, phenocam, and satellite platforms and establish a mechanistic understanding of the environmental drivers of phenology and primary production.

Objective 4. Ecological Site information. Ecological site descriptions (ESDs) have been characterized as the world's largest land management framework (Twidwell et al. 2013). They comprise a database and document collection used throughout the United States to provide management guidance in rangelands and, increasingly, in forests, wetlands, and croplands. ESDs are specific to fine-grained (1:12,000) land classes called "ecological sites" that differ in soil, landscape position, or climate and therefore in potential productivity and plant composition. Different ecological sites call for differences in the details of management actions such as stocking rates, restoration seed mixes, and strategies for managing soil health. These recommendations are based on long-term research and models (e.g. Objectives 1-3) and are linked to distinct ecological states (or conditions) of a site via the state-and-transition model (STM) part of ESDs. ESDs have become central tools for land management in the United States, primarily used by the NRCS, the BLM, and the USFS. ESDs are used for activities including the evaluation of rangeland health, decision support for the selection of conservation or restoration practices, communication with land managers, and stratification and interpretation of monitoring data. Past Jornada research has been instrumental in the design of ESDs, and thousands of ESDs in varying stages of completion have been created, spanning the U.S.

ESD information is currently housed and accessed primarily as text documents. The current reliance on documents for dissemination of ecological site information limits the information that can be included in STMs, updating, and ease of access. This approach also precludes use on mobile devices and linkages to other, web-based databases and tools. In the previous funding cycle, we overcame these limitations by conceiving and developing a new web-based, contributor-supported information system designed to help catalog, construct, find, and share ESDs (Bestelmeyer et al. 2016). The Ecosystem Dynamics Interpretive Tool (EDIT) provides a globally accessible environment for ESD standardization, exploration, and application, while allowing considerable flexibility in how ESDs are constructed (https://edit.jornada.nmsu.edu).

In the upcoming funding cycle, we will continue to collaborate with the NRCS Ecological Site program and New Mexico State University to expand the capabilities of EDIT and connect it to decision-making processes. First we will develop new database tables that link directly to the NRCS conservation planning process, including synthetic information on soil health indicators and indicators of other ecosystem services of interest. Second, we will develop multiple hierarchical levels of ESD information to serve distinct needs, including information at the fine-grained "ecological site level" of soil map unit components used for within-farm planning and at the "ecological site group" level of coarser land units (e.g. STATSGO soils data) for use in landscape-level planning. Third, we will accelerate population of EDIT via new training strategies for NRCS and other agency staff and iteratively update the database in light of national field efforts. We are also supporting partners in international governments (Argentina and Mongolia) in their implementation of ESD concepts and the EDIT database.

Objective 5. Monitoring, interpretation, and site-specific decision tools. High quality information is critical to empower land managers working with other stakeholders to use natural resources sustainably and achieve economic and conservation goals. Standardizing data collection across jurisdictions allows managers to work collaboratively to understand rangeland conditions at multiple scales as well as to understand drivers of changes in rangeland conditions which may span multiple ownerships. National monitoring efforts, such as the BLM Assessment, Inventory, and Monitoring (AIM) and the NRCS National Resources Inventory (NRI) programs collect standardized rangeland indicators at multiple spatial scales to provide consistent information about the condition of rangelands in the United States (Taylor et al. 2014). During the past 5 years, the Jornada has supported increasingly widespread adoption of the standardized rangeland monitoring protocols described in Herrick et al. (2017). More than 20,000 locations have been sampled over the last 5 years alone. This large dataset can now be used to inform management at multiple scales of inquiry. During the past year, the value of these data to inform policy and management has begun to be explored and demonstrated. Initial applications include understanding post-fire restoration treatment effectiveness (McCord et al. 2017), characterizing greater sage-grouse (*Centrocercus urophasianus*) habitat suitability (Stiver et al. 2015), producing preliminary national estimates of wind erosion potential (Webb et al. 2017), and understanding drought impacts on rangeland conditions (Boyte and Wylie 2016).

While these examples illustrate the potential value of these datasets, the ability of managers and policymakers to fully exploit them is limited by both current data structures and other factors. The amount of monitoring data that is now available presents new challenges for synthesis in support of decision making. New tools to support data processing, analysis and interpretation are needed to provide monitoring information to land managers and support use of these data in management decisions. Accessible visualization and web-based statistical tools are needed to assist with analyses. Data must be interpreted in the context of ecological potential via potential-relevant benchmarking approaches, such as ESDs (Karl et al. 2017).

The application of scientific information in management decision-making has increasingly relied on sophisticated Geographic Information Systems (GIS). During the past several years it is increasingly recognized that while GIS is useful for some applications, it has proved insufficient to inform decisions at specific locations. Furthermore, much of the data collected by land managers (e.g. monitoring plots) is measured at a point, even if it is ultimately used to attribute a larger area. This has led to calls, even within the GIS community (Johnson 2017), for "location-centric" approaches to deliver knowledge and information. This shift is reflected in the continued development of tools for precision agriculture (Cassman 1999) and precision conservation (Berry et al. 2003). The development of location-centric approaches in rangelands has been limited by the lack of tools for rapidly identifying and delivering relevant site-specific information to managers in a usable form, and by an inability to spatially disaggregate soil map units into soil map unit components. This limitation is particularly important in edaphically diverse rangelands, where a single map unit often includes soils correlated with two or more ecological sites, each having different potentials (and therefore standards for evaluation), and requiring different management strategies. Thus, we will develop new decision-support capabilities based on the Land-Potential Knowledge System (LandPKS; Herrick et al. 2017). The LandPKS will be adapted and expanded to support land management, and particularly rangeland management, in the United States. A key element of the work will be integration with the EDIT database (Objective 4). Initial development of the LandPKS mobile application (app) and cloud computing system was supported with funding from the U.S. Agency for International Development (USAID) with a focus on Africa. As of late 2017, two modules had been developed and deployed through the iOS App Store and the Android Play Store as the "LandPKS" app. The LandInfo module supports collection by non-soil scientists of basic soil profile and topographic information necessary for soil and ecological site identification. The LandCover module allows rapid (20 minutes) collection of general vegetation cover and structure, and soil surface cover information necessary to define ecological states, and monitor management-relevant (e.g. shrub to grass) shifts in plant community composition. These tools will be used to link to site-specific management information within the EDIT database.

Objective 6. Climate-informed decision tools. Impacts of climate variability and change on agriculture include redistribution of water availability, changes in the thermal suitability for agricultural zones and changes in erosion and crop productivity. Rising temperatures are projected to have far-reaching impacts on the agricultural sector in the US (Schauberger et al., 2017), especially in combination with decreased water availability (C. Anderson et al., 2015). In February 2014, the USDA announced the formation of ten Hubs across the nation to help farmers, ranchers and foresters adapt to the effects of climatic change. As part of the USDA Climate Hub network, the Southwest Climate Hub (SWCH) serves stakeholders in six states (AZ, CA, HI, NM, NV, UT), as well as the U.S. affiliated islands west of Hawaii to support and enable climate-informed decision-making. The Southwest is one of the hottest, driest regions in the world, yet irrigated agriculture successfully continues where there is access to water (Steele et al. 2017). In the SW, the market value of agricultural products sold approaches $52 billion per year with roughly 60% from crop sales and 40% from livestock enterprises and their products (National Agricultural Statistics Service 2017).

Climate Hubs operate in three thematic areas: a) research and scientific information synthesis, b) tool development, technology exchange and implementation assistance and c) stakeholder education, outreach and engagement. In the nearly four years of operation, the SWCH achieved measurable successes and identified knowledge gaps. With regard to research and scientific information synthesis, a regional vulnerability assessment was developed in collaboration with the California specialty hub (Elias et al. 2015b). The foundational content of this assessment became a special issue of seven articles in the journal Climatic Change. Snowmelt runoff modeling of basins in the SW supplying much of the surface water for downstream use indicates future shifts in regional hydrographs. Both of these efforts bring to light an important uncertainty for the future of SW agriculture. Specifically, how will increased dryness and water scarcity impact SW agricultural production and rural communities? Efforts focused on identification of water related vulnerabilities and creative solutions to cope with water scarcity represent one branch of planned SWCH efforts.

Climate Hubs are also charged with carefully identifying decision support needs and then filling gaps via accessible and creative technology exchange. Among other efforts, the SWCH has produced information to assist managers following catastrophic fires (https://postfiresw.info/) and an interface to depict crop indemnities and cause of loss (https://swclimatehub.info/rma/). A critical and fundamental component of climate adaptation is the feedback from producers to tool developers. The SWCH will continue to operate in this arena, gathering responses from farmers, ranchers and foresters to produce the most critical information in support of climate adaptation for Southwestern stakeholders.

Finally, the SWCH strives for strong stakeholder collaboration to ensure development and delivery of relevant, practicable information, specifically with agricultural advisors, youth and tribal representatives. The SWCH helped form the Southwest Extension Partnership (SWEXT), a group of climate extension specialists. We will continue to support this group via targeted newsletters, website maintenance (https://extension.swclimatehub.info/) and support of future climate forums. The SWCH encourages youth engagement with climate issues via scientifically rigorous education units aligned with common core state standards and next generation science standards (https://swclimatehub.info/education), in collaboration with the Asombro Institute for Science Education. Tribal engagement includes identifying and reporting tribal adaptation efforts. Knowledge co-production is needed to ensure that the SWCH effectively responds to the needs of agricultural advisors, youth and youth educators and tribal communities.

Objective 7. LTAR network activities. The Long-Term Agroecosystem Research (LTAR) network was established in 2012 to advance knowledge and application of sustainable intensification strategies, accounting for local variations in agroecosystem structure. Region-specific research seeks to contrast “business-as usual” with “aspirational” management strategies (addressed in Objective 1) using a uniform set of concepts to facilitate network-level research. In the previous funding cycle, the Jornada led a network-level synthesis to understand general strategies and barriers to sustainable intensification in the U.S., which resulted in the first network-level publication on the common experiment (Spiegal et al., 2018). This synthesis pointed to several knowledge gaps that inform our contributions to network activities in the next funding cycle. We will lead or contribute to network-level research on 1) the modelling and management of wind erosion in different production systems (see Subobjective 2B), 2) using phenology to understand management impacts on production (see Subobjective 3B), 3) recoupling nutrient cycles in U.S. agriculture (MacDonald and McBride 2009, Sharpley et al. 2016), and 4) documenting the greenhouse gas and economic implications of business-as-usual versus aspirational production systems (Diaz et al. 2015). Improved estimation of the environmental and economic effects of alternative production systems via this research will enhance network-level understanding of ecosystem service trade-offs, which should ultimately shape the characteristics of aspirational strategies and inform policies that incentivize their adoption (MacLeod and Brown 2014).

RELATED RESEARCH

This project plan was developed with an explicit awareness of ARS project plans of the Rangeland Resources Research Unit in Cheyenne, WY, the Pasture and Meadows Research Unit in Burns, OR, and the Southwest Watershed Research Center in Tucson, AZ. In addition, this project plan relates closely to the project plans of the Grazinglands Research Laboratory in El Reno, OK, the Northwest Watershed Research Unit in Boise, ID, and the Northern Great Plains Research Laboratory in Mandan, ND in order to facilitate interactions during the 2018-2022 period. These plans include shared foci on rangeland management and change, collaborative adaptive management, the use of ecological site descriptions, and soil health.

Objective 7 specifies network-level interactions across diverse sites within the LTAR network including cropland and pastureland emphases, via the overarching common theme of sustainable intensification and specific themes related to soil health, climate resilience, and others detailed in Spiegal et al. (2018). We will coordinate with these sites in many upcoming activities. In addition, our project includes a collaboration with other units focused on the vesicular stomatitis virus/big data Grand Challenge.

A search of the current CRIS database revealed 12 other main projects addressing rangeland agroecosystems. These projects are largely based in the western US. Of these 12 projects, 4 address livestock management, 2 focus on weed management, 2 are devoted to water quality or availability issues, 2 focus on disease ecology (with whom we collaborate), and one focuses largely on erosion rate estimation. A few projects are focused on identifying ecological principles with application to restoration and land management, but none of these are in hot, arid environments. No other projects focus broadly on national-level guidance with regard to monitoring, data analysis, and decision support for rangeland management. Furthermore, no other projects focus on new livestock biotypes that are adapted to Southwestern environments.

APPROACH AND RESEARCH PROCEDURES

Objective 1: Develop or improve livestock management and restoration practices to promote resilience to climate variability and adaptation to increasingly shrub-dominated environments.

Subobjective 1A: Compare productivity and environmental impacts of Raramuri Criollo cattle to conventional livestock production systems in the arid Southwest (part of LTAR Common Experiment; Estell, Vacant Range Specialist, Browning).

Hypothesis statement: The objective of this study is to 1) compare behavior and productivity of Raramuri Criollo (RC) cattle with desert-adapted cattle breeds typically found on extensive, shrub-dominated rangelands of the southwestern U.S. and 2) to determine whether key Chihuahuan Desert vegetation parameters respond differently to conservative stocking with RC cattle vs. breeds typically produced in the region. Our hypotheses are a) that RC cattle will exhibit characteristics and behaviors that will translate to different impacts on long-term plant community dynamics in the Chihuahuan Desert ecosystem and b) that RC cattle will require fewer external inputs than Brangus breeds commonly used in the region.

Experimental design: First, a long-term replicated grazing experiment will be established to determine whether key desert vegetation parameters respond differently to conservative stocking rates of RC and common desert-adapted breeds. Second, behavioral attributes will be compared and their relationships with any impacts on vegetation dynamics will be evaluated. Third, input and output parameters will be monitored to evaluate productivity of these two types of cattle.

We will utilize pastures (i.e. fenced areas of rangeland that are typically several hundred hectares) in which effects of cattle stocking rates on desert vegetation dynamics have been examined for the past 25 years, featuring a single breed (Brangus). Because these pastures have been monitored in great detail for more than two decades, they will allow us to determine not only the immediate impact of our treatments, but also provide a baseline to assess whether long-term vegetation trajectories are altered in response to RC grazing. A divergent vegetation trajectory from the baseline Brangus grazing would illustrate such an effect.

We will use four pastures on the Chihuahuan Desert Rangeland Research Center which have been stocked year-round with Brangus cattle at either conservative (pastures 4 and 14) or light (pastures 1 and 15) rates (35-40 or 10-15% utilization of key forage species annually). No differences in precipitation recorded in the four pastures were detected over a 15-year period between 1997-2011 (Thomas et al. 2015). The treatments also produced no significant differences in perennial grass biomass, and so all four pastures are starting the new experiment with similar vegetation. Breeds will be randomly assigned (RC or Brangus) to pastures 4 and 14 and separately to pastures 1 and 15 (stratified by previous stocking rate treatments) and will be stocked year-round with mature cows (4 years of age or older) at a conservative stocking rate. Although pasture replication is low, the long-term baseline data will allow us to detect any strong effects. Stocking rates will be adjusted annually to maintain nearly constant grazing pressure over time. During the 1997-2011 period, the two conservatively grazed pastures were stocked annually with an average of 11.5 AU/pasture (Thomas et al. 2015). Therefore, this study will require approximately 28 RC and 20 Brangus cows, assuming body weights of 360 and 545 kg, respectively. Although preliminary comparisons at the Jornada were between RC and Hereford/Angus crosses, this experiment will use Brangus to take advantage of historical data.

Bred cows will be selected for the study at weaning in the fall of 2018. In 2019 and each year thereafter, all cows will be bred via artificial insemination during the late spring/early summer such that calving will occur in February-April each year. Cow weight and body condition score (BCS) will be recorded in January, May, and October each year. Reproductive performance and calf weaning weights will be determined in October. Breed-specific BCS-based criteria will be developed to determine feed supplementation strategies. The same vaccination and parasite control protocols and other general management practices will be applied to both herds. All inputs (supplemental feed, veterinary costs, etc.) and outputs (kg of weaned calf) will be recorded to assess productivity of these two production systems. Spatial foraging patterns of Brangus and RC cows will be documented via GPS collars during six annual periods (20 to 30 days every other month). Fecal samples will be collected monthly to conduct near infrared reflectance spectroscopy analysis to predict diet quality of each breed (Lyons and Stuth 1992).

Vegetation sampling will follow the protocol used in the previous 25-year study (Khumalo et al. 2007; Mohamed et al. 2011), which involves annual measurements of total herbaceous standing crop, forage production, and plant basal cover in 10 key areas in each pasture (40 sampling sites total). We will continue to use the permanent transects established in each area (Khumalo et al. 2007; Mohamed et al. 2011) in order to make meaningful inferences regarding vegetation trend. In addition to standard vegetation measurements, we will also determine soil surface stability and vegetation gap size (Pyke et al. 2002) each year and will include periodic measurements of soil C, N and microbial diversity (Eldridge et al. 2017) at each of the 40 permanent transects. In addition, we will use MODIS and Sentinel-2 image sequences to compare annual green-up parameters for each pasture (Browning et al. 2017a; 2018). We will also develop GIS layers containing a map of ecological states of each pasture to interpret animal movements.

Data Analysis and Interpretation: The basic experimental design will focus on two treatments, (Brangus or RC grazing) and four large pastures (each ca. 600 ha), therefore n=2 for each treatment. We will test for effects of recent land use legacy (conservative or light grazing by cattle), but effects on vegetation are currently not distinguishable. Individual animals and transects will be treated as sampling units. Analysis of these data will include initial conditions and/or annual precipitation as a covariate. Repeated measures analysis will be conducted where possible to account for temporal autocorrelation of vegetation and soil response variables. State changes will be monitored and analyzed as described by Bagchi et al. (2012). Detailed data about the spatial distribution of cattle herbivory and proximity to water will be coupled with spatially explicit vegetation and soil responses. Standard mapping and analysis methods for livestock GPS data will be used (Black-Rubio et al. 2008; Peinetti et al. 2011; Perotto-Baldivieso et al. 2012; Sawalhah et al. 2014). The study will continue for a minimum of 10 years. After 10 years, the study will be evaluated to determine if it should be extended.

Contingencies: A prolonged drought that requires a large reduction in cattle numbers for an extended time could result in inadequate sample size for certain variables during certain years. We anticipate that comparisons regarding animal behavior and productivity will be achievable during a five-year timeframe; however, depending on environmental conditions, our ability to detect treatment effects on plant community and soil response variables may require a longer timeframe. Again, that is not a major issue since the study is a long-term experiment.

Collaborations: We are currently collaborating with faculty at New Mexico State University, especially Dr. Andres Cibils, who will lead vegetation studies, supervise students, and coordinate use of NMSU pastures (Appendix 5). At the international level, colleagues at the Instituto Nacional de Tecnologia Agropecuaria in Argentina set up a companion study using the protocols that we will implement at the Campo Anexo Los Cerrillos in Chamical La Rioja (Appendix 5). That study, which began collecting preliminary data in September 2017, will compare the environmental footprint of raising Angus vs. Argentine Criollo cattle in Argentina's semiarid dry Chaco region. Plans for a third site in Chihuahua, Mexico are underway (Appendix 5). Although these collaborations are not critical to the success of our experiment, they allow us to extend inference to other ecosystems. In addition, we are collaborating with New Mexico State University and producers on studies of the marketability of Angus and Brangus cross-breds and meat quality of RC compared to conventional breeds.

Subobjective 1B: Develop collaborative science approaches to test the efficacy of practices to recover and sustain perennial grass cover in the desert grassland region (Bestelmeyer, Vacant Range Specialist, Herrick).

Rationale statement: Our goal is to create a generalized understanding of the biophysical constraints to grass recovery that can guide future restoration actions, as well as to sustain collaborative science with agencies and ranchers. This will involve two distinct long-term experiments: the Restore New Mexico (Restore NM) project and the Duneland Restoration Project (DuRP).

Hypothesis statement: a) Grass recovery rates in brush management areas (Restore NM) can be predicted by variation in climate, inherent soil water holding capacity, and surface soil function (aggregate stability, infiltration, crusts). b) Spatial variation in *S. flexuosus* establishment (DuRP) can also be explained by soil properties that govern surface soil moisture availability. Manipulation of soil surface properties can increase the likelihood of grass establishment.

Experimental design: *Restore NM*. In collaboration with the BLM and NRCS, the ARS initiated a region-scale, long-term monitoring experiment embedded within 60 (and expanding) shrub removal treatments beginning in 2007. Within planned shrub removal areas selected as part of NRCS EQIP projects, ARS established treatment and control plots (900 m^2) that were matched according to soils and initial ecological state prior to treatments; control plots were excluded from herbicide treatment. Line-point intercept and belt transects were used to measure vegetation cover prior to and periodically after treatments (i.e. a Before-After-Control-Intervention design), focused on perennial grasses including *S. flexuosus*, *Muhlenbergia porteri*, Aristida spp. and others. We will extend these long-term measurements, add new treatments, and measure soil profile and soil surface properties and net primary production in a subset of these treatments to interpret variations in grass response. In addition, via a funded USDA NIFA grant, we will collaborate to add measures of production, soil C and N, wildlife populations, and wind erosion to a subset of the plot pairs.

DuRP: We will initiate a new study in order to test the role of soil properties in determining the potential for *S. flexuosus* establishment and persistence in eroded shrubland areas. Sampling will occur in an area circumscribing patches of remnant, historical (*Bouteloua eriopoda*) grassland, recently-established *S. flexuosus* stands in *Prosopis glandulosa* shrublands, and *P. glandulosa* shrublands without *S. flexuosus*. In 12 replicates of each of these patch types, we will measure soil profiles (by horizon, including particle size analysis) and surrounding microtopography (using structure-from-motion photogrammetry via unmanned aerial vehicle imagery). Surface soil properties including bulk density, infiltration, aggregate stability, and total organic C, total organic N, pH, soil nutrients (base cations, CEC, etc.), and electrical conductivity will be measured. In addition, we will monitor surface soil moisture dynamics for at least 2 years using time-domain reflectometry. Finally, surface soil samples will be evaluated for seed pools (by germinating seeds in a greenhouse). Based on the results from this comparative study, we will then design and test manipulations to establish *S. flexuosus* in as yet uncolonized patches that may include soil surface modification (e.g. trampling), seed addition, and modifications to lateral wind and water connectivity via artificial structures (i.e. connectivity modifiers; Rachal et al. 2015).

In both experiments the soil surface measures are 0-5cm and a similar battery of measurements will be performed, focused primarily on soil C and N in Restore NM. Soil profiles are measured at all DuRP and Restore NM sites to a depth of 75 cm (when possible) for calculation of AWC.

Data Analysis and Interpretation: Both studies will rely on conventional statistical approaches, especially repeated measures mixed models (Restore NM) and generalized linear models (DuRP). Since the plant species involved in this subobjective are identifical to those in pastures used in 1a, we will link interpretations of 1a and 1b to draw broad conclusions about the management of shrub-dominated rangelands.

Contingencies: No contingencies are anticipated for the ongoing Restore NM study, which is already producing high quality data. The DuRP study may indicate that an unmeasured factor is responsible for the variation in grass establishment, which will complicate any effort to manipulate a key factor to promote establishment in the latter study phase. In this case, we would delay restoration trials and conduct additional studies on biophysical constraints and conduct additional analyses to detect unforeseen relationships (e.g., multiplicative or nonlinear effects). In addition, a severe multi-year drought would delay implementation of restoration trials.

Collaborations: Restore NM and DuRP involve a close collaboration with the Bureau of Land Management, Las Cruces District Office as they are the implementing agency for the treatments, as well as New Mexico Association of Soil and Water Conservation District and NRCS as partners. In addition, we collaborate with the University of Illinois, Urbana, via a funded USDA NIFA grant.

Objective 2: Leveraging temporal and spatial datasets from the Jornada and surrounding region, design and implement big data-model integration approaches to predict and/or resolve disease outbreaks and other regional agricultural problems.

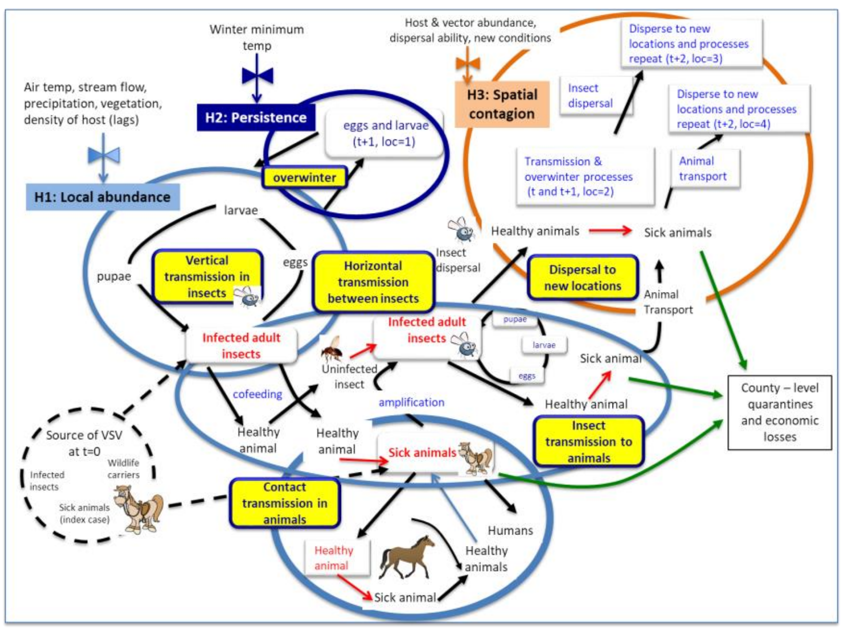

Figure 9. Systems diagram for VSV showing three hypotheses and the associated processes: H1. Local abundance processes (vertical transmission, transmission between insects, insect transmission to hosts, contact transmission between hosts) (light blue circle); H2. Persistence processes (overwintering) (dark blue circle), and H3. Spatial processes that influence dispersal to new locations (orange circle). A subset of potential environmental drivers or variables is given for each hypothesis.

Subobjective 2A: Develop a strategy and operational framework for agricultural grand challenges that require big data and trans-disciplinary scientific expertise based on spatio-temporal modeling of cross-scale interactions and interactive machine learning (Peters, Vacant Soil Science, Bestelmeyer).

Rationale statement: The strategy described below can be used to solve complex, region-scale problems. As a Grand Challenge project, our broad goal is to not only address VSV, but also to refine the implementation of this approach for other problems.

Goal statement: To identify processes and environmental factors governing local, landscape and regional-scale spatial and temporal patterns in disease or other ecological responses.

Research approach: The novelty of our approach is to use interactive machine learning to select, harmonize, analyze, and interpret a large amount and variety of data in a predictive framework. The four major steps are iterative with learning and refinement: 1) form a trans-disciplinary team and develop a multi-scale understanding of the system, 2) develop initial hypotheses to identify potential processes and explanatory variables, 3) conduct harmonization, integration, and statistical analyses followed by 4) interpretation of results and generation of new hypotheses that will be tested by our collaborators.

The trans-disciplinary team has domain expertise in: VS disease components (epidemiology, viral phylogeny, entomology), the ecology of the region (ecohydrology, livestock ecology, landscape ecology), and software and statistical analyses for big data. In the past two years, we developed a conceptual model (Fig. 9) to identify key vector and host processes, and their relationships with potential environmental drivers in space and time. Because the VS incidence data consist of the presence of an individual infected animal and its geo-referenced location by date of occurrence, we identified nine environmental drivers expected to be important to six processes related to a) local disease transmission (vertical transmission in vectors; co-feeding and amplification in vectors; vector transmission to hosts; contact transmission among hosts), b) overwintering of eggs and larvae, or c) dispersal of insects or hosts. We also identified two factors related to host density (number of animals, number of ranch/farm properties).

We will use the conceptual diagram to strategically select variables for analysis by developing hypotheses that link biological (e.g., biting midge egg density) and environmental variables (e.g., soil water-holding capacity) needed to explain vector or host lifecycle stages under natural conditions (e.g., biting midge eggs are found in small, shallow puddles of water) that are expected to contribute to disease spread. Online, open access databases will be identified for each environmental driver and biotic factor with the appropriate temporal and spatial resolution, extent, and duration to allow hypotheses to be developed and harmonization to the format of the VSV occurrence data to be analyzed. Each variable map will be first geo-referenced to the same projection system with the same origin as the base VS map, and then each variable map will be harmonized to the base map. We will use a common 1 km^2 grid over the ca. 1.1 M km^2 study area that best links the available resolution of the environmental data and adequately captures uncertainty in the location of VSV occurrence data. We will also consider finer-grained resolutions as data permit.

Data analysis and interpretation: Spatial data layers will be collated into a data cube to enable calculations and predictions to be carried out in geographical space. Time series raster data will be classified/summarized into calendar units (months, seasons, years). Maxent niche modelling will be used to predict the spatial and temporal distribution of VSV occurrence. “Maxent” is machine-learning technique called maximum entropy modeling. From a set of environmental (e.g. climatic or soil) grids and georeferenced occurrence localities, the model expresses a probability distribution where each grid cell has a predicted suitability of conditions for disease occurrence. The R package MaxentVariableSelection will be used to control model complexity, to avoid collinearity among predictor variables, and to optimize parameters for analysis. Variables will be removed from the analysis whose contribution to the model is < 5% and whose correlation with another variable is > 0.7 (such variables are uninformative). A map of probabilities of VSV occurrence under different climatic conditions will be used to provide a spatial synthesis of results that can be used for management, and management recommendations for different locations will be summarized. Furthermore, the harmonized environmental data will provide coverage for > 1 M km and be available for use for other Grand Challenge problems. Specific products from this work will be 1) a predictive model of VSV occurrence, and 2) publications on general approaches to applications of machine learning based on large spatial datasets for regional to national agricultural problems.

Contingencies: Data availability will limit the types of data at each spatial and temporal scale in the analysis. We will pursue data of lower quality with less spatial or temporal coverage and conduct kriging procedures to gap fill for harmonization of these data. Kriging using a variety of models has proven to be an adequate approach in similar studies.

Collaborations: Several scientists and veterinarians have collaborated with this project since it was initiated in May 2016. Responsibilities include: virology and phylogenetics of VSV (Luis L. Rodriguez, Steven J. Pauszek, ARS, Plum Island Animal Disease Center), biology of arthropod vectors (D. Scott McVey, Barbara Drolet and Lee Cohnstaedt, ARS, Arthropod-borne Animal Diseases Research), animal epidemiology (Angela M. Pelzel-McCluskey, Jason Lombard, USDA Animal and Plant Health Inspection Service; APHIS), range science (Justin D. Derner), agricultural economics (Dannele Peck, ARS, Rangeland Resources & Systems Research). A headquarters-funded Grand Challenge postdoctoral associate will perform model-building using machine learning techniques.

Subobjective 2B: Develop national wind erosion assessments using big data and models developed through the National Wind Erosion Research Network. (Herrick, Vacant Soil Science)

Rationale Statement: This project will take an observational research approach, while establishing the research and data infrastructure necessary for supplementary experimental studies, effectively supporting and facilitating research by university and other partners. Standardized and networked monitoring and research are required to effectively assess wind erosion across U.S. agroecological systems. Standardization is needed to upscale and generalize our understanding of aeolian processes and impacts. Networked research is needed to coordinate data collection, big data and knowledge sharing, and the development, testing, and application of numerical models that will underpin wind erosion assessments applicable to all land uses. Networked research is also needed to facilitate collaboration among existing monitoring programs that can utilize wind erosion information to support management and policy options.

Goal statement: Create national datasets and management- and policy-relevant tools to assess wind erosion rates and their responses to land use and land cover change across U.S. agroecological systems.

Research approach: A national, standard, public dataset will be generated through leadership of the National Wind Erosion Research Network (Webb et al. 2017), including data collection, management, and curation. Data quality assurance (QA) and quality control (QC) procedures will be implemented to ensure high standards are maintained from establishment of Network sites through data collection, management, and analyses. On-site training will be used to support data collection and QA and QC processes. A new generalized database system will be developed for Network data that has greater compatibility with complementary monitoring databases maintained by the BLM and NRCS. Scripts will be written in Python and R languages to support automated data QC, big data management activities, data extraction for analyses, and to support integration of assessment tools (e.g., numerical models) with monitoring data. New Network sites will be installed across public and private lands to expand the relevance of Network data and products across U.S. croplands, rangelands, and desert ecosystems.

A physically-based numerical wind erosion model (Aeolian EROsion, AERO) developed from existing parameterization schemes will be calibrated and tested using Network data to quantify the model output uncertainty. A subset of the National Wind Erosion Research Network data will be used to calibrate AERO, with the remaining data used to test (cross-validate) the model. Model calibration will be conducted across multiple cropland and rangeland sites and over time. The model is currently in development, but the core schemes were published in several previous papers (Shao and Lu 2000, Shao 2004, Okin 2008). The model physics will be refined through an iterative calibration process with a focus on improving the drag partition to represent wind momentum transfer to exposed soil surfaces between different vegetation structures (e.g. grasses, shrubs, crops) and effects of erodible and non-erodible surface roughness features (e.g. oriented soil ridges in croplands). These refinements will be critical for developing a model that produces accurate wind erosion estimates across agroecological systems. A national map of soil particle-size distributions, required to predict size-resolved dust emission and assess dust impacts, will be produced using physical samples from the NRCS National Soil Information System (NASIS) database. Soil and dust particle size analyses will be run at the Jornada using a Beckman Coulter LS 13 320 laser particle size analyzer and in collaboration with the ARS Rangeland Resources and Systems Research Unit, Fort Collins, CO. Options for improving the accuracy and temporal resolution of meteorological inputs to AERO will be investigated through a survey of available gridded sub-daily climate datasets produced by the National Oceanic and Atmospheric Administration (NOAA). We are evaluating the use of NCEP-NARR (Mesinger et al., 2006), GRIDMET (Abatzoglou, 2012) and the Global Land Data Assimilation System (Rodell et al., 2004) wind speed data to drive the AERO and GEE models. Products showing improved accuracy and resolution over the current North American Regional Reanalysis (NARR) data product used for AERO will be incorporated into the model system. The AERO model will be coded in Fortran into the Agricultural Policy / Environmental eXtender (APEX) model (Wang et al. 2012) and calibrated using Network data so that comparable wind erosion estimates can be included by the NRCS in farming systems simulation experiments.

An objective of the National Wind Erosion Research Network is to address the deficiencies of data previously used to calibrate and test wind erosion and dust models. Previous data have provided biased estimates of aeolian transport rates with large uncertainties due to samples designs with very small samples sizes that inadequately capture spatiotemporal variability in transport, and are not available across the range of model application environments. Testing and calibrating AERO with robust datasets collected across agroecological systems will be a critical first step toward identifying how we can make further improvements to the model physics, beyond those that are obvious now (e.g., representing soil erodibility dynamics).

Data Analysis and Interpretation: Applications of the calibrated AERO model will be developed to produce multi-scale assessments (points, farms, regional, national) of wind erosion and dust emission across U.S. agroecological systems. A national wind erosion assessment will be run by ingesting data from the BLM Assessment, Inventory and Monitoring (AIM) and NRCS National Resources Inventory (NRI) programs into AERO. Although the NRI data are not available to the public but can be used to produce publicly available estimates of aeolian sediment transport and wind erosion at e.g., the county scale, or summarized in frameworks that support management and for which precise spatial locations do not need to be reported – e.g., within ecological site descriptions (ESDs) and for ecological site groups (ESGs). We are using NRI data to produce plot-scale estimates of aeolian transport which we then scale to the ESD, ESG and broader spatial scales – county, Major Land Resource Area (MLRA), Level III Ecoregion. Modelled sediment mass fluxes produced at the point scale will be scaled up for the national assessment using point weights derived for the AIM and NRI sampling designs (Goebel 1998). Regional and project-level (e.g. BLM restoration treatments) assessments of wind erosion will be extracted from the national model simulations to produce focused assessments of the impacts of land use and land cover change and to identify thresholds of land degradation/restoration that significantly influence sediment mobilization. AERO model applications will be coupled with wind erosion assessments from a separate spatially-explicit wind erosion model run in the Google Earth Engine (GEE) using Moderate Resolution Imaging Spectroradiometer (MODIS) albedo data (Chappell and Webb 2016). The spatial GEE model (that will also be calibrated using Network data) enables continuous (500 m) wind erosion estimates at 3 hr temporal resolution over the MODIS time series (2000 – present), which could be used to downscale estimates to the farm level. The GEE model outputs provide spatial and temporal context, and another line of evidence, for interpreting point-scale AERO assessments of wind erosion across agroecological systems.

Note that it is not our intention to couple the AERO and albedo-based GEE models. The two models are complementary in that, unlike other dust emission models, they are both sensitive to the spatial distribution of surface roughness that is the first-order control on wind erosion. The AERO model will be applied at the plot scale to standardized monitoring data collected by the BLM and NRCS. It will produce higher-precision but lower frequency (spatial and temporal resolution) estimates than the GEE model which estimates aeolian transport continuously in space and frequently over time (e.g., 500 m pixels, every 3 hrs). The GEE model will be used to build a regional-scale picture of aeolian transport while the AERO model will be used more often to assess farm-scale and treatment effects on aeolian transport (e.g., fire, brush removal effects).

Spatial patterns of dust concentration measurements from IMPROVE and AERONET will be interpreted with respect to spatial patterns of simulated dust emissions. Air parcel trajectory modeling (e.g., using the NOAA HYSPLIT model) will be used to assess dust transport pathways and link measured dust concentrations to the modeled dust sources. Time series dust concentration measurements will be related to simulated dust emissions and indices of regional climate variability associated with e.g., the El Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), using canonical correlation analysis, partial least squares regression, and time series decomposition methods such as Breaks for Additive Season and Trend (BFAST) to detect the timing and direction of season and trend shifts in modeled dust emissions and their correction with onset of drought and land cover change. Ecological site maps and available land cover data will be used to assess the impacts of land use and land cover change at short (seasonal) and long (decadal) time scales. Resulting data and metadata will be published to publically-available data journals/data repositories on a periodic basis. The primary products will be tools to produce scalable estimates of management impacts on wind erosion based on vegetation monitoring data inputs.

Contingencies: The greatest anticipated challenge will be to maintain a high level of productivity in data collection across the Network and to coordinate new wind erosion research projects across Network sites that may not have a primary interest in aeolian processes. To address these challenges, training for data collection, QA and QC will be run at Network sites, communications infrastructure provided by the LTAR network will be used to increase the frequency of dialogue among Network sites, and LTAR annual meetings will be used to plan new research projects using Network data and to identify opportunities to expand the Network research impact.

Collaborations: This project will be coordinated through the National Wind Erosion Research Network. Network partners include the USDA-ARS and LTAR network (Objective 7), NRCS, BLM, Department of Defense (DoD), US Geological Survey (USGS) and The Nature Conservancy (TNC) who will collect local data. For specific partner sites, see https://winderosionnetwork.org/.

Objective 3: Improve understanding of ecological state change in the desert grassland region through synthesis and analysis of long-term climate, vegetation, and livestock data, alongside numerous ongoing short- and long-term experiments, including how gradual and abrupt transitions occur in rangeland agroecosystems and how they can be managed.

Subobjective 3A: Predict alternative states in western rangelands by integrating multiple lines of evidence including spatiotemporal modeling (Peters, Bestelmeyer, Vacant Soil Science).

Rationale statement: Although this project will focus on data from JER and nearby research sites, the insights generated will be applicable to the desert grassland region and the modelling procedures we develop will be useful in other landscape-scale agroecosystems.

Goal statement: To understand the processes and environmental factors governing historic state change dynamics and provide spatially-explicit predictions of the likelihood of state transitions under alternative climate and management scenarios.

Research approach: We will focus on modelling spatial variation in temporal dynamics of vegetation cover and production from the Jornada chart quadrat (JERQUAD) dataset (Yao et al. 2006) and the Jornada Basin LTER net primary production (LTERNPP) dataset (Peters et al. 2014b). The JERQUAD dataset includes 122 1m^2 quadrats distributed across the JER and spans 101 years (1915-2016). Vegetation cover or numbers by species has been recorded using pantograph methods and converted to standardized data (see Chu et al. 2013) periodically over that period, resulting in 5,668 charts. The LTERNPP dataset includes 15 sites distributed across the JER and New Mexico State University property at which permanent quadrats were established in 1989 and sampled non-destructively to estimate annual net primary production by species (see Peters et al. 2012 for details). Soil texture data is available for LTERNPP and a subset (60) of JERQUAD sites. Both datasets have been used in several manuscripts in the ecological literature. In addition, similar plot-level data on production and cover have been gathered as part of other long-term ecological studies on JER.

We will first standardize and integrate these disparate plot (point) datasets into a single database featuring cover and/or production by key plant species and functional groups over time. We will then build a geodatabase of environmental and related response variables for JER and adjacent areas to a common raster resolution, including 1) a new digital map of soil properties, particularly available water holding capacity, using recent machine-learning techniques (e.g., Random Forest, neural networks; Brungard et al. 2015, Levi et al. 2015), 2) hydrologic indices based on a high resolution (5m) digital elevation model (Interferometric Synthetic Aperture Radar [IFSAR]), 3) multitemporal, interpolated climate data based on the JER rain gauge network (1915-present) and federated, widely-available climate data, 4) spatially-explicit, multitemporal data on land use, including stocking rates and brush management treatments, and 5) multitemporal remotely-sensed imagery, including Landsat Normalized Difference Vegetation Index (NDVI) (30-m; 1989-present) and 4-band Digital Globe imagery with ca. 1 m^2 resolution (2009-present). These activities will enable us to improve spatial precision of key soil (such as depth to a petrocalcic horizon) and other environmental properties across the extent of JER at a fine resolution (we anticipate 20 m for modeling purposes). Other soil map products, such as the global ISRIC product, are 250 m resolution and do not model critical soil properties like the depth and stage of the petrocalcic horizon .There is a large amount of as-yet unexplained spatial variation in vegetation that we expect can be explained by high resolution, multivariate environmental data.

We will first assemble and harmonize these datasets. The reconstruction of the historical land use of the JER will require considerable effort to convert historical information into spatial data. We will also develop new, high resolution digital soil and ecological site maps (Maynard and Karl 2017); both of these resources will be useful for research conducted by LTER, LTAR, and other partners. We will use clustering algorithms to classify distinct patterns in vegetation cover and production time series for analysis (Williamson et al. 2016, Bagchi et al. 2017) and employ user-guided machine learning approaches similar to that described for Subobjective 2a to determine if environmental data can be used to predict differences in vegetation trajectories and reconcile seemingly contradictory vegetation responses to experimental manipulations conducted in different locations on JER. We will then use spatial data to map the likelihood of particular types of state transitions across JER (Levi and Bestelmeyer 2016) and create spatially-explicit forecasts based on projected climate scenarios (Peters et al. 2010). These statistical models will be integrated with process-based models (e.g. ECOTONE) in the future. Success in the present study is defined by the quality of predictive models; if the models are poor, we will include other variables and generate additional knowledge of the controls of vegetation heterogeneity.

Contingencies: We do not anticipate any specific limitations to this model-building activity, assuming we are able to fill vacant scientist positions.

Collaborations: This work will be conducted in collaboration with the Jornada Basin LTER program at New Mexico State University (NMSU) and involve collaborating scientists from Arizona State University, University of Arizona, University of California, Los Angeles, and University of Illinois, Urbana who will contribute specific datasets and help guide model building exercises**.** In particular, we will collaborate with Dr. Colby Brungard at NMSU on the use of machine learning techniques.

Subobjective 3B: Formulate phenological indicators of gradual and abrupt changes in primary production using integration of remotely-sensed imagery and ground-based observations (Browning, Peters).

Rationale statement: This project will take an observation research approach to develop and validate novel phenological indicators of state change. As with Objective 3A, we will leverage data from JER to develop insights and approaches that can be broadly applied to diverse agroecosystems, particularly via interactions within the LTAR network (Objective 7).

Goal statement: The goals are three-fold: 1) quantify seasonal metrics and identify environmental factors most correlated with timing of the plant growth processes (e.g., green up, tillering, senescence) and reproduction (flowering, seed set) based on field observations; 2) quantify phenological indicators using vegetation indices derived from satellite and phenocam time series; and 3) evaluate correspondence between field observations and remotely-sensed indicators to model production in dryland agroecosystems.

Research approach: We will employ three levels of inquiry and data integration: a) plant-level observations of phenology co-located with meteorological data stations and phenocams, and phenological metrics derived from time series greenness indices from b) phenocam image and c) satellite image time series. Weekly field observations of plant phenology are made using standardized protocols devised by the USA-National Phenology Network (NPN; Denny et al. 2014) for 15 species at five locations (10 C4 perennial grasses and 5 C3 shrubs or sub-shrubs). For each species, there are 3 to 5 focal plants at each site. Phenocams are established at 4 JER study sites and upload images acquired every 15 minutes during mid-day hours to the phenocam network gallery (https://phenocam.sr.unh.edu/webcam/gallery/). The 250-m MODIS NDVI data product (MOD13Q1) will be acquired from the Land Process Distributed Active Archive Center (LP DAAC). We will use the DAAC2Disk utility to compile a time series of 16-day NDVI imagery for each study site. Extraction of seasonal metrics (e.g., start and end of season) for MODIS NDVI and phenocam time series data will be accomplished using the 'phenopix' module in the R program (Filippa et al. 2016). In addition, we will explore the use of Sentinel-2 data. Development of phenological indicators from MODIS NDVI and phenocam time series data will be done using the Breaks for Abrupt and Seasonal Trends (BFAST) model by Verbesselt et al. (2010). Phenological indicators from MODIS imagery constitute significant breaks in the long-term trend and the recurring seasonal signal in the NDVI time series. Long-term breaks may indicate NPP loss or increase associated with plant mortality/land degradation/drought or plant growth/wet periods/vegetation recovery, respectively. Seasonal breaks may indicate shifts in plant functional group dominance commonly associated with ecological state change in the absence of net primary production (NPP) loss. Trend and seasonal breaks will be compared to nearby long-term net primary production NPP data gathered via the Jornada Basin LTER and LTAR programs.

Data Analysis and Interpretation: We will use a combination of methods specific to each level of inquiry. To identify the environmental factors most correlated with the timing of phenophase transition (e.g., unfolded leaves or start of season, flower or fruit production), we will use proportional hazards models (Cox 1972) for plant functional groups (i.e., C4 perennial grass species, C3 deciduous shrubs, and C3 evergreen shrubs). Proportional hazards models are "time-to-event" models well-suited to phenology data (Gienapp et al. 2005). We will follow by developing predictive models for plant phenology and use phenocam-based seasonal metrics to verify predicted outcomes. Seasonal metrics from field observations will serve as the basis for comparison to seasonal metrics from remotely-sensed time series (using the 'phenopix' R package). Phenological indicators will be developed using greenness index values from phenocam and satellite time series. The BFAST model decomposes time series into models representing the long-term trend, the recurring seasonal signal, and the residual "noise" (Verbesselt et al. 2010). The BFAST technique applies the modeled trend and seasonal trends to identify "breaks" that represent significant departures from the trend and seasonal models. We will use long-term NPP data and seasonal metrics derived from field and phenocam observations to evaluate whether BFAST breaks coincide with ecologically-meaningful changes in vegetation state. In addition, we will use mechanistic models [e.g., ALMANAC, (Baez-Gonzalez et al. 2018)] to elucidate the role of climate on plant growth and reproduction.

Contingencies: If phenocam data are lost over the course of this project, we will be limited to the 18 site-years of data that exist currently. In addition, we would identify additional sites available on the phenocam network (https://phenocam.sr.unh.edu/webcam/). If the research plan proceeds faster than anticipated, we can expand the phenocam to MODIS model comparisons to other sites in the LTAR network using imagery available at the phenocam network site.

Collaborations: The proposed work features on-going collaborations with Jake Weltzin, Theresa Crimmins and Ellen Denny (USA-National Phenology Network (USA-NPN)) to support proportional hazards model development and migration of field observations to USA-NPN Nature's Notebook database. The 'phenograss' model implementation will be done in collaboration with Guillermo Ponce and Phil Heilman at ARS, Tucson, AZ. Andrew Richardson (Northern Arizona University) assists with phenocam model development and phenocam data streams for all sites used in the analysis.

Objective 4: Complete development of a new database to improve quality, accessibility, and utility of Ecological Site Description (ESD) information nationwide, and collaborate with NRCS to complete national population of ESD information (Bestelmeyer, Herrick, Vacant Soil Science, Vacant Ecology).

Rationale statement: This project builds on 15 years of effort to develop and implement standard concepts for national ESD development in collaboration with NRCS. The finalization and handover of the new database complete this long-term effort. Next steps will include the use and updating of the database content via application to conservation programs.

Goal statement: Provide a complete EDIT database to NRCS, complete migration of existing ESD information from the Ecological Site Information System (ESIS) to EDIT, and provide guidelines for the population of EDIT with new information via collaborative groups.

Research approach: We will expand EDIT's capabilities to enhance the user experience and make management-relevant information available. The current database in development can be accessed at https://edit.jornada.nmsu.edu. In the coming 5 years, we will complete migration of existing ESD information in ESIS and expand EDITs capabilities as a relational database in which individual tables are created for each element of the STM portion. Data stored in these tables will include both quantitative and conceptual characteristics of each STM. The database will also be expanded to relate literature references, land manager testimonies, and restoration outcomes to ecological sites and individual STM elements. A variety of tools will be built upon the relational database foundation, such as interactive maps for visualizing potential ecosystem change, interactive keys for determining ecological class and state, and decision trees for application of conservation practices. We will establish links between EDIT and LandPKS (Objective 5B) and the Wind Erosion Research Network (Objective 3B). Populating the database on national scales will begin with guidelines already in place, including collation of existing information, inventory, and workshops with land users to elicit information about ecosystem change, and workshops to produce STMs (Bruegger et al. 2016). Workshops will be targeted to geographic regions such as Major Land Resource Areas, Land Resource Units, or ecoregion sections/subsections. Once information is gathered, designated leaders can populate or modify their entries in EDIT. We will work with NRCS in the design of these workshops and provide training as needed. Progress will be evaluated via analytics on website use gathered within EDIT.

Contingencies: The EDIT database was initially conceived as an informal tool in the previous project plan, but has recently been adopted as a core part of the NRCS Ecological Site and Soil Business Systems national programs. Thus, the specific directions we will take with the development of this database will depend strongly on continued support, evolving needs, and business processes of NRCS and its customers.

Collaborations: Our primary collaboration is with Joel Brown, NRCS National Leader for Ecological Sites and his staff housed at the Jornada.

Objective 5: Develop tools and techniques for managing and integrating ground-based assessment and monitoring data, remotely sensed and digital spatial data, and connect data to interpretive frameworks and models to develop actionable interpretations for land management.

Subobjective 5A: Develop tools and techniques for managing and integrating ground-based assessment and monitoring data, remotely sensed and digital spatial data, and connect data to interpretive frameworks and models to develop actionable interpretations for land management (Herrick, Bestelmeyer, Vacant Ecology).

Rationale Statement: This project will take an observational research approach. Standardized and networked monitoring and research are required to effectively determine rangeland conditions at multiple spatial scales across the U.S. Measurements and monitoring must be standardized to upscale and generalize our understanding of rangeland condition in response to multiple ecosystem drivers. Data quality and data management systems are critical to improving access and confidence in these standardized data. Analysis and interpretation tools are needed to improve the integration of standardized data, information from models and other data sources to provide decision support tools to rangeland managers.

Goal Statement: Provide guidance to rangeland monitoring programs to collect and manage high quality standardized data, and to develop analysis and interpretation tools to provide decision support information and frameworks to land managers.

Research approach: We will develop innovative training and user support systems for the BLM AIM program, the NRCS NRI program, and other entities and land managers seeking to use the standardized methods. Training improves data collection quality through direct knowledge transfer as well as calibration opportunities between instructors and data collectors. Training will be implemented as in-person 3-5 day workshops as well as webinars and self-guided course materials hosted on the Landscape Toolbox (www.landscapetoolbox.org). In response to user feedback, method development will take place to improve guidance on proper implementation of methods, including sample size requirements and implementation trade-offs. Where the methods are applied in new ecosystems (e.g. forests), or novel information needs arise, new rangeland condition indicators and methods will be developed using field, model, and remote-sensing based approaches. For all methods, existing and new, quality assurance (QA) and quality control (QC) improvement plans will be developed and distributed via the Landscape Toolbox. Improving QA and QC procedures will require analyzing the success of current strategies and assessing method accuracy. With an understanding of existing quality shortcomings, this project will develop strategies for improving data quality and will work with BLM, NRCS, and other interested parties to implement those QA and QC strategies. We will also upgrade the monitoring program of the Malpai Borderlands Group, a rancher-led landscape-level collaborative group circumscribing 400,000 ha, via a cooperative agreement, and use this experience to recommend approaches that can be implemented by other collaboratives.

This project will work to make standardized data discoverable, accessible, interoperable, and re-usable by developing and supporting data infrastructures that can be used by BLM and NRCS but also generalized to other monitoring programs. Standardized data infrastructures improve the accessibility and ease of analyses for data collected in different, but standardized monitoring programs. The Database for Inventory, Monitoring, and Assessment (DIMA) is an Access database developed and supported by the Jornada since 2005. Standardized data are collected using DIMA by BLM, researchers at ARS, USGS, universities, foreign governments, and non-governmental organizations worldwide. We will continue to maintain and develop DIMA in response to user needs and changing information technology demands. While DIMA is an excellent resource for data collection, analyses of small datasets, and short-term archiving of monitoring data, large scale datasets combined across management jurisdictions and spatial scales will require a data management infrastructure that can collate multiple DIMA databases and store large, long-term project datasets. We will use the BLM's Terrestrial AIM Database (TerrADat) as a framework to build a generalized geodatabase system which can be employed by all DIMA users and provide links to analysis tools to calculate indicators, run models, and produce other analyses to provide meaningful information for management.

We will assist land managers in interpreting standardized data by developing benchmark approaches to understand if rangelands are in desired condition or if there are issues of concern that warrant changes in management. Management-relevant benchmarks require understanding of ecological potential and expected ecosystem indicator responses relevant to ecological potential. Approaches to developing indicator benchmarks include leveraging existing standardized monitoring data to understand the distribution of indicator values, matching of locations to reference sites, and the use of state and transition models in ESDs (Objective 4) and empirical models (e.g. wind erosion, Subobjective 2B) to predict indicator responses. Such models will also link to specific management remedies via ESDs. To the extent possible, these interpretations will also be made available on mobile devices through the Land-Potential Knowledge System (LandPKS – Objective 5B).

We will use the Landscape Toolbox to provide tools to land managers for analyzing data. These web-based interfaces will allow users to upload data and create basic visualizations (e.g., frequency distributions, boxplots, data in relation to remote sensing variables). Web-based statistical analysis tools (e.g. ANOVA, sample sufficiency calculator) will also be hosted on the Landscape Toolbox. We will also publish R scripts and packages to support local estimates of rangeland condition as well as inference-based estimates of rangeland condition building on the framework of the spsurvey R package and the Github platform. Success will be evaluated using web analytics on use of the tools and inclusion of the tools in agency programs and directives.

Data Analysis and Interpretation: This subobjective is intended to create data management, analysis and interpretation tools. The Jornada's own use of these data for research purposes (and the analyses that would be used) is described in Objective 2B. Where appropriate, we will complete simple statistical analyses (ANOVA, regression) to evaluate the effectiveness of the tools developed. For example, we will analyze the results of field crew calibration tests using t-tests and ANOVA to evaluate the impact of new training protocols on accuracy and precision.

Contingencies: This project will build on established BLM and NRCS monitoring programs and so the risk of failure is relatively low. The possibility exists that BLM or NRCS could change their approach to data collection, making this research less relevant. However, based on the long-term (since 1997) collaboration, we expect that we would simply adapt our research program to address the evolving needs of our stakeholders.

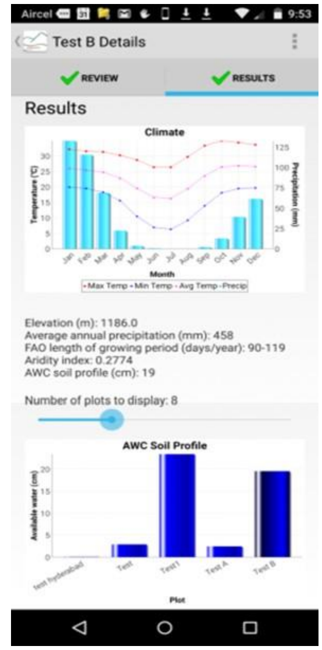

Figure 10. A screen shot of output data from the LandInfo app developed by the Jornada.

Collaborations: Dr. Mike Duniway (USGS) will contribute training, Dr. Jason Karl (University of Idaho) will expand the Landscape Toolbox, benchmark identification tools, and new analysis approaches. We will also implement this work with the Malpai Borderlands Group (Douglas, AZ) in assisting expansion of their rangeland monitoring program, via a cooperative agreement.

Subobjective 5B: Develop, test, and facilitate adoption of a data collection and decision support system that increases land manager ability to monitor their land, and to access, evaluate, integrate and apply local and scientific knowledge (Herrick, Vacant Ecology)

Rationale Statement: In spite of the wide-spread adoption of monitoring tools by federal agencies (Objective 5A), there has been only limited adoption by individual land managers, and no systems exist that effectively integrate data collection with the knowledge necessary to support decisions. This subobjective focuses on mobile app development and cloud computing to solve this problem.

Goal statement: Our goal is to develop and implement a flexible, user-friendly decision support system with integrated data collection functions that leverages existing information and knowledge-bases.

Research approach: This project will build on the LandPKS mobile apps and models (https://www.landpotential.org). LandPKS is being developed using Apache Cordova (https://cordova.apache.org/) so it can be relatively easily deployed across multiple platforms (Android and iOS) with one code base. During the next 5 years we will develop additional data collection and interpretation (decision-support) modules following standard user-centered design practices. This will be supported by established collaborations with the NRCS and BLM (including through Objective 5A), both of which are contributing directly to development of the LandPKS, and by continuing to expand our extensive network of other U.S. and international collaborators.

During the first three years of the project development we will focus on four elements: 1) deploying a soil identification tool that will allow non-soil scientists to identify their soil, including the correct soil components from NRCS soils maps as well as key soil properties including soil texture and organic matter levels; 2) improving the quality of user inputs; 3) expanding the number of possible user inputs through successively more comprehensive versions of new “LandManagement” and “SoilHealth” modules; and 4) providing actionable, location-centric information that can be used to evaluate outcomes and adapt management. This fourth element will be addressed by providing the user with a) tabular and graphical summaries of their own data; b) modeled outputs including soil erosion (Objective 2B); c) relevant reference data such as vegetation cover values from national databases for their ecological site using data from Objective 5A; and d) integration of existing NRCS and BLM data with soil survey and ecological site information via EDIT (Objective 4). While most of this data and information is currently available on the internet, it is virtually impossible for even a skilled researcher to identify and access the data relevant to a specific location so that the users’ own data can be interpreted in context. We also plan to develop tools that allow the users to provide feedback on the quality of the information provided by the system, setting the stage for continuous improvement. All LandPKS collected data will be publically available and can be related to other public datasets.

During the last two years of the project, we will use the user feedback and the data generated by the system to further improve the outputs. User feedback will also be used to adapt future development of the input functions to better meet stakeholder needs.

In order to support soil identification, we will develop algorithms that compare user inputs (e.g. location, soil texture by depth, color – see Fan et al. 2017) to existing soil survey databases to identify the most probable soil map unit component. In addition to allowing us to provide the best possible prediction of the soil at the user's location, university and NRCS soil scientists have indicated that they plan to use this crowd-sourced information to improve both traditional and digital soil maps, and to compare the relative accuracy of the different map products. Improvement of user inputs for soil identification will focus on soil texture and color. This will be achieved through the development of improved keys for soil texture by hand, and new algorithms for soil color using the phone's camera with a standard color reference (see Fan et al. 2017; Salley et al. in review). Improvements of user inputs for the SoilHealth module will focus on those properties selected by the NRCS that can be easily determined in the field, including but not limited to soil aggregate stability. Success will be evaluated using web analytics on use of the tools and inclusion of tools in agency programs and directives.

Data Analysis and Interpretation: We will use standard statistical tests (ANOVA and regression) to compare user and laboratory determinations of soil texture and color.

Contingencies: The work described in this project also depends on continued feedback from users on the development of the app; however, it does not require feedback from any particular user. It does, however, very much depend on the Jornada's continued ability to benefit from the services of a highly skilled software developer as we, like many others, have discovered that developing and supporting a commercial-grade app that people will actually use cannot be achieved with the programming skills typically available at ARS units and universities. To that end, we have developed a strong collaboration with the University of Colorado, Boulder, which has access to a very strong and growing software development community in the Front Range.

Collaborations: Development of the LandPKS has benefited from input from a large number of US and international collaborators. Two key collaborators will contribute significantly to this subobjective. Dr. Jason Neff (University of Colorado, Boulder) will contribute modeling expertise (Appendix 5). Rachel Murph, (NRCS State Rangeland Management Specialist, Colorado) will contribute 25% of her time for the first two years to guide the development of the app for use by rangeland managers.

Objective 6: Develop new tools and information to assist agricultural stakeholders in coping with climate variability through: research, science translation and information synthesis; tool development and technology transfer; and stakeholder outreach and education (Southwest Regional Climate Hub; Rango (Elias), Browning, Vacant Soil Science).

Rationale Statement: This subobjective covers a wide range of the USDA Southwest Climate Hub (SWCH) responsibilities, including research and outreach, the latter in coordination with the collective leadership of the 10 Hubs.

Goal statement: The SWCH has three goals related to our thematic areas 1) advanced understanding of future sustainability of agricultural and rangeland systems under increasing climate variability and change; 2) improved accessibility to information and tools to support resilience in agricultural and forest systems; and 3) strong collaboration with stakeholders and partners to ensure development and delivery of relevant, practicable information.

Research approach: *Goal 1*: We will use a combination of biophysical analyses and social science methodologies to evaluate the likely impacts of climate change on the hydrologic cycle and agricultural communities. We will build on the work in Snowmelt Runoff Modeling (Elias et al. 2015a; Rango 2006; Rango and Martinec 1999; Steele et al. 2017; these references describe the datasets used) to assess the impacts of warming temperatures and changing precipitation patterns on annual streamflow timing and water availability, focused on 24 subbasins of the Upper Rio Grande basin. This scientific information will be used to launch two-way dialogue and communication with agricultural advisors, water managers and producers to evaluate the contextual vulnerability of agricultural systems to climate driven water scarcity. In addition, we will build upon the spatial analytical techniques highlighted in the aforementioned papers to evaluate hot-spots of agricultural vulnerability across the region and identify contextual vulnerabilities and adaptation options.

Goal 2: Tools to support forest and agricultural decision-making will be developed in-house in collaboration with user and commodity groups. Specific efforts include refinements to our Risk Management Agency (RMA) data tool (https://swclimatehub.info/rma) to support adaptation, evaluation and modification of the After Fire toolkit (https://www.climatehubs.oce.usda.gov/hubs/southwest/tools/after-fire-toolkit-southwest) and development of localized precipitation and forage availability forecasts via new, online tools.

Goal 3: The SWCH will engage with stakeholders via traditional (newsletters, webpages, social media and webinars) and direct (field days, drought workshops and in-person meetings) pathways to provide relevant, stakeholder-driven adaptation information. Where practicable, the SWCH will collect and relay information about stakeholder needs back to scientists and managers in an effort to engage in a knowledge co-production framework. SWCH will continue to partner with the Asombro Institute for Science Education to develop and deliver materials for K-12 education throughout the Southwest region (e.g. https://swclimatehub.info/education/climate-change-and-water-cycle).

Data Analysis and Interpretation: Tool development and outreach/education activities will be evaluated based upon stakeholder feedback on tools and webinars, both from direct interaction and via common analytical tools to measure interest and use in specific content (Google Analytics). Other Hubs evaluate their outreach with a variety of methods and we learn and apply novel techniques about how to best serve stakeholders as a network in frequent communication across Hubs.

Contingencies: The SWCH operates successfully in both climate research and adaptation outreach arenas. It is not anticipated that these foci will change; however, we rely on collaboration with stakeholders (cooperative extension, NRCS) and with university partners. Often, challenges or limitations experienced by one partner are supported by another partner in a collaborative manner.

Collaborations: The 10 hubs work collaboratively within the network and with partners from ARS, NRCS, Risk Management Agency (RMA), APHIS, and the USFS on a variety of projects.

Outside of the USDA family, the SWCH works with members of other federal climate-services organizations such as the National Oceanic and Atmospheric Administration, Regional Integrated Sciences and Assessments Program, the U.S. Geological Survey Climate Science Centers and many land grant university partners, including strong collaboration with cooperative extension.

Objective 7: Operate and maintain the Jornada Experimental Range LTAR (JER-LTAR) network site using technologies and practices agreed upon by the LTAR leadership. Contribute to the LTAR working groups and common experiments as resources allow. Submit relevant data with appropriate metadata to the LTAR Information Ecosystem. (Bestelmeyer, Estell, Peters, Browning, Herrick, Vacant Range Specialist, Vacant Ecology, Vacant Soil Science, Rango).

Rationale Statement: This objective addresses our network contributions and core observatory responsibilities for LTAR. Our LTAR common experiment contribution is described in Objective 1.

Goal statement: Develop new knowledge and technologies to advance sustainable intensification in rangeland agroecosystems and other agroecosystems nationwide.

Research approach: LTAR efforts will include three major lines of activity: 1) network-level research focused on national sustainable intensification, 2) local research focused on sustainable intensification in the region represented by JER-LTAR that leverages the LTAR network, and 3) data submission with appropriate metadata to the LTAR Information Ecosystem.

The JER-LTAR leads several network research initiatives and participates in several others:

National Wind Erosion Network: Comprising 15 sites, including seven LTAR network sites and an additional three ARS units, the JER-led National Wind Erosion Network is developing open-access technologies (e.g., models) to assess wind erosion and dust emission that integrate new data sources (e.g., remote sensing, atmospheric modeling) with existing national rangeland, pastureland and air quality monitoring programs (see Subobjective 2B). Through these activities, the National Wind Erosion Network facilitates collaboration among scientists and resource management agencies to address wind erosion impacts on soil quality, agricultural production, ecosystem dynamics, and air quality. Within LTAR, the Wind Erosion Network administers the LTAR Wind Erosion Working Group, which will contribute to achieving Subobjective 2B.

LTAR Phenology Initiative: The JER-led LTAR Phenology Initiative is a cross-site effort designed to quantify growing season dynamics in U.S. cropland, rangeland, and pastureland systems, in order to identify environmental constraints on agricultural production and inform adaptive management. The integration of remotely-sensed data with field and sensor-based measurements will allow LTAR researchers to develop and optimize models of net primary production (NPP) and nutrient flux. Models can then be used to examine effects of genetics (e.g. crop varieties, forage species), management practices (e.g. crop rotation, invasive species eradication), and environmental context (climate, soil health) on productivity via experiments of participating LTAR sites. Data quality standards will be defined via the LTAR Phenology working group.

LTAR Regional Manureshed Project: JER-LTAR will lead a collaborative effort with Upper Chesapeake Bay, Walnut Gulch, Upper Mississippi River Basin, and Lower Mississippi River Basin LTAR sites to identify opportunities to recouple manure-based nutrient supply and demand, with a focus on the regional footprints of the 18 LTAR sites. Collaborators will quantify county-level crop demand and animal production in terms of nitrogen and phosphorus (Kellogg et al. 2000), and then aggregate that county-level data to the level of the LTAR region. The analysis will identify the regional agroecosystems in which manure-based nutrient production exceeds demand, or demand exceeds production. LTAR management expertise will then be leveraged to identify aspirational management strategies for field, farm, region, and industry scales.

Environmental footprints and profitability of beef production in the Southwest: JER-LTAR will collaborate with Dr. Al Rotz of Upper Chesapeake Bay LTAR to compare environmental and economic costs of the business-as-usual and aspirational production systems under investigation in the JER-LTAR common experiment. The project will use the Integrated Farm Systems Model (IFSM), which was designed to estimate annual production costs and environmental impacts of a given production system in a given region with a focus on production within farm gates. For beef cattle, the typical scope includes feed yards but excludes processing and marketing (e.g. Rotz et al. 2015). We will explore the possibility of expanding the model's scope to include these later phases of production. JER-LTAR will partner with ranchers across the western U.S. to provide data about management inputs used to raise grass-fed heritage and conventional cattle. This effort also has the benefit of introducing Raramuri Criollo genetics obtained by the Jornada into real-world ranching operations. Ranches in New Mexico, Arizona, Utah, Texas, California, and South Dakota are working with animals originating from the Jornada herd, and we are learning from the experiences and economics of several producers.

Submit relevant data with appropriate metadata to the LTAR Information Ecosystem. Experimental data pertaining to field-based cattle and restoration studies, economic data from the JER working ranch, and common measurements as requested by LTAR working groups (e.g., meteorological, CO_2 flux, non-CO_2 flux, Wind Erosion Network, phenocam) are being submitted. In tandem, JER-LTAR will maintain the Jornada Information Management System (http://jornada.nmsu.edu/lter/data/management-plan) and the Jornada web-available data catalog (http://jornada.nmsu.edu/data-catalogs).

Science education. JER-LTAR will continue our long-term partnership with the Asombro Institute for Science Education to provide inquiry-based, K-12 educational programs based on LTAR research (see P. 44 for additional details on this program).

Data Analysis and Interpretation: Specific approaches are described in relevant subobjectives.

Contingencies: Success in all network endeavors relies on sustained collaborations within the network, which seems likely. Specific products require site participation.

Collaborations: In addition to the 17 other LTAR sites, our specific projects will involve collaborations with Al Rotz (cradle to farm gate modeling; Appendix 5) and Peter Kleinman (Regional Manureshed Project) of the ARS Pasture Systems and Watershed Management Research Unit and Guillermo Ponce (Regional Manureshed Project), ARS Southwest Watershed Research Center.

PHYSICAL AND HUMAN RESOURCES

The 300-square mile JER serves as a field station in support of the scientific mission of the 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 associated with this field station have resulted in a record of diverse, accessible, and well-documented data sets spanning 106 years. The Jornada is, at its core, a long term agricultural research field station. In recent decades, however, the Jornada has expanded its scope to include support of cutting-edge ecological and atmospheric research, novel computational approaches, development of mobile and web-based applications and databases, and outreach activities that have impacts far beyond Western rangelands. The involvement or leadership of this facility in a broad array of national science programs, research networks, and long-term collaborations also contributes substantially to the Nation's science infrastructure. These networks currently include: 1) the National Science Foundation (NSF)-funded LTER program that, in cooperation with New Mexico State University, conducts long-term research on ecosystem change since 1982; 2) the LTAR network that develops strategies for long-term sustainability of agricultural systems; 3) the Southwestern Regional Climate Hub that develops and delivers science-based information for risk adaptation and mitigation of climate change effects; 4) the National Wind Erosion Network that develops models and estimates of wind erosion at a national scale. In addition, the Jornada houses: 5) the USDA Natural Resources Conservation Service Ecological Site Description National Program that provides a nationwide land potential and management interpretation system. Jornada infrastructure and scientists support: 6) the U.S. Global Agricultural Monitoring Initiative that disseminates timely and accurate information on agricultural production; 7) the Bureau of Land Management Assessment and Inventory Monitoring Program that provides quantitative information on renewable resources of the nation's public lands; 8) the National Ecological Observatory Network, which is a continental-scale observation system for examining ecological change; and 9) the non-profit Asombro Institute for Science Education that improves science literacy through inquiry-based education programs in New Mexico and west Texas. In addition, a variety of independent research projects occur on the JER, including a large micrometeorology study of the U.S. Army Research Laboratory, NMSU research on drone technologies, and several NSF- and USDA-funded projects involving universities across the country. These diverse activities create unprecedented synergies in the use of science toward solving agricultural problems. Below, we describe the resources that support these activities.

Staffing, offices, laboratories: There are 9 permanent full-time category 1 ARS scientists (including 3 vacant positions we will fill once the hiring freeze is lifted), 14 full-time postdoctoral research positions (either ARS associates or NMSU equivalent as of January 2018), and 2 collaborating permanent full-time USDA-NRCS scientists housed within this facility for a total of 25 scientists on site. Background and recent accomplishments of federal ARS and NMSU postdocs directly associated with this project plan appear in Appendix 2; these scientists provide the technical flexibility required by our rapidly evolving program. Scientists are supported by 21 ARS FTE technical and administrative staff (including 2 vacancies), some of which are supported by extramural grants and contracts, and 15 state technical FTE supported by a base-funded agreement with NMSU and by extramural grants and contracts. A full-time statistician is on site to assist with study design and analysis of all objectives. In addition, from 15-20 part-time students are supported on various projects. Tasks associated with vacancies are delegated to existing staff, postdocs, or students as possible. 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/LTAR and LTER programs. We recently-acquired a Beckman-Coulter LS13-320 Particle Size Analyzer to support soil-related studies.

In addition, 5 ARS FTE technical staff (including one vacancy) are assigned to the Jornada Experimental Range field station in support of maintenance, repair, and research assistance activities. These staff are housed at the field station headquarters (HQ) and provide all needed technical and logistical support for field station activities. In total, the Jornada has a staff of ca. 80 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 overall administrative and scientific functions and operations of the Jornada research unit and its cooperative research activities. Lead scientists serve as Principal Investigators for the unit research project. 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 50,000 gallons 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 (1.54 MB for phones and some desktops) and a wireless backhaul (400 MB for research sites, other desktops, and wireless mesh)
- a 2000 ft^2 multi-user facility.
- a 80 KW solar array is being installed that will make JER net zero electricity consumption.

Jornada Field Station Research Sites: Research sites across the Jornada can be characterized within one of two general categories; 1) long-term, monitoring or manipulative field studies and 2) sensor networks. Metadata are associated with both categories, and both documentation and data sets can be accessed on line (https://jornada.nmsu.edu/data-catalogs). 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 Appendix 4 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, UV/B network) networks. Core LTAR measurement infrastructure is shown in Fig. 11. In addition, the Jornada hosts a National Ecological Observatory Network site (http://www.neonscience.org/field-sites/field-sites-map/JORN) and a network of 60 towers featuring meteorological and ground sensing instrumentation connected to a wireless network supported by collaboration with the Army Research Laboratory.

Literature database: Our literature database (https://jornada.nmsu.edu/biblio) includes citations and links to papers produced by the Jornada ARS, LTAR, and LTER programs, and key papers

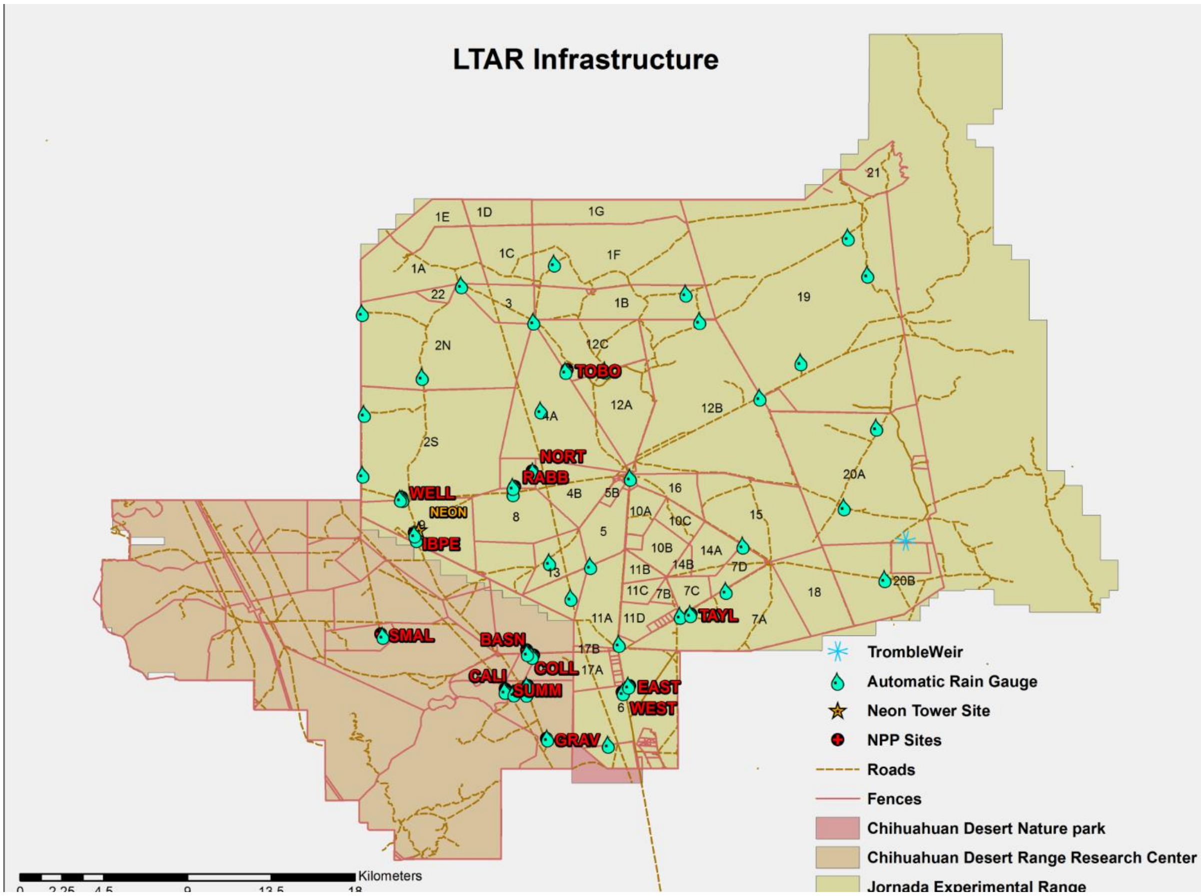

Figure 11. Core monitoring sites for the Jornada LTAR observatory, including an experimental watershed, rain gauges, flux tower (NEON site), and measurement of net primary production (NPP).

for the Jornada Basin preceding the establishment of the Jornada, dating to 1850. There are currently over 3200 entries in the searchable database. Geosemantic search capabilities for Jornada and other papers were developed by Jornada staff at journalmap.org.

Jornada Datasets: The Jornada maintains a data catalog comprised of over 177 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. Some datasets, such as the permanent chart quadrat (vegetation) data and climate data, now exceed 100 years. These data are accessible at https://jornada.nmsu.edu/data-catalogs.

The Jornada 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. The Jornada has an extensive collection of aerial photographs providing complete coverage of JER beginning in 1935. Our spatial data sets are an active area of effort to provide access to all researchers via web-based interactive portals and other means. All of these spatial data sets (maps, shape files, GIS coverages) are available to the public.

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/jornada/photos) as well as within Jornada photo gallery web site (see: https://jornada.nmsu.edu/jornada/photo-gallery).

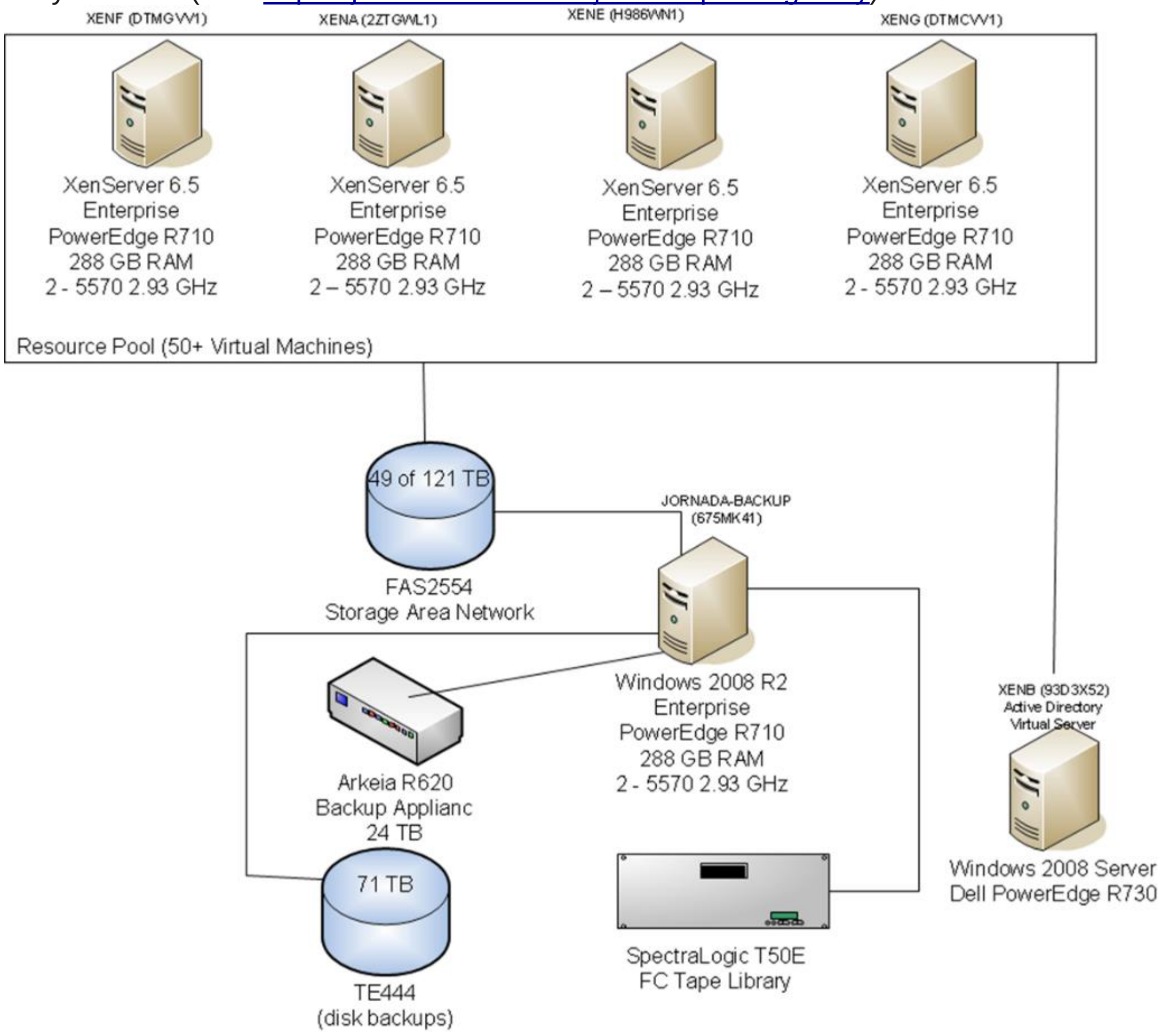

Figure 12. Jornada network server system

Information Technology/Management System: The Jornada Information Management System (JIMS) is staffed by 5 full-time personnel funded by both USDA and NSF-LTER programs. JIMS is integrated with a GIS and is composed of a relational database management system and metadata repository. Hardware and virtual servers include five Dell PowerEdge R710, 288 GB RAM 2-5570 2.99GHz; one Dell PowerEdge R730 144 GB RAM 2-E5-2699 2.3GHz; a NetApp FAS 2554 with a NetApp DS4246 Shelf, 121 TB formatted capacity; a Spectra Logic T50e Tape Library with two LTO 5 Drives, and 95 TB disk storage for backup. Computational services include virtual machines (servers [Linux: 40, Windows: 33]; desktops [10]); Drupal websites (30 websites on 3 Aegir servers); storage provisioning (49 TB of 121 TB used); relational databases (SQL Server, MySQL, PostgreSQL); backup and restore (tape- and disk-based); and cloud services (Heroku, QNAP, Dropbox). See Fig. 12 for schematic.

Websites

The Jornada has built and continues to manage and maintain the following websites:

National Wind Erosion Research Network (http://winderosionnetwork.org/)
The Jornada (http://jornada.nmsu.edu)
Southwest Regional Climate Hub (http://swclimatehub.info/)
After Fire: Toolkit for the Southwest (https://postfiresw.info/)
Western Snow Conference (https://westernsnowconference.org/)
US GEOGLAM (https://www.usgeoglam.org/)
Land Ecology (https://www.landecology.org/)
Ecosystem Dynamics Interpretive Tool (https://edit.jornada.nmsu.edu/content?page=about/)
LandPotential.org (https://www.landpotential.org/index.html)
EcoTrends (https://ecotrends.info/)
Landscape Toolbox (http://www.landscapetoolbox.org/)

These websites are currently in Drupal 7.52. Websites will be maintained in Drupal 7 and will be migrated in the future to Drupal 8. In addition, staff support the ***USDA Climate Hubs*** website (https://www.climatehubs.oce.usda.gov/) as content managers. Finally, staff volunteer as web developers for Asombro (http://www.asombro.org/) to create content, forms, etc. to help them connect the public with educational materials. This work is completed in WordPress.

K-12 Education and Outreach Program: For nearly two decades, the Jornada has supported quality, inquiry-based science education opportunities to K-12 teachers and students throughout New Mexico and west Texas. Over this time period, program staff have directly worked with hundreds of teachers who have participated in one-day to two-week teacher professional development workshops. These workshops enhance teachers' science knowledge and introduce them to science-based lessons they can use in their classrooms. These lessons and curriculum units have been developed through a Cooperative Agreement (Appendix 3) with the Asombro Institute for Science Education (see http://asombro.org/). Lessons focus on Jornada research and are aligned with New Mexico and national science and math education standards. Our partnership with Asombro was established in 1998 alongside the Jornada Basin LTER. Asombro manages a K-12 education program that includes schoolyard studies, science investigation kits, teacher workshops, field trips, and classroom programs. Over the past 5 years, more than 95,000 students have been involved in Asombro's programs. Approximately 5% of these students participate in field activities conducted on-site at the Jornada. 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.

DATA MANAGEMENT PLAN

Data collected at the Jornada complies with the Jornada Information Management System (https://jornada.nmsu.edu/lter/data/policies; Figure 13). Within 90 days of initial data collection, any researchers working at the Jornada (scientists, technicians, students, collaborators, etc.) are required to fill out both Research Project and Data Set documentation forms (available online at http://jornada.nmsu.edu/lter/data/documentation). Usually these forms are finalized with assistance from data managers to ensure completeness, accuracy, and standardization of terminology. Data managers then parse the documentation forms into Ecological Metadata Language (EML) or other metadata specifications. Within 2 years of submission, data are made publicly available online at the Jornada Data Catalog (http://jornada.nmsu.edu/data-catalogs/jornada). Data sets listed as "ongoing" are updated on a regular basis. Data are backed

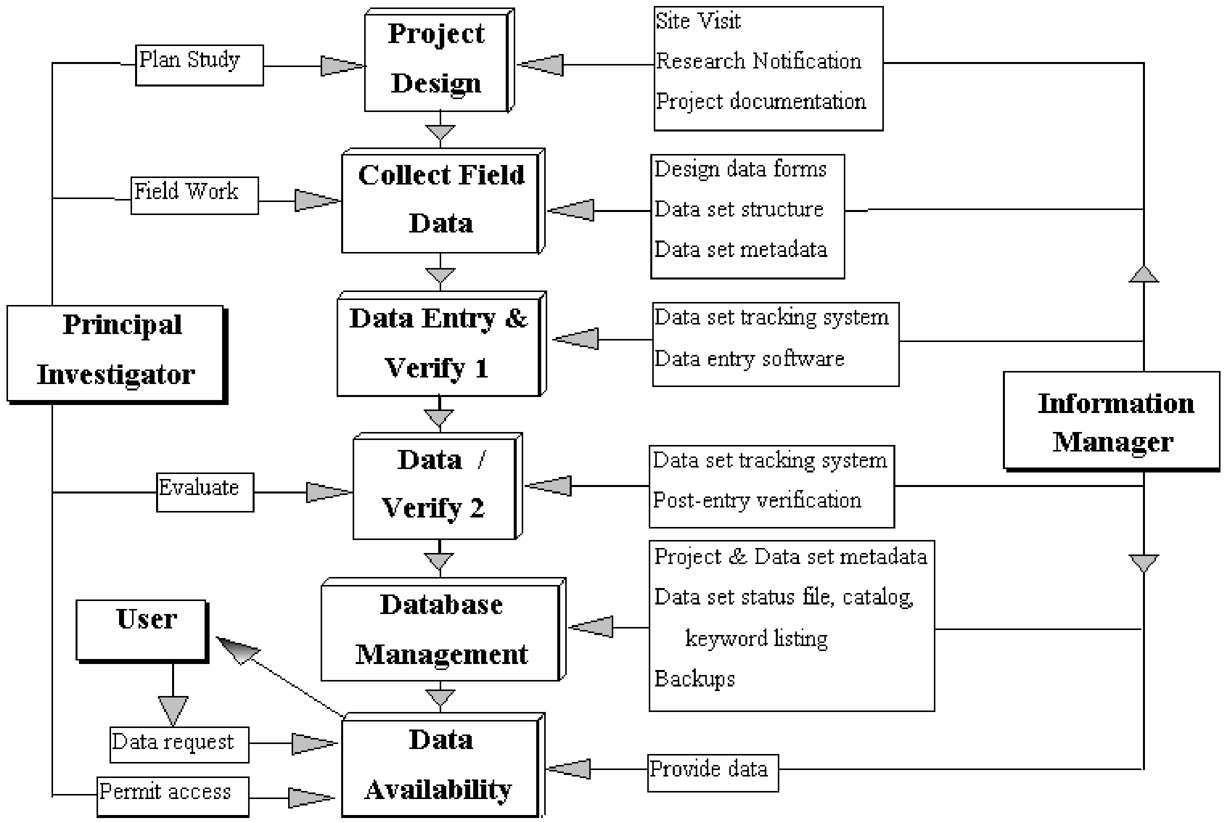

Figure 13. Jornada data management process

up using the CommVault Backup solution. We back up all of our Virtual Servers and file systems to disk and then to tape for offsite storage. The data are on disk for 90 days. The backup to tape is done once a month and we can store three monthly backups and biannual backups.

Our goal is to make this process more streamlined and automated by developing and implementing the following: 1) a web interface for online data set submission that generates and verifies metadata automatically; 2) scripts for automatically detecting errors in sensory network data in real time; 3) tools to allow users to query all data sets by spatial and temporal attributes, and; 4) tools to allow users to interactively link, visualize, and analyze data sets on our website.

In compliance with the REE Data Initiative, the Jornada is making all data sets available via the National Agricultural Library (NAL). The NAL will provide users either the data sets themselves or with links to the data sets on the Jornada Data Catalog. In December 2017, 74 Jornada data sets were successfully harvested into the Provenance Aware Synthesis Tracking Architecture database (PASTA; the LTER data repository) and are available for automatic ingestion into NAL databases.

PROJECT MANAGEMENT AND EVALUATION

Category 1 scientists participating in the proposed project have been with this unit for a minimum of 8 years. 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. Category I vacant positions will assist the lead scientists once they are hired and may lead or expand certain components, and in the event of a lengthy hiring delay, postdocs and students will be able to complete needed tasks.

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 manages numerous extramural research agreements that link project research objectives to similar objectives of partner agencies and institutions (Appendix 3). These 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.

MILESTONE TABLE

SY Team:
AR – Al Rango
DP – Deb Peters
JH – Jeffrey Herrick
BB – Brandon Bestelmeyer
DB – Dawn Browning
RE – Richard Estell

Project Title	Science and Technologies for the Sustainable Management of Western Rangeland Systems		**Project No.**	3050-11210-008-00D **9/25/17 – 9/24/22**	
National Program	216 - Agricultural Systems Competitiveness and Sustainability				
Objective	1: Develop or improve livestock management and restoration practices to promote resilience to climate variability and adaptation to increasingly shrub-dominated environments.				
Subobjective	1A: Compare productivity and environmental impacts of Raramuri Criollo cattle to conventional livestock production systems in the arid southwest.				
NP Action Plan Component	1: Building Agroecosystems for Intensive, Resilient Production via GxExM				
NP Action Plan Problem Statement	1b: Sustainable & resilient grazing land systems				
Research Hypothesis	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Criollo cattle will exhibit characteristics and behaviors that translate to different impacts on long-term plant community dynamics and will require fewer external inputs than conventional breeds.	RE	12	Implement field study		
		24			
		36	Analyze initial animal behavior data		
		48			
		60	Complete data analyses and interpret effects of breeds on vegetation dynamics		Publications, workshop materials, publication summaries for producers
Subobjective	1B: Develop collaborative science approaches to test the efficacy of practices to recover and sustain perennial grass cover in the desert grassland region				
NP Action Plan Component	1: Building Agroecosystems for Intensive, Resilient Production via GxExM				
NP Action Plan Problem Statement	1b: Sustainable & resilient grazing land systems				
Research Hypothesis	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Grass recovery rates can be predicted by variation in climate, inherent soil water holding capacity, and surface soil function	BB	12	Establish DuRP study		
		24	Complete Restore NM analysis for 10 y/5y datasets and report		
		36	Complete soil water monitoring in DuRP		
		48	Initiate restoration trials in DuRP		
		60	Report DuRP results to stakeholders		Publications, restoration guideline documents, workshops
Objective	2: Leveraging temporal and spatial datasets from the Jornada and surrounding region, design and implement big data-model integration approaches to predict and/or resolve disease outbreaks and other regional agricultural problems.				
Subobjective	2A: Develop a strategy and operational framework for agricultural grand challenges that require big data and trans-disciplinary scientific expertise based on spatio-temporal modeling of cross-scale interactions coupled with human and machine learning				
NP Action Plan Component	3: Achieving Agroecosystem Potential				
NP Action Plan Problem Statement	3c. 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**

Identify processes (fine-scale, spatially contagious) and environmental factors governing local to landscape- and regional-scale patterns in disease or other ecological responses occurring in different years or periods	DP	12	Collect datasets relative to scale-specific processes for years when VS occurs in US since 2004, including fine-scale datasets on irrigation channels and animal movement		
		24	Integrate and harmonize data		
		36	Conduct premise-level and landscape-scale analyses to identify processes and factors explaining within-county patterns in VS occurrence		
		48	Conduct broad-scale analyses across the region to understand reasons why VS stops spreading spatially		
		60	Analyze and interpret VS results in light of other complex GC problems		Publications on VS and big data analytical procedures, predictive spatial models
Subobjective	2B: Develop national wind erosion assessments using big data and models developed through the National Wind Erosion Research Network.				
NP Action Plan Component	3: Achieving Agroecosystem Potential				
NP Action Plan Problem Statement	3b: Enhancing ecosystem services				
Research Goal	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Create national datasets and management- and policy-relevant tools to assess wind erosion rates and their responses to land use and land cover change across US agroecosystems.	JH	12	Standardized monitoring protocols and training implemented across National Wind Erosion Research Network		
		24	All-lands wind erosion model calibrated for cropland and rangeland applications		
		36	Database system to store standardized monitoring data developed and accessible to public		
		48	Regional simulations of wind erosion patterns and trends conducted		
		60	Wind erosion information analyzed in context of ecological sites		Publications, database, improved AERO model, simulation GIS products
Objective	3: Improve understanding of ecological state change in the desert grassland region through synthesis and analysis of long-term climate, vegetation, and livestock data, alongside numerous ongoing short- and long-term experiments, including how gradual and abrupt transitions occur in rangeland agroecosystems and how they can be managed				
Subobjective	3A: Predict alternative states in western rangelands by integrating multiple lines of evidence including spatiotemporal modeling.				
NP Action Plan Component	1: Building Agroecosystems for Intensive, Resilient, Production via GxExM				

NP Action Plan Problem Statement	1b: Sustainable & resilient grazing land systems				
Research Goal	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Understand the processes (fine-scale, spatially contagious) and environmental factors governing historic state change dynamics and predict state change dynamics under alternative climate and management scenarios for under-sampled locations and future time periods.	DP, BB	12	Identify standard set of variables and datasets and initiate standardization		
		24			
		36	Complete spatial database of existing data		
		48	Complete soil map and design models		
		60	Predict dynamics for under-sampled locations and future time periods under alternative scenarios		Publications on state change processes and procedures for spatial extrapolation
Subobjective	3B: Formulate phenological indicators of gradual and abrupt changes in primary production using remotely-sensed image time series and characterize plant seasonal dynamics to verify these indicators with long-term datasets.				
NP Action Plan Component	1: Building Agroecosystems for Intensive, Resilient, Production via GxExM				
NP Action Plan Problem Statement	1b: Sustainable & resilient grazing land systems				
Research Goal	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Evaluate relationships between field observations and remotely-sensed phenological indicators to develop forecasts of change in rangelands and other agroecosystems	DB	12	Develop framework for integrating phenological metrics in livestock management		
		24	Compile and standardize satellite image time series		
		36	Quantify and evaluate phenological indicators denoting abrupt change in production		
		48			
		60	Implement and evaluate phenological indicators of change at locations outside JER		Publications on novel phenological indicators and their use
Objective	4. Complete development of a new database to improve quality, accessibility, and utility of Ecological Site Description (ESD) information nationwide, and collaborate with NRCS to complete national population of ESD information				
NP Action Plan Component	3: Achieving Agroecosystem Potential				
NP Action Plan Problem Statement	3c: Enabling decision support sustainability				
Research Goal	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Create and transfer to the NRCS a new database (EDIT) to house Ecological Site Descriptions that increases their scientific rigor, utility, and availability	BB	12	Complete beta test of EDIT functionality with NRCS users		
		24	Complete intake of ESIS database into EDIT		
		36	Develop new tables for linkage to conservation practices and implement training program		
		48			
		60	Finalize provisional ESDs in EDIT, pending NRCS timelines		Publications and publically accessible EDIT database and related mobile apps

Objective	5. Develop tools and techniques for managing and integrating ground-based assessment and monitoring data, remotely sensed and digital spatial data, and connect data to interpretive frameworks and models to develop actionable interpretations for land management				
Subobjective	5A: Develop, test and support adoption of data collection, data processing, analysis and interpretation tools to support federal and private land management monitoring efforts				
NP Action Plan Component	2: Increasing Efficiencies for Agroecosystem Sustainability				
NP Action Plan Problem Statement	2b: Technologies to Enhance Efficiency				
Research Goal	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Provide guidance to rangeland monitoring programs to collect and manage high quality standardized data, and to develop analysis and interpretation tools to provide decision support information and frameworks to land managers	JH	12	Standardized rangeland monitoring training and QA&QC procedures developed, drafted and tested.		
		24	Revised monitoring manual published.		
		36	Geodatabase to store standardized monitoring data and indicator calculations created and deployed.		
		48			
		60			Publications including manuals and region-scale science products, geodatabase for use by managers and scientists
Subobjective	5B: Support Outcome-based land management, including grazing management, by developing, testing and facilitate adoption of a data collection and decision support system that increases land manager ability to monitor their land, and to access, evaluate, integrate and apply local and scientific knowledge				
NP Action Plan Component	2: Increasing Efficiencies for Agroecosystem Sustainability				
NP Action Plan Problem Statement	2c: Decision support				
Research Goal	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**
Develop and implement a flexible, user-friendly decision support system with integrated data collection functions that leverages existing information and knowledge-bases	JH, BB	12	LandPKS soil identification enabled and first version of management module deployed		
		24			
		36	LandPKS data interpretation deployed and used		
		48			
		60	LandPKS-EDIT integration complete		Mobile applications and publications on development and use

Objective	6. Develop new tools and information to assist agricultural stakeholders in coping with climate variability through: research, science translation and information synthesis; tool development and technology transfer; and stakeholder outreach and education. (Southwest Regional Climate Hub)				
Subobjective	6A: Climate variability effects on rangeland production and water				
NP Action Plan Component	3: Achieving Agroecosystem Potential				
NP Action Plan Problem Statement	3c: Enabling decision support sustainability				
Research Goal	**SY Team**	**Months**	**Milestones**	**Progress/Changes**	**Products**

Advance and disseminate understanding of future sustainability of southwestern agricultural and rangeland systems under increasing climate variability and change	AR, BB, DB	12			
		24	Complete analysis of RMA and After Fire toolkit		
		36			
		48	Complete streamflow climate scenario analysis		
		60	Complete agricultural hotspot analysis		Publications, web-based applications and materials, extension products

Objective	7: Operate and maintain the Jornada Experimental Range LTAR network site using technologies and practices agreed upon by the LTAR leadership. Contribute to the LTAR working groups and common experiments as resources allow. Submit relevant data with appropriate metadata to the LTAR Information Ecosystem.
NP Action Plan Component	1: Building Agroecosystems for Intensive, Resilient Production via GxExM
NP Action Plan Problem Statement	1d: Long Term Agroecosystem Research (LTAR) Network

Research Goal	SY Team	Months	Milestones	Progress/Changes	Products
Leverage LTAR network interactions to produce new knowledge to advance sustainable intensification in US agroecosystems	BB, RE	12			
		24	Complete Manureshed project		
		36	Complete LTAR-site wind erosion analysis		
		48	Finalize modelling of Southwestern beef production		
		60	Complete application of phenology indicators to participating LTAR sites		Jornada-led and co-authored publications reflecting LTAR network science

ACCOMPLISHMENTS FROM PRIOR PROJECT PERIOD

1. Terminating ARS research project number: 6235-11210-007-00D
2. Title: Management Technologies for Conservation of Western Rangelands
3. Project period: 9/25/12 – 9/24/17
4. Investigators: Dean M. Anderson, Brandon T. Bestelmeyer, Richard E. Estell, Kris M. Havstad, Jeffrey E. Herrick, Debra C. Peters, Albert Rango, Jason Karl, Dawn Browning (Post docs: Emile Elias, Matt Levi, Jonathan Maynard, Julian Reyes, Shawn Salley, Sheri Spiegal, Caiti Steele, Nicholas Webb, Jin Yao)
5. Project accomplishments and impact: The following subsections capture the key elements of our research program productivity by ARS scientists and our colleagues working at the Jornada over the past 5 years.

Publications and funding. We published a combined average of 45 papers, book chapters, and proceedings papers per year, and a total-to-date for the last 5 years of 177 journal articles and 34 book chapters and proceedings papers. The EcoTrends synthesis, based on standardized long-term data from 50 long-term sites and leading to our big data approaches, was published in 2013. In addition, we developed journal special issues for Rangeland Ecology and Management (November 2012), Frontiers in Ecology and Environment (February 2015), and Rangelands (April 2014, December 2016). We also supported production, chapter authorship, and open access to a new textbook on rangeland ecology and management, Rangeland Systems: Processes, Management, and Challenges (D. D. Briske, ed.), Springer, 2017. Several of our papers occurred in high visibility/impact journals, including Nature, Trends in Ecology and Evolution, BioScience, and Ecology Letters. Our 10 most significant publications (Table 2) over the past 5 years were selected based on: impact on Jornada research development, significance to agricultural research, contribution to theory and general understanding of agroecological systems, and impact on land management. We have been awarded, as Principal Investigators, from 2012-2017 an average of $3.2M/yr in support of our collaborative research. These extramural awards have been primarily from the National Science Foundation, the Department of Defense, the NRCS, USAID, and the BLM. All of these funds have been used in support of our scientific activities directly related to our ARS research objectives.

1. Protocols for data-driven ecological site descriptions. A general framework for integration of various data types for Ecological Site Description production was developed and tested by Jornada scientists using data collected from several locations in the western U.S. Trainings were developed for these concepts and performed for the BLM on use of ecological sites for planning. Training and analytical support for development of ecological site descriptions were also provided in Argentina and Mongolia. A strategy for automated assignment of soil map units to ecological site classes was devised in collaboration with NRCS and strategies for mapping ecological sites and states were developed and refined. These efforts have improved the consistency and quality of ecological site descriptions produced by interagency groups and enhanced the ability of land managers globally to make science-informed land management decisions.

2. Ecological dynamics national database. General models of vegetation change at regional scales are needed to improve consistency of state-and-transition models (STMs) among ecological sites. Jornada scientists developed and refined a database to house national ecological site information and imported data from the NRCS Ecological Site Information System into the database, known as the Ecosystem Dynamics Interpretive Tool. This web-accessible database provides a mechanism for rapid communication and updating of management options to the public and policymakers, with consistent, evidence-based concepts for state-and-transition model development. The database continues to be refined via collaborations with NRCS National Program staff. The database dramatically improves the quality of ecological site products for land managers and decision makers, and increases public awareness of ecosystem change in the U.S.

3. Innovative approaches for remotely monitoring land surface conditions. Improved remote sensing methodologies and data acquisition technologies are needed to quickly and accurately map and monitor rangelands and inform land managers. The Unmanned Aircraft System (UAS) program at the Jornada was expanded to increase payload and instrumentation capabilities to improve spatial and spectral resolution. Time series UAS imagery was used to develop a protocol for accurately mapping rangeland vegetation. Remotely sensed data were also used to monitor plant phenology. Ground verification of remotely sensed estimates of canopy greenness from multiple data sources, including tower cameras (phenocams), UAS-based digital imagery, and satellite sensors (Landsat and MODIS), demonstrated that inexpensive phenocams provide valuable data in near real-time. These technologies are being used to rapidly obtain accurate information regarding the land surface for monitoring vegetation over much larger areas at reduced cost.

4. Tools and techniques for multi-scale inventory, monitoring, and assessment. Standardized approaches for monitoring rangelands are needed to allow land managers and public land agencies to collect and share data that address numerous rangeland management and policy needs. Jornada scientists led development and implementation of core monitoring indicators, field methods, and sampling design techniques that are now being applied to over 500 million acres of BLM and private land (via NRCS National Resource Inventory) in the U.S. Jornada scientists also created web-based tools for monitoring program design, data analysis and reporting, mobile and tablet-based data collection applications, and extensive training modules that are used by U.S. agencies and international partners. The inventory, monitoring, and assessment techniques and tools and resources (available via landscapetoolbox.org) developed at the Jornada provide managers and policy makers with information needed to manage resources at local to continental scales over millions of acres of rangelands.

5. Land-Potential Knowledge System (LandPKS) development and implementation. Land managers currently lack an efficient system for accessing and sharing knowledge about land management that is relevant to the potential of their land. Because land potential depends on soil, topography and climate, the identification of appropriate management systems begins by matching areas with similar conditions. Jornada scientists developed two new smart-phone applications that allow managers to use a mobile phone to rapidly collect and store soil and topographic information (LandInfo) and monitor vegetation (LandCover) for a given area. The LandPKS app functions on iOS and Android phones and tablets. Algorithms were developed to identify soils based on user inputs, and a feature was added to determine soil color using smartphone cameras. This app has increased the ability of land managers to identify appropriate management options for a particular site.

6. Tools for scientific information dissemination. A thorough literature search is necessary to conduct meaningful research, identify appropriate land management techniques, and avoid duplicating previous efforts. JournalMap was developed by Jornada scientists to advance the ARS's mission to develop and transfer solutions to agricultural problems in the U.S. and globally. JournalMap is the first true map-based search engine for scholarly publications and has expanded the ability of the scientific community to quickly and easily locate relevant knowledge in scientific literature based on geographic location. This search engine allows scientists to locate relevant research for specific or similar locations worldwide, avoid duplication of efforts and wasted resources, and assist with the identification of new analytical methods. The Jornada will continue to support this effort, that was led by a former ARS scientist (Jason Karl) who recently took a university position.

7. Evaluation of conservation practices. Conservation practices to maintain or restore desired ecosystem states are often applied without a clear understanding of their effects on various ecosystem services. The lack of information on conservation effects can lead to undesired outcomes and wasted resources. Jornada scientists collaborated with the BLM to test effects of brush management and fire on different ecological sites as part of the BLM's Restore New Mexico monitoring program. Monitoring sites continue to be added to this on-going program (currently 180 total monitoring sites, including experimental and observational sites) and preliminary data analyses have been performed. This long-term monitoring effort will benefit agencies, producers and land managers by providing information about where brush management practices have the most potential for success.

8. Low input livestock production strategies. Arid and semiarid regions of the western U.S. experience droughts and environmental extremes that result in highly variable and often low forage production that can restrict beef production. New world cattle biotypes offer opportunities to match genetic traits with rangeland environments. Raramuri Criollo cattle were compared to conventional breeds (Angus x Hereford crosses) typically found in the region. An economic analysis of the two production systems was conducted. Although marketing opportunities are limited for the smaller-framed Raramuri Criollo, they compared favorably with traditional Angus crosses, in part because they flourish in harsh desert environments with fewer inputs and utilize forage further from water. Diet selection of Angus crossbreds and Criollo cattle was also examined. Preliminary analyses suggest wide differences in diet diversity between the two breeds. Biotypes that are productive in shrub-dominated desert environments will benefit beef producers in arid regions.

9. Prediction of climate-driven vegetation state changes. Directional decreases or increases in precipitation are predicted for aridlands in the future. Long-term data from the Jornada that included multi-year drought and wet periods were used to predict the response of perennial grasses on sites dominated by different shrub species (mesquite, creosotebush, and tarbush) under future drier or wetter climate scenarios. Production was linearly related to rainfall during drought and no-trend years. However, during an extended wet period, a nonlinear increase in grass production occurred. The fastest grass response occurred in mesquite-dominated sites, intermediate responses in tarbush-dominated sites, and slowest responses in creosote-dominated sites. These site-specific responses were related to soil texture and plant available water. Results were used to parameterize mechanistic models that are being used to predict state changes from shrub- to grass-dominated under alternative land use-climate scenarios.

10. Wind erosion network development and implementation. Rangeland wind erosion results in reduced soil productivity, highway fatalities, human health problems, and infrastructure damage. Methods to accurately measure and model effects of management practices on wind erosion are needed in order to mitigate this problem. A wind erosion monitoring network was established as part the National Wind Erosion Research Network and the LTAR Wind Erosion Research Network to provide a framework for the long-term study of wind erosion on multiple ecological sites across the Western U.S. A standardized set of protocols was developed to measure impacts of management strategies and land use change, and to improve existing wind erosion models. Network sites were selected and established that collect a suite of measurements (e.g., sediment mass flux, meteorological conditions, dust deposition) in real time (15 locations currently in operation). New insights into spatial and temporal patterns of wind erosion across land use and land cover types will inform producers and land managers regarding land use practices that help reduce wind erosion and improve land management.

11. Rio Grande Basin watershed characterization. Increased knowledge of the characteristics and capacities of watersheds in the Rio Grande Basin is crucial to understanding their ability to deliver water to farmers and ranchers that depend on these systems. Twenty four selected sub-basins of the Upper Rio Grande were used to estimate snowmelt runoff and improve hydrologic modeling and water supply predictions. High density, ground-based hydrologic instruments were installed and data from these highly instrumented basins are being used to provide runoff estimates from two major mountain ranges, the San Juan Mountains and Sangre de Cristo Mountains. The Snowmelt Runoff Model (SRM) was revised to improve its ability to assess effects of climatic variability on runoff predictions under multiple scenarios. The model was tested on 10 basins across the Southwest with standard condition simulations and under variable climate scenarios. The SRM is being used by the hydrological modeling community to forecast snowmelt runoff on which farmers and ranchers rely.

12. K-12 Science Education materials on climate change. The Jornada established a cooperative agreement with the Asombro Institute for Science Education to develop educational materials for teachers and students about energy conservation and the impacts of climate change as part of the Southwest Regional Climate Hub for Risk Adaptation and Mitigation of Climate Change. An energy audit classroom program for 7th graders was developed and tested in Las Cruces Public Schools and then expanded to grades 7-12. The program teaches climate-smart and energy conservation concepts that will be used in urban and rural schools throughout the Southwest region. A unit entitled Climate Change and the Hydrologic Cycle was completed and tested and is available for educators in both English and Spanish (http://swclimatehub.info/education/climate-change-and-water-cycle). Kits with all necessary materials were distributed to an “early adopter” teacher in each Southwest Hub State (AZ, NM, UT, CA, NV and HI) and the Navajo Nation. A second module, Climate Change and Agriculture, is in the final stages of testing and refinement.

13. Climate smart decision-making technologies. Partnerships were established with New Mexico, Arizona, Hawaii, Nevada, and Utah to develop climate-smart decision-making tools. As a member of the USDA Southwest Climate Hub, Jornada scientists participated in developing, synthesizing and providing information to assist Southwestern farmers, ranchers and foresters in strategically adapting to climate variability. Education specialists developed climate-smart curricula for use by specially trained middle school teachers. The group developed the Climate Hub Tool Shed (http://tools.serch.us/tbl_tools_list.php), specialty crop fact sheets for vital crops grown in the region (http://swclimatehub.info/publications-research), and an online adaptation menu for crops, livestock and forestry (http://swclimatehub.info/adaptation-menu-crops). Jornada scientists also worked with NRCS to build a template for regional drought vulnerability assessments using the Major Land Resource Area geographic database and state and transition models, linking adaptation options to improve rangeland resilience during drought. The SWCH also partnered with Farm Services Agency and ranchers to build a more comprehensive system of precipitation measurement via the Community Collaborative Rain, Hail and Snow (CoCoRAHS) network. Precipitation data collected by producers feed into the U.S. Drought Monitor, which provides weekly updates on drought conditions across the U.S. The group also partnered with the Forest Service to create a tool for forest managers hosted on-line: https://postfiresw.info/ that provides a toolbox of information, resources, funding and publications related to managing the landscape following wildfire.

Table 2. Ten most significant publications from 2013-2018 led by Jornada staff

Authors	Journal citation	Impact or significance
Spiegal, S., Bestelmeyer, B.T., Archer, D.W., Augustine, D.J., Boughton, E.B., Boughton, R.K., Cavigelli, M.A., Clark P.E., Derner, J.D., Duncan, E.W., Hapeman, C., Harmel, D.H., Heilman, P., Holly, M.A., Huggin,s D.R., King, K., Kleinman, P.J.A., Liebig, M.A., Locke, M.A., McCarty, G.W., Millar, N., Mirsky, S.B., Moorman, T.B., Pierson, F.B., Rigby, J.R., Robertson, G.P., Steiner, J.L., Strickland, T.C., Swain, H.M., Wienhold, B.J., Wulfhorst, J.D., Yost, M.A., Walthall, C.L.	2018. Evaluating strategies for sustainable intensification of US agriculture through the Long-Term Agroecosystem Research network *Environmental Research Letters*, 13 034031.	Synthesis of the LTAR common experiment that provides national overview of LTAR activities and provides foundation for future network-level research
Browning, D. M., Maynard, J.J., Karl, J. W., Peters, D.P.C.	2017. Breaks in MODIS time series portend vegetation change: verification using long-term data in an arid grassland ecosystem. *Ecological Applications*. 27:1677-1693.	New approach to detection of changes in land condition based on phenological patterns and longer-term trends.
Elias, E.H., Schrader, T.S., Abatzoglou, J.T., James, D., Crimmins, M., Weiss, J., Rango, A.	2017. County-level climate change information to support decision-making in working lands. *Climatic Change*, https://doi.org/10.1007/s10584-017-2040-y.	New tool for downscaled climate information and represents vision for multiple web-based tools we will develop.
Webb, N.P., Herrick, J.E., Van Zee, J.W., Courtright, E. et al.	2016. The National Wind Erosion Research Network Building a standardized long-term data resource for aeolian research, modeling and land management. *Aeolian Research*. 22:23-36	Describes establishment and vision for Wind Erosion Research Network
Havstad K.M., Brown J.R., Estell R., Elias E., Rango A., Steele C.	2016. Vulnerabilities of Southwestern U.S. rangeland-based animal agriculture to climate change. *Climatic Change* 10.1007/s10584-016-1834-7	Climate-informed outlook that is guiding many research activities
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PAST ACCOMPLISHMENTS OF 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

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:

Dr. Estell developed a program to examine the biochemical basis of diet selection. Dr. Estell identified tarbush (a common unpalatable shrub) as a shrub model for exploring phytochemistry-herbivore relationships, and characterized its nutritional and toxicological attributes and secondary chemistry profile. Dr. Estell demonstrated that livestock discriminate between individual plants when forced to consume tarbush, and this differential use was related to epicuticular wax concentration. Dr. Estell showed that removal of compounds from tarbush with organic solvents increased consumption by sheep, and that crude fractions isolated from sequential extractions of tarbush with hexanes, ether, and ethanol all dramatically decreased consumption when applied to alfalfa pellets. Dr. Estell identified relationships of specific mono- and sesquiterpenes to degree of use by livestock and established a protocol for a bioassay to test effects of specific chemicals on intake by sheep. Four (camphor, α-pinene, camphene, and caroyphyllene oxide) of the 25 compounds tested reduced intake when applied individually to alfalfa pellets. Dr. Estell tested mixtures of monoterpenes and sesquiterpenes and demonstrated a relationship between sesquiterpenes and intake. Dr. Estell collaborated to study the role of secondary chemistry in shrub consumption by ruminants and mechanisms to increase intake of unpalatable shrubs. Collectively, these efforts have contributed to the view that rangeland science should explore a variety of novel approaches to enhance livestock use of shrubs in the face of ongoing shrub encroachment and grassland loss in arid regions. Recently, Dr. Estell built an innovative, collaborative research program to understand the ecology and production potential of a little known cattle biotype--the Raramuri Criollo which has undergone >500 years of natural selection in shrub-dominated landscapes-- that could provide a new option for livestock production in arid rangelands. Preliminary results suggest Criollo exhibit a broader diet breadth and a wider distribution pattern than conventional British crossbred cattle in extensive arid rangelands.

Peer-reviewed Publications:

1. 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. Appl. Anim. Behav. 107:58-65.
2. **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 Rumin. Res. 73:272-276.

3. 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. J. Chem. Ecol. 33:1867-1875.
4. **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. J. Anim. Sci. 86:1478-1484.
5. Rogosic, J., **Estell, R.E**., Ivankovic, S., Kezic, J. and Razov, J. 2008. Potential mechanisms to increase shrub intake and performance of small ruminants in Mediterranean shrubby ecosystems. Small Rumin. Res. 74:1-15.
6. Lucero, M.E., **Estell, R.E.**, Tellez, M.R., Fredrickson, E.L. 2009. A retention index calculator simplifies identification of plant volatile organic compounds. Phytochem. Anal. 20:378-384.
7. **Estell, R.E.** 2010. Coping with shrub secondary metabolites by ruminants. Small Rumin. Res. 94:1-9.
8. **Estell, R. E.**, Utsumi, S. A., Cibils, A. F. 2010. Measurement of monoterpenes and sesquiterpenes in serum, plasma, and rumen fluid from sheep. Anim. Feed Sci. Tech. 158:104-109.
9. 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 Ecol. Manage. 63:373-386.
10. **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 Ecol. Manage. 65:553-562.
11. Anderson, D.M., **Estell, R.E.**, Cibils, A.F. 2013. Spatiotemporal cattle data - a plea for protocol standardization. Positioning 4:115-136.
12. **Estell, R.E.**, James, D.K., Fredrickson, E.L., Anderson, D.M. 2013. Within-plant distribution of volatile compounds on the leaf surface of Flourensia cernua. Biochem. Syst. Ecol. 48:144-150.
13. Utsumi, S.A., Cibils, A.F., **Estell, R.E.**, Soto-Navarro, S.A., Chen, L., Hallford, D.M. 2013. Effects of adding protein, condensed tannins, and polyethylene glycol to diets of sheep and goats fed one-seed juniper and low quality roughage. Small Rumin. Res. 112:56-68.
14. Anderson, D.M., **Estell, R.E.**, Schrader, T.S. 2014. Calculating foraging area using global navigation satellite system (GNSS) technology. Rangelands 36:31-35.
15. **Estell, R.E.**, Havstad, K.M., Cibils, A.F., Anderson, D.M., Schrader, T.S. 2014. The changing role of shrubs in rangeland-based livestock production systems: Can shrubs increase our forage supply? Rangelands 36:25-31.
16. **Estell, R.E.**, Utsumi, S.A., Cibils, A.F., Anderson, D.M. 2014. Is differential use of Juniperus monosperma by small ruminants driven by terpene concentration? J. Chem. Ecol. 40:285-293.
17. Anderson, D.M., **Estell, R.E.**, Gonzalez, A.L., Cibils, A.F., Torell, L.A. 2015. Criollo cattle: Heritage genetics for arid landscapes. Rangelands 37:62-67.
18. **Estell, R.E.**, Anderson, D M., James, D.K. 2016. Defoliation of Flourensia cernua (tarbush) with high-density mixed-species stocking. J. Arid Env. 130:62-67.
19. **Estell, R.E.**, Fredrickson, E.L., James, D.K. 2016. Effect of light intensity and wavelength on concentration of plant secondary metabolites in the leaves of Flourensia cernua. Biochem. Syst. Ecol. 65:108-114.
20. Nyamuryekung’e, S., Cibils, A.F., **Estell, R.E.**, Gonzalez, A.L. 2016. Use of an unmanned aerial vehicle-mounted video camera to assess feeding behavior of Raramuri Criollo cows. Rangel. Ecol. Manage. 69:386-389.

PAST ACCOMPLISHMENTS OF BRANDON T. BESTELMEYER
SUPERVISORY 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

2016-present	Supervisory Research Ecologist, Range Management Research Unit USDA, ARS, Las Cruces, NM
2003- 2016	Research Ecologist, Range Management Research Unit USDA, ARS, Las Cruces, NM
2000-2003	Postdoctoral Ecologist, Range Management Research Unit USDA, ARS, Las Cruces, NM

Accomplishments:
Dr. Bestelmeyer developed concepts and protocols for the production of state-and-transition models within Ecological Site Descriptions that have been incorporated into national interagency (USDA Natural Resources Conservation Service [NRCS], Bureau of Land Management [BLM], and US Forest Service [USFS]) guidelines. These protocols were also recently adopted by the national government of Mongolia and applied by a government agency in Argentina. A new database structure was developed to house and disseminate Ecological Site Description information. Dr. Bestelmeyer conceived applications of model-based information for monitoring and management with the BLM and in Mongolia. Research on the role of soil properties and spatial heterogeneity in state transitions has influenced Ecological Site Description development and led to the adoption of new soil surface indicators by NRCS. Dr. Bestelmeyer led a network of researchers from a variety of ecosystems to develop novel concepts and methods for general analysis of ecological dynamics and, more specifically, vegetation states and transitions. Empirical work on ecological thresholds has provided new insights to desertification processes and the use of indicators in management.

Peer-reviewed Publications:

1. **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.
2. **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.
3. **Bestelmeyer, B**., Moseley, K., Shaver, P., Sanchez, H., Briske, D., Fernandez-Gimenez, M. 2010. Practical guidance for developing state-and-transition models. Rangelands 32: 23-30.
4. **Bestelmeyer, B.,** Ellison, A., Fraser, W.R., Gorman, K., Holbrook, S.J., Laney, C., Ohman, M.D., Peters, D.C., Pillsbury, F. C., Rassweiler, A., Schmitt, R.J. 2011. Analysis of abrupt transitions in ecological systems. Ecosphere 2:1-26.
5. **Bestelmeyer, B.T.,** Goolsby, D., Archer, S.R. 2011. Spatial perspectives in state-and-transition models: a missing link to management? Journal of Applied Ecology 48:746-757.
6. **Bestelmeyer, B.T.,** Briske, D. D. 2012. Grand challenges for resilience-based management of rangelands. Rangeland Ecology and Management 65:654-663.

7. **Bestelmeyer, B.T.,** Estell, R.E., Havstad, K.M. 2012. Big questions emerging from a century of rangeland science and management. Rangeland Ecology and Management 65:542-544.
8. Steele, C., **Bestelmeyer, B.T.**, Burkett, L.M., Smith, P., Yanoff, S. 2012. Spatially explicit representation of state-and-transitions models. Rangeland Ecology and Management 65:213-222.
9. Bagchi, S., Briske, D.D., Wu, X.B., McClaran, M.P., **Bestelmeyer, B.T.**, Fernandez-Gimenez, M. 2012. Empirical assessment of state-and-transition models with a long-term vegetation record from the Sonoran Desert. Ecological Applications: 22:400-411.
10. Williamson, J., **Bestelmeyer, B.T.**, Peters, D.C., 2012. Spatiotemporal patterns of production can be used to detect state change across an arid landscape. Ecosystems 15:34-47.
11. **Bestelmeyer, B.T.**, Duniway, M.C., James, D.K., Burkett, L.M., Havstad, K.M. 2013. A test of critical thresholds and their indicators in a desertification-prone ecosystem: more resilience than we thought. Ecology Letters 16:339-345.
12. Sayre, N., McAlister, R., **Bestelmeyer, B.T.**, Moritz, M., Turner, M. 2013. Earth stewardship on rangelands: Coping with ecological, economic, and political marginality. Frontiers in Ecology and the Environment 11:348-354.
13. Coffman, J., **Bestelmeyer, B.T.**, Kelly, J.F., Wright, T.F., Schooley, R.L. 2014. Restoration practices have positive effects on breeding bird species of concern in the Chihuahuan Desert. Restoration Ecology 22:336-344.
14. Standish, R., Hobbs, R., Mayfield, M., **Bestelmeyer, B.,** Suding, K., Battaglia, L., Eviner, V., Hawkes, C., Temperton, V., Cramer, V., Harris, J., Funk, J., Thomas, P.A. 2014. Resilience in ecology: abstraction, distraction, or where the action is? Biological Conservation 177:43-51.
15. **Bestelmeyer, B.T.,** Okin, G.S., Duniway, M., Archer, S.R., Sayre, N., Williamson, J., Herrick, J.E. 2015. Desertification, land use, and the transformation of global drylands. Frontiers in Ecology and the Environment 12:28-36.
16. Svejcar, L.N., **Bestelmeyer, B.T.**, Duniway, M., James, D. Scale-dependent feedbacks between patch size and plant reproduction in desert grassland. Ecosystems 18:146-153. 2015.
17. **Bestelmeyer, B.T.** 2015. National assessment and critiques of state and transition models: The baby with the bathwater. Rangelands 37:125-129.
18. **Bestelmeyer, B.T**., Williamson, J.C., Talbot, C.J., Cates, G.W., Duniway, M.C., Brown, J.R. 2016. Improving the effectiveness of Ecological Site Descriptions: general state and transition models and the Ecosystem Dynamics Interpretive Tool (EDIT). Rangelands 38(6):329-335.
19. Williamson, J.C., **Bestelmeyer**, **B.T**., McClaran, M.P., Robinett, D., Briske, D.D., Wu, X.B., Fernandez-Gimenez, M. 2016. Can ecological land classification increase the utility of long-term monitoring data? Ecological Indicators 69: 657-666.
20. Ratajczak, Z., D'Odorico, P., **Bestelmeyer**, **B.T.**, Collins, S.L., Isbell, F.I., Nippert, J. B. The interactive effects of press/pulse intensity and duration on regime shifts at multiple scales. Ecological Monographs 87:198–218. 2017.

PAST ACCOMPLISHMENTS OF DAWN M. BROWNING, RESEARCH ECOLOGIST

Education:

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

Work Experience:

2013-present	Research Ecologist, Range Management Research Unit, USDA, ARS, Las Cruces, NM
2009-2013	Post-doctoral Physical Research Scientist, Range Management Research Unit, USDA, ARS, Las Cruces, NM
2007-2009	Instructor, University of Arizona, Tucson, AZ

Accomplishments:
Dr. Browning devised a multi-scale approach to document seasonal patterns in primary production (i.e., plant phenology) in arid lands using platforms that range from field to near-surface camera to satellite. This approach along with prior work using time series aerial photography yields insights regarding vegetation dynamics and ecological state change at broad spatial extents. Dr. Browning bridges the fields of ecology and remote sensing to quantify vegetation state change and generate image-based data products designed to inform decision-making. Published studies have focused on shrub-encroached ecosystems in the Sonoran and Chihuahuan Deserts of the southwestern U.S. and assessment of remotely-sensed indicators of land surface condition and vegetation change. Dr. Browning has mentored three graduate students to develop models using ecological, meteorological, and soils data using machine learning and Bayesian methods.

Peer-reviewed Publications:

1. **Browning, D.M.**, Archer, S.R., Asner, G.P., McClaran, M.P., Wessman. C.A. 2008. Woody plants in grasslands: Post-encroachment dynamics. Ecological Applications 18(4):928-944.
2. **Browning, D.M.**, Archer, S.R., Byrne, A.T. 2009. Field validation of historic aerial photography: How much are we missing? Journal of Arid Environments 73:844-853.
3. Rango, A., Laliberte, A., Herrick, J. Winters, C., Havstad, K., Steele, C., **Browning, D.** 2009. UAV-based remote sensing for rangeland assessment, monitoring, and management. Journal of Applied Remote Sensing 3(1):033542.
4. 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 55:1, 101-115.
5. **Browning, D.M.**, Laliberte, A.S., Rango, A. 2011. Temporal dynamics of shrub proliferation: Linking patches to landscapes. International Journal of Geographical Information Science 25:6, 913-930. doi: 10.1080/13658816.2010.498789.
6. **Browning, D.M.**, Archer, S.R. 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.
7. **Browning, D.M.**, Duniway, M.C. 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.
8. Laliberte, A.S., **Browning, D.M.**, Rango, A. 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.

9. **Browning, D.M.**, Duniway, M.C., Laliberte, A.S., Rango, A. 2012. Hierarchical analysis of vegetation dynamics over 71 years: Soil-rainfall interactions in a Chihuahuan desert ecosystem. Ecological Applications 22(3):909-926.
10. Karl, J.W., Herrick, J.E., **Browning, D.M.** 2012. A strategy for rangeland management based on best available knowledge and information. Rangeland Ecology and Management 65(6):638-646.
11. **Browning, D.M.**, Steele, C.M. 2013. Vegetation index differencing for broad-scale assessment of productivity under prolonged drought and sequential high rainfall conditions. Remote Sensing 5:327-341; doi:10.1155/2011/421904.
12. Peters, D. C., Yao, J., **Browning**, **D.M.**, Rango, A. 2014. Mechanisms of grass response in grasslands and shrublands during dry or wet periods. Oecologia 174:1323-1334.
13. **Browning, D.M.**, Franklin, J., Archer, S.R., Gillan, J.K., Guertin, D.P. 2014. Spatial patterns of grassland-shrubland state transitions: a 74-year record on grazed and protected areas. Ecological Applications. 24(6):1421-1433.
14. Laundre, J.W., Hernadez, L., Medina, P.L., Campanella, A., Lopez-Portillo, J., Gonzalez-Romero, A., Grajales-Tam, K.M., Burke, A.M., Gronemeyer, P., **Browning, D.M.** 2014. The landscape of fear: the missing link to understand top-down and bottom-up controls of prey abundance? Ecology. 95(5):1141-1152.
15. **Browning, D.M.**, Rango, A., Karl, J.W., Laney, C.M., Vivoni, E.R., Tweedie, C.E. 2015. Emerging technological and cultural shifts advancing dryland research and management. Frontiers in Ecology and the Environment. 13(1): 52-60. 2015.
16. Maynard, J. J., Karl, J.W., **Browning, D. M.** 2016. Effect of spatial image support in detecting long-term vegetation change from satellite time-series. Landscape Ecology 31:2045-2062.
17. McCord, S. E., Buenemann, M., Karl, J.W., **Browning, D.M.**, Hadley, B.C. 2017. Integrating Remotely Sensed Imagery and Existing Multiscale Field Data to Derive Rangeland Indicators: Application of Bayesian Additive Regression Trees. Rangeland Ecology & Management 70:644-655.
18. **Browning, D. M.,** Karl, J.W., Morin, D., Richardson, A.D., Tweedie, C.A. 2017a. Phenocams bridge the gap between field and satellite observations in an arid grassland ecosystem. Remote Sensing 9.
19. **Browning, D. M.**, Maynard, J.J., Karl, J.W., Peters, D.C.2017b. Breaks in MODIS time series portend vegetation change: verification using long-term data in an arid grassland ecosystem. Ecological Applications 27:1677-1693. doi: 10.1002/eap.1561.

**PAST ACCOMPLISHMENTS OF JEFFREY E. HERRICK,
SOIL SCIENTIST**

Education

1993 Ohio State University, Agronomy, Ph.D.
1987 Lincoln College (now University - New Zealand), Agricultural Science, Diploma
1985 Swarthmore College, Biology, BA.

Work Experience

1998-present Soil Scientist, Range Management Research Unit, USDA ARS, Las Cruces, NM

Accomplishments:

Dr. Herrick led (monitoring) and co-led (assessment) development of standard rangeland soil and vegetation protocols that have been nationally adopted by the USDA Natural Resources Conservation Service [NRCS] and the Bureau of Land Management [BLM]. These protocols have been applied at over 50,000 plots throughout the US and globally and are used for local to national-level reporting on over 500 million acres. Dr. Herrick is now leading development of a global Land-Potential Knowledge System (LandPKS), which combines mobile apps and cloud computing to provide users with access to soil- and site-specific management information as well as a tool for recording and storing their own information. Dr. Herrick serves as a member of the International Resource Panel (IRP – since 2012) and for the past 6 years (since 2011) has led science-related negotiations as the official US science representative to the UN Convention to Combat Desertification (UNCCD). Dr. Herrick is nationally and internationally recognized for applying knowledge of soils and soil quality to rangeland management and policy, for developing integrated, multiscale approaches to rangeland monitoring.

Peer-reviewed Publications:

1. **Herrick, J.E.**, Sarukhan, J. 2007. A strategy for ecology in an era of globalization. Frontiers in Ecology and the Environment 5:172-181.
2. Godinez-Alvarez, H., **Herrick**, **J. E.,** Mattocks, M. Toledo, D., Van Zee, J. 2009. Comparison of three vegetation monitoring methods: their relative utility for ecological assessment and monitoring. Ecological Indicators 9:1001-1008.
3. Duniway, M.C**., Herrick, J.E.,** Monger, H.C. 2009. Spatial and temporal variability of plant available soil water in arid ecosystems and consequences for resilience. Oecologia 163:215-226.
4. **Herrick, J.E**., Van Zee, J.W., Belnap, J., Johansen, J.R., Remmenga, M. 2010. Changes in infiltration capacity and erodibility of coarse-textured soils following trampling disturbance suggest critical role of fine gravel and minimal effect of weak cyanobacterial crusts. Catena 83:119-126.
5. Duniway, M.C., **Herrick, J. E.**, Pyke, D.A., Toledo, D. 2010. Assessing transportation impacts on rangelands: test of a standard rangeland protocol. Rangeland Ecology and Management 63:524-536.
6. 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.
7. **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.

8. Riginos, C., **Herrick, J.E**. 2010. Monitoring Rangeland Health: A Guide for Pastoralists and Other Land Managers in Eastern Africa, Version II. Nairobi, Kenya: ELMT-USAID/East Africa.
9. Karl, J.W., **Herrick, J.E**., Browning, D.M. 2012. A strategy for rangeland management based on best available knowledge and information. Rangeland Ecology and Management. 65:638-646.
10. **Herrick, J.E**., J.R. Brown, J.R., Bestelmeyer, B.T., Andrews, S.S., Baldi, G., Davies, J., Duniway, M., Havstad, K.M., Karl, J.W., Karlen, D.L., Peters, D.C. P., Quinton, J.N., Riginos, C., Shaver, P.L., Steinaker, D., Twomlow, S. 2012. Revolutionary land use change in the 21st century: is (rangeland) science relevant? Rangeland Ecology and Management 65:590-598.
11. **Herrick, J.E**., Duniway, M., Pyke, D.A., Bestelmeyer, B. T., Wills, S. A., Brown, J.R., Karl, J.W., Havstad, K.M. 2012. A holistic strategy for adaptive land management. Journal of Soil and Water Conservation. 67(4):105A-113A.
12. Karl, J.W., **Herrick, J E**., Unnasch, R.S., Gillan, J.K., Ellis, E.C., Lutters, W.G., Martin, L. J. 2013. Discovering ecologically relevant knowledge from published studies through geosemantic searching. Bioscience. 63(8):674-682.
13. **Herrick, J.E**., Urama, K.C., Karl, J.W., Boos, M-V., J., Johnson, V., Shepherd, K., Hemple, D. J., Bestelmeyer, B.T., Davies, J, Guerra, J.L., Kosnik, C., Kimiti, D.W., Ekai, A.L., Muller, K., Norfleet, L., Ozor, M., Reinsch, T., Sarukhan, J. and West, L.T. The global Land-Potential Knowledge System (LandPKS): 2013. Supporting evidence-based, site-specific land use and management through cloud computing, mobile applications, and crowdsourcing. Journal of Soil and Water Conservation 68: 5A-12A.
14. Toledo, D., Sanderson, M.A., Goslee, S.C., **Herrick, J.E.** 2014. An integrated approach to grazingland ecological assessments and management interpretations. Journal of Soil and Water Conservation. 69:110A-114A.
15. **Herrick, J.E**., Beh, A., Barrios, E., Bouvier, I., Coetzee, M., Dent, D., Elias, E., Hengl, T., Karl, J.W., Liniger, H., Matuszak, J., Neff, J.C., Wangui Ndungu, L., Obersteiner, M., Shepherd, K.D., Urama, K.C., van den Bosch, R., Webb, N.P. 2016. The Land-Potential Knowledge System (LandPKS): mobile apps and collaboration for optimizing climate change investments. Ecosystem Health and Sustainability. 2(3).
16. Webb, N.P., **Herrick, J.E.,** Van Zee, J.W., Courtright, E.M., and others. 2016. The National Wind Erosion Research Network: Building a standardized long-term data resource for aeolian research, modeling and land management. Aeolian Research 22:23-36.
17. Liebig, M., **Herrick**, **J.E.,** Archer, D.W., Dobrowolski, J., Duiker, S., Franzluebbers, A., Hendrickson, J. R., Mitchell, R., Mohamed, A., Russell, J., Strickland, T. 2017. Aligning Land Use with Land Potential: The Role of Integrated Agriculture. Agricultural & Environmental Letters. 2:170007.
18. Faist, A., **Herrick, J. E.,** Belnap, J., Van Zee, J. W., Barger, N. N. 2017. Biological soil crust and disturbance controls on surface hydrology in a semi-arid ecosystem. Ecosphere 8:3.
19. Fan, Z., **Herrick, J.E**., Saltzman, R., Matteis, C., Yudina, A., Nocella, N., Crawford, E., Parker, R., Van Zee, J., 2017. Measurement of Soil Color: A Comparison Between Smartphone Camera and the Munsell Color Charts. Soil Science Society of America Journal, 81(5), pp.1139-1146.
20. **Herrick, J.E**., Karl, J.W., McCord, S. E., Buenemann, M., Riginos, C., Ganguli, A., Angerer, J., Brown, J., Kimiti, D., Saltzman, R., Beh, A., Bestelmeyer, B. 2017. Two New Mobile Apps for Rangeland Inventory and Monitoring by Landowners and Land Managers Rangelands. 2017. Rangelands 39(2): 46-55.

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

Education

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

Work Experience

2011-present	Rangeland Ecologist, Range Management Research Unit, USDA, ARS, Las Cruces, NM
2016-2017	Senior Advisor for Earth Observations, Office of the Under Secretary for Research, Education, and Economics, US Department of Agriculture, Washington, DC
2014-2016	Senior Advisor for Agriculture Systems and Technology, Office of the Chief Scientist, US Department of Agriculture, Washington, DC
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

Accomplishment:

Dr. Peters developed individual plant-based conceptual and simulation models for arid and semiarid rangelands, and incorporated spatial processes into these models to improve management of diverse rangelands in the U.S. Dr. Peters led development of a conceptual framework to connect patterns and processes across multiple scales resulting in emergent behavior, and led a diverse team of university and government researchers to test these ideas under a long-term studies program funded by the National Science Foundation. Dr. Peters led the development and writing of journal articles in three special features by national and international teams of scientists with diverse research interests and expertise. These products are applicable to tens of millions of acres of rangelands. Dr. Peters led a data synthesis project and publication of a book that covered the major ecosystems of the U.S. Dr. Peters published an innovative approach to integrating big data and theory using machine and human learning, and applied these ideas as part of a collaborative ARS Grand Challenge Project on the spread of animal disease in western rangelands.

Peer-reviewed Publications:

1. **Peters, D.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.
2. **Peters, D.C**., Bestelmeyer, B.T., Turner, M.G. 2007. Cross-scale interactions and changing pattern-process relationships: consequences for system dynamics. Ecosystems 10:790-796.
3. Moran, M.S., **Peters**, D.C., McClaran, M., Nichols, M.A., Adams, M. 2008.Long-term data collection at USDA experimental sites for studies of ecohydrology. Ecohydrology 1:377-393.
4. **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 5:229-237.

5. Okin, G.S., Parsons, A.J., Wainwright, J., Herrick, J.E., Bestelmeyer, B.T, **Peters**, D.C., Fredrickson, E.L. 2009. Do changes in connectivity explain desertification? BioScience 59:237-244.
6. **Peters, D.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.
7. **Peters, D.C.** 2010. Accessible ecology: synthesis of the long, deep, and broad. Trends in Ecology and Evolution 25:592-601.
8. Bestelmeyer, B.T., Ellison, A.M., Fraser, W.R., Gorman, K.B., Holbrook, S.J., Laney, C.M., Ohman, M.D., **Peters, D.C.,** Pillsbury, F.C., Rassweiler, A., Schmitt, R.J., Sharma. S. 2011. Analysis of abrupt transitions in ecological systems. Ecosphere 2: art 129.
9. **Peters, D.C.,** Lugo, A.E., Chapin, F.S. III, Pickett, S.T.A., Duniway, M., Rocha, A.V., Swanson, F.J., Laney, C., Jones, J. 2011. Disturbance complexities and generalities emerging from cross-system comparisons. Ecosphere 2:art 81.
10. **Peters, D.C.,** Yao, J., Sala, O.E., Anderson, J. 2012. Directional climate change and potential reversal of desertification in arid and semiarid ecosystems. Global Change Biology 18:151-163.
11. **Peters, D.C.**, Yao, J. 2012. Long-term experimental loss of foundation species: consequences for dynamics at ecotones across heterogeneous landscapes. Ecosphere 3:art 27.
12. **Peters, D.C.,** Belnap, J., Collins, S.L., Ludwig, J., Paruelo, J., Hoffman, T. 2012. How can science be general yet specific: the conundrum of rangelands science in the 21st century. Rangeland Ecology and Management 65:613-622.
13. **Peters, D. C**., Laney, C. M., Lugo, A. E., Collins, S. L., Driscoll, C. T., Groffman, P. M., Grove, J. M., Knapp, A. K., Kratz, T. K., Ohman, M. D., Waide, R. B., Yao, J. 2013. Long-term trends in ecological systems: a basis for understanding responses to global change. USDA Agricultural Research Service Technical Bulletin No. 1931. Springfield, Virginia: National Technical Information Service. 378 p. (Book). [available online: http://www.ars.usda.gov/is/np/LongTermTrends/LongTermTrendsIntro.htm]
14. Ponce-Campos, G.E., Moran, M.S., Huerte A., Zhang, Y., Bresloff, C., Huxman, T.E., Eamus D., Bosch, D.D., Buda, A.R., Gunter, S.A., Scalley, T.A., Kitchen, S.G., McClaran, M.P., McNab, W.H., Montoya D.S., Morgan, J.A., **Peters, D.C**., Sadler, E.J., Seyfried, M.S., Starks, P.J. 2013. Ecosystem resilience despite large-scale altered hydroclimatic conditions. Nature 494: 349-352. doi:10.1038/nature11836.
15. **Peters, D.C**., Yao, J., Browning, D.M., Rango, A. 2014. Mechanisms of grass response in grasslands and shrublands during dry or wet periods. Oecologia 174: 1323-34. doi 10.1007/s00442-013-2837-y.
16. **Peters, D.C.,** Havstad, K.M., Cushing, J., Tweedie, C.E., Fuentes, O., Villanueva-Rosales, N. 2014a. Harnessing the power of big data: infusing the scientific method with machine learning to transform ecology. Ecosphere 5: art6. http://dx.doi.org/10.1890/ES13-00359.1.
17. **Peters, D.C.**, Loescher H.W., SanClements M.D., Havstad, K.M. 2014b. Taking the pulse of a continent: building on site-based research infrastructure for regional to continental scale ecology. Ecosphere 5:art29. http://dx.doi.org/10.1890/ES13-00295.1.
18. **Peters, D.C.,** Havstad, K.M., Archer, S.R., Sala, O.E. 2015. Beyond desertification: new paradigms for dryland landscapes. Frontiers in Ecology and the Environment 1: 4-12.
19. Moran, M.S., Heilman, P., **Peters, D.C.**,. Collins, C.H. 2016. Agroecosystems research with big data and a modified scientific method using machine learning concepts. Ecosphere 7(10):e01493.10.1002/ecs2.1493. doi:10.1002/ecs2.1493.
20. **Peters, D.C.**, Okin, G.S. 2017. A toolkit for ecosystem ecologists in the time of big science. Ecosystems 20:259-266.

PAST ACCOMPLISHMENTS OF 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 Jornada Experimental Range, Las Cruces, NM
2014-2017	Director, USDA Southwest Climate Hub
1994-2001	Research Hydrologist, USDA-ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD
1993-1997	Principal Investigator, CRADA, Regional Watershed Modeling under Conditions of Change, Electric Power Research Institute, Palo Alto, CA
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 Hydrology Laboratory, Beltsville, MD
1972-1983	Hydrologist and Branch Head, Hydrological Sciences Branch, NASA's Goddard Space Flight Center
1969-1972	Assistant Professor of Meteorology, Pennsylvania State University

Accomplishment:
Dr. Rango led development of visual and digital methods for extracting snow covered area from a variety of satellite sensors. Dr. Rango 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. Dr. Rango 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. Dr. Rango 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. Dr. Rango is the principal investigator for the Jornada Experiment (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. Dr. Rango 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. Dr. Rango 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. Dr. Rango also served as the Director of the Southwest Climate Hub from its inception in 2014 to 2017.

Peer-reviewed Publications:

1. Steele, C., Dialesandro, J., Darren, J., Elias, E., **Rango, A**., Bleiweiss, M. 2017. Evaluating MODIS snow products for modelling snowmelt runoff: case study of the Rio Grande headwaters. International Journal of Applied Earth Observation and Geoinformation. 63:234-243.
2. Elias, E., **Rango, A**., Smith, R., Maxwell, C., Steele, C., Havstad, K. 2016. Climate change, agriculture and water resources in the Southwestern United States. Journal of Contemporary Water Research and Education. 158:46-61.
3. Elias, E., **Rango, A.**, Steele, C., Mejia, J., Smith, R. 2015. Assessing climate change impacts on water availability of snowmelt-dominated basins of the Upper Rio Grande. Journal of Hydrology. 3:525-546.
4. Browning, D.M., **Rango, A.**, Karl, J., Laney, C., Vivoni, E., Tweedie, C. 2015. Emerging technological and cultural shifts advancing drylands research and management. Frontiers in Ecology and the Environment. 13(1): 52-60.
5. Templeton, R.D., Vivoni, E., Mendez-Barrosso, L.A., Pierini, N., Anderson, C. **Rango, A**., Laliberte, A., Scott, J. 2014. High-resolution characterization of a semiarid watershed: Implications on evapotranspiration estimates. Journal of Hydrology. 509:306-319.
6. Peters, D.C., Yao, J., Browning, D.M., **Rango, A.** 2014. Mechanisms of grass response in grasslands and shrublands during dry or wet periods Oecologia. 174:1323-1334.
7. Thorp, K.R., French, A.N., **Rango, A.** 2013. Effect of image spatial and spectral characteristics on mapping semi-arid rangeland vegetation using multiple endmember spectral mixture analysis (MESMA). Remote Sensing of the Environment. 132:120-130.
8. Laliberte, A., Browning, D.M., **Rango, A.** 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.
9. Harshburger, B.D., Walden, V.P., Humes, K., Moore, B. C., Blandford, T., **Rango, A**., 2012. Generation of ensemble streamflow forecasts using an enhanced version of the snowmelt runoff model. 48:643-655.
10. Browning, D.M., Duniway, M., Laliberte, A., **Rango, A.** 2012. Hierarchial analysis of vegetation dynamics over 71 years: soil-rainfall interactions in a Chihuahuan Desert ecosystem. Ecological Applications. 22:909-926.
11. 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.
12. 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.
13. 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.
14. Laliberte, A.S., Winters, C., **Rango, A.** 2011. UAS remote sensing missions for rangeland applications. Geocarto International 26, 141-156.
15. **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: 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.

National Environmental Policy Act: 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 (NEPA).

Human Studies: The research does not involve human subjects.

Laboratory Hazards/Safety: 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 classroom and on-line testing and evaluations.

Occupational Safety and 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 Safety Data Sheets.

Biosafety/Biosecurity/Quarantine: Not Relevant.

Intellectual Property: Patents are developed in accordance with ARS policies. Intellectual property issues are coordinated through the ARS Office of Technology Transfer and the Plains Area Technology Transfer Coordinator. Intellectual property collaborations are covered under guidelines in established Cooperative Agreements (see Appendix 3).

EXISTING SPECIFIC COOPERATIVE AGREEMENTS (SCAs): see Appendix 3

APPENDICES

Appendix 1. List of acronyms.

AERO	Aeolian erosion
AERONET	Aerosol Robotic Network
AIM	Assessment, Inventory and Monitoring
ANOVA	Analysis of Variance
APHIS	Animal and Plant Health Inspection Service
APEX	Agricultural Policy / Environmental eXtender
ARS	Agricultural Research Service
BCS	Body condition score
BFAST	Breaks for Abrupt and Seasonal Trends
BLM	Bureau of Land Management
CoCoRAHS	Community Collaborative Rain, Hail and Snow network
DIMA	Database for Inventory, Monitoring & Assessment
DoD	Department of Defense
DuRP	Duneland Restoration Project
EDIT	Ecosystem Dynamics Interpretive Tool
ESD	Ecological Site Description
FMD	Food-and-Mouth Disease
GEE	Google Earth Engine
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring Initiative
GIS	Geographic Information Systems
GPS	Global Positioning Systems
HA	Hereford x Angus
IMPROVE	Interagency Monitoring of Protected Visual Environments
JER	Jornada Experimental Range
JERQUAD	Jornada Chart Quadrat
LandPKS	Land-Potential Knowledge System
LTAR	Long-Term Agroecosystem Research
LTER	Long-Term Ecological Research
LTERNPP	Long-Term Ecological Research Net Primary Production
MODIS	Moderate Resolution Imaging Spectroradiometer
NARR	North American Regional Reanalysis
NASIS	National Soil Information System
NDVI	Normalized Difference Vegetation Index
NIFA	National Institute of Food and Agriculture
NOAA	National Oceanic and Atmospheric Administration
NPN	National Phenology Network
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NSF	National Science Foundation
PASTA	Provenance Aware Synthesis Tracking Architecture
QA	Quality Assurance
QC	Quality Control
RC	Raramuri Criollo
Restore NM	Restore New Mexico
RMA	Risk Management Agency
SES	Social-ecological system
STM	State-and-transition model
SWCH	Southwest Climate Hub
SWEXT	Southwest Extension Partnership

TerrADat	Terrestrial AIM Database
TNC	The Nature Conservancy
US	United States
USAID	US Agency for International Development
USA-NPN	USA National Phenology Network
USDA	US Department of Agriculture
USFS	US Forest Service
USGS	US Geological Survey
VS	Vesicular Stomatitis
VSV	Vesicular Stomatitis Virus

Appendix 2A: PAST ACCOMPLISHMENTS OF EMILE ELIAS, POST DOCTORAL RESEARCH ASSOCIATE – 2015-2017

Education

2010	Auburn University, Hydrology, Ph.D.
2002	Colorado State University, Watershed Science, M.S.
1996	University of Colorado, Environmental Biology, B.S.

Work Experience

2017-present	Acting Director, USDA Southwest Climate Hub USDA, ARS, Las Cruces, NM
2012-present	Postdoctoral Hydrologist, Range Management Research Unit USDA, ARS, Las Cruces, NM
2010-2012	Postdoctoral Hydrologist, New Mexico State University Las Cruces, NM
2004–2006	Environmental Scientist, AL Department of Environmental Management Montgomery, AL

Accomplishments:

Dr. Elias investigates the impacts of stressors (land use change, climate change) on various components of the hydrologic cycle and agroecosystems. Using hydrologic modeling techniques Dr. Elias investigates how dynamic systems impact water quantity, water quality, seasonal shifting in water parameters and the ensuing social and economic impacts of changes in water availability. Research centers on the hydrologic impacts of changing precipitation patterns and increased temperatures using downscaled global climate models and snowmelt runoff modeling for subwatersheds of the western United States. Efforts involve improving snowmelt runoff modeling technology to keep pace with the improvements in climate modeling. Hydrologic modeling efforts support the activities of the USDA Southwest Climate Hub (SWCH), the hub most likely impacted by future water scarcity. Along with the impacts of water limitation, Dr. Elias evaluates the biophysical and contextual impacts of future increased temperatures on Southwestern agriculture including lead authorship of the USDA Vulnerability Assessment of the Southwest and the successful proposal and direction of a special issue on the topic in the journal *Climatic Change*. Dr. Elias is serving as an author of the Southwestern chapter of the 4th National Climate Assessment. In addition, Dr. Elias spearheads technology transfer efforts of the SWCH including development of county-level national temperature and precipitation projections for adaptation planning, the post-fire flooding online toolkit and RMA your Way: tool for cause of loss and crop vulnerability (with Julian Reyes; SWCH fellow).

Peer-reviewed Publications:

1. **Elias, E. H.**, Dougherty, M., Srivastava, P., Laband, D. 2011. The impact of forest to urban land conversion on streamflow, total nitrogen, total phosphorus, and total organic carbon inputs to the converse reservoir, Southern Alabama, USA. Urban Ecosystems, 16:79-107. doi:10.1007/s11252-011-0198-z.
2. **Elias, E.H**., Laband, D., Dougherty, M. 2013. Estimating the Public Water Supply Protection Value of Forest. Journal of Contemporary Water Research & Education, 152:94-104. http://ucowr.org/journal-of-contemporary-water-research-and-education/issue-152.
3. Sharma, S., Srivastava,P., Kalin, L., Fang, X., **Elias, E.H**. 2014. Predicting Total Organic Carbon Load with El Niño Southern Oscillation Phase Using Hybrid and Fuzzy Logic Approaches. Transactions of the ASABE: 1071-85. DOI 10.13031/trans.57.10568.

4. **Elias, E H**., Steele, C.M., Havstad, K., Steenwerth, K., Chambers, J.C., Deswood, H., Kerr, A., Rango, A., Schwartz, M.W., Stine, P., Steele, R., Anderson, T. Ed. 2015. "Southwest Regional Climate Hub and California Subsidiary Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies." In: edited by U.S. Department of Agriculture, 76.
5. **Elias, E.H**., Rango, A., Steele, C.M., Mejia, J.F., Smith, R. 2015. ssessing climate change impacts on water availability of snowmelt-dominated basins of the Upper Rio Grande basin. Journal of Hydrology: Regional Studies. 3: 525-46.
6. Havstad, K., Brown, J.R., Estell, R., **Elias, E**., Rango, A., Steele, C.M. 2016. Vulnerabilities of Southwestern US Rangeland-Based Animal Agriculture to Climate Change, Climatic Change. doi:10.1007/s10584-016-1834-7.
7. **Elias, E.H.,** Rodriguez, H., Srivastava, P., Dougherty, M., James, D., Smith, R. 2016. Impacts of Forest to Urban Land Conversion and ENSO Phase on Water Quality of a Public Water Supply Reservoir. Forest., 7:29.
8. **Elias, E.H**., Rango, A., Steele, C.M., Mejia, J.F., Baca, R., James, D.K., Schrader, T.S., Gronemeyer, P. 2016. Simulated impact of Climate Change on hydrology of multiple watershed using traditional and recommended Snowmelt Runoff Methodology. Journal of Water and Climate Change. 7.4:665-682. doi: 10.2166/wcc.2016.097.
9. Herrick, J. E., Beh, A., Barrios, E., Bouvier, I., Coetzee, M., Dent, D., **Elias, E.,** Hengl, T., Karl, J.W., Liniger, H., Matuszak, J., Neff, J.C., Wangui Ndungu, L., Obersteiner, M., Shepherd, K.D., Urama, K.C., van den Bosch, R., Webb, N.P. 2016. The Land-Potential Knowledge System (LandPKS): mobile apps and collaboration for optimizing climate change investments. Ecosystem Health and Sustainability. 2: http://onlinelibrary.wiley.com/doi/10.1002/ehs2.1209/pdf.
10. **Elias, E.H**., A. Rango, A., Smith, R., Maxwell, C., Steele, C.M., Havstad, K. 2016. Climate change, agriculture and water resources of the Southwestern United States. Journal of Contemporary Water Research & Education, 158: 46-61.
11. **Elias, E.H.,** Marklein, J., Abatzoglou, T., Dialesandro, J., Brown, J.,Steele, C.M., Rango, A., Steenwerth, K. 2017. 'Vulnerability of field crops to midcentury temperature changes and yield effects in the Southwestern USA. Climatic Chang., https://doi.org/10.1007/s10584-017-2108-8.
12. Kerr, A., Dialesandro, J., Steenwerth, K., **Elias, E**. and Lopez-Brody, N. Vulnerability of California specialty crops to projected mid-century temperature changes, Climatic Change. https://doi.org/10.1007/s10584-017-2011-3. 2017
13. **Elias, E.H**., Schrader, T.S., Abatzoglou, J.T., Crimmins, M., Weiss, J. and Rango, A. 2017. County-level climate change information to support decision-making on working lands within USDA Climate Hub regions. Climatic Change. https://doi.org/10.1007/s10584-017-2040-y.
14. Steele, C., Dialesandro, J., James, D., **Elias, E**., Rango, A., Bleiweiss, M. 2017. Evaluating MODIS snow products for modelling snowmelt runoff: Case study of the Rio Grande headwaters. International Journal of Applied Earth Observation and Geoinformation. 63:234-243.
15. **Elias, E.H**., Reyes, J.R., Steele, C.M., Rango, A. Diverse landscapes, diverse risks: Synthesis of the special issue on climate change and adaptive capacity in a hotter, drier Southwestern United States. Climatic Change. Revisions submitted 12/7/2017.
16. Steele, C. Reyes, J. **Elias, E**., Aney, S., Rango, A. Cascading impacts of climate change on southwestern U.S. cropland agriculture. Climatic Change. Under revision. 12/8/17.

Appendix 2B: PAST ACCOMPLISHMENTS OF JONATHAN J. MAYNARD, POST DOCTORAL RESEARCH ASSOCIATE – 2013-2017

Education

2010	University of California, Davis, Soils and Biogeochemistry, Ph.D.
2008	University of California, Davis, Soil Science, M.S.
2000	University of California, Davis, International Agricultural Development, B.S.

Work Experience

2013-present	Postdoctoral Research Ecologist, Range Management Research Unit USDA, ARS, Las Cruces, NM
2010-2013	Postdoctoral Research Scientist, Western Ecology Division U.S. EPA, Corvallis, OR
2003-2010	Graduate Research Assistant, Department of Air and Water Resources U.C. Davis, Davis, CA

Accomplishments:

Dr. Maynard developed novel techniques for the spatial modeling and digital mapping of soil properties/classes and ecological sites/states that are being evaluated by the Natural Resources Conservation Service [NRCS] as part of a national ecological site mapping initiative. This modeling framework is also being tested in Mongolia in an effort to create a national-scale ecological site map. Dr. Maynard worked collaboratively with Bureau of Land Management [BLM] staff to develop and advance the use of remote sensing technologies for the inventory, assessment and monitoring of public land. Research on time-series statistical modeling of multi-decadal high-frequency satellite imagery has demonstrated its utility in detecting ecosystem disturbance in arid/semi-arid environments. A high throughput proximal sensing technique for assessing soil ecosystem disturbance was developed using fingerprint mid-infrared spectroscopy and chemometric modeling. Dr. Maynard collaborated with a diverse network of researchers (U.S. Environmental Protection Agency [US EPA]; US Geological Survey [USGS]; NRCS, BLM, and universities) to advance the use of proximal and remote sensing technologies for assessing soil/ecosystem disturbance and recovery. Development of analytical modeling techniques has provided new insights to ecological resilience concepts and implementation of resilience-based management by both public and private land managers.

Peer-reviewed Publications:

1. O'Geen, A.T., **Maynard, J.J.,** Dahlgren, R.A. 2007. Efficacy of constructed wetlands to mitigate non-point source pollution from irrigation tailwaters in the San Joaquin Valley, California, USA. Water Science and Technology. 55(3):55-61.
2. **Maynard, J.J.**, O'Geen, A.T., Dahlgren, R.A. 2009. Bioavailability and fate of phosphorus in constructed wetlands receiving agricultural runoff in the San Joaquin Valley, CA. Journal of Environmental Quality 38:360-372.
3. **Maynard, J.J.**, O'Geen, A.T., Dahlgren, R.A.. 2009. Spatial relationships of phosphorus sorption in a seasonally saturated constructed wetland soil. *Soil Science Society of America Journal*. 73:1741-1753.
4. O'Geen, A.T., Budd, R., Gan, J., **Maynard, J.J.,** Parikh, S.J., Dahlgren, R.A. 2010. Mitigating nonpoint source pollution in agriculture with constructed and restored wetlands. In Donald Sparks, editor: Advances in Agronomy, Vol. 108, Burlington: Academic Press, pp. 1-76.
5. **Maynard, J.J.**, O'Geen, A.T., Dahlgren R.A. 2011. Sulfide induced mobilization of wetland phosphorus depends strongly on redox and iron geochemistry. Soil Science Society of America Journal. 75:1986-1999.

6. **Maynard, J.J.**, O'Geen, A.T., Dahlgren, R.A. 2011*.* Soil carbon cycling and sequestration in a seasonally saturated wetland receiving agricultural runoff. Biogeosciences, 8:3391-3406.
7. **Maynard, J.J.**, O'Geen, A.T., Dahlgren, R.A. 2012. Quantifying spatial variability and biogeochemical controls of ecosystem metabolism in a Eutrophic Flow-Through Wetland. Ecological Engineering. 47:221-236.
8. **Maynard, J.J.**, O'Geen, A.T.,Dahlgren, R.A. 2014. Autochthonous and allochthonous carbon cycling in a eutrophic flow-through wetland. Wetlands 34:285-296.
9. **Maynard, J.J.**,Johnson, M.G. 2014. Scale-dependency of LiDAR derived terrain attributes in quantitative soil-landscape modeling: effects of grid resolution vs. neighborhood extent. Geoderma. 230-231:29-40.
10. Sharifi, A., Kalin, L., Hantush, M.M., O'Geen, A.T., Dahlgren, R.A., **Maynard, J. J.** 2015. Capturing spatial variability of concentrations and reaction rates in wetland water and soil through model compartmentalization. Journal of Hydrologic Engineering. 22(1), D4015001.
11. Brauer, N.E., O'Geen, A.T., **Maynard, J.J.,** Dahlgren, R.J. 2015. Fate of nitrate in deep seepage from a restored wetland receiving agricultural tailwater. Ecological Engineering, 81:207-217.
12. **Maynard, J.J.**, Johnson, M.G. 2016. Uncoupling the complexity of forest soil variation: influence of terrain attributes, vegetation indices, and spatial variability. Forest Ecology and Management,369: 89-101.
13. **Maynard, J.J**., Karl, J.W., Browning, D.M. 2016. Effect of spatial image support in detecting long-term vegetation change from satellite time-series. *Landscape* Ecology. 31(9): 2045-2062*.*
14. **Maynard, J.J**., Levi, M.R. 2017. Hyper-temporal remote sensing for digital soil mapping: Characterizing soil-vegetation response to climatic variability. Geoderma. 285: 94-109.
15. Browning, D.M., **Maynard, J.J.,** Karl, J.W., Peters, D.C. 2017. Breaks in MODIS time series portend vegetation change – verification using long-term data in an arid grassland ecosystem. Ecological Applications. 27(2):1677-1693.
16. **Maynard, J.J**., Karl, J.W. 2017.0A hyper-temporal remote sensing protocol for high-resolution mapping of ecological sites. PLOS ONE. 12(4): e0175201.
17. **Maynard, J.J.**, Johnson, M.G. *Accepted.* Applying fingerprint FTIR spectroscopy and chemometrics to assess soil ecosystem disturbance and recovery. Journal of Soil and Water Conservation.

Appendix 2C: PAST ACCOMPLISHMENTS OF JULIAN REYES, POST DOCTORAL RESEARCH ASSOCIATE – 2016-2017

Education

2018	Washington State University, Civil Engineering, Ph.D. (expected)
2010	Washington State University, Civil Engineering, B.S.

Work Experience

2016-present Research Hydrologist, Range Management Research Unit
USDA, ARS, Las Cruces, NM

Accomplishments:

Dr. Reyes led development of research and outreach products related to crop insurance data through the Risk Management Agency (RMA). Research applications include trend analysis of crop payments by different causes of loss such as drought and correlative analysis between payments and weather/climate variables. Dr. Reyes co-developed an online data portal called the "RMA Data Viewer" to allow crop insurance data to be accessible and discoverable. Dr. Reyes has sought feedback on the RMA project from academic partners, cooperative Extension, RMA officials, commodity groups, and regional partners (e.g., Ogallala Coordinated Agricultural Project (CAP)). This work contributes to the mission of the USDA Climate Hubs program to developed science-based, region-specific information to enable climate-smart decision-making. Dr. Reyes has also led various working groups to convene diverse stakeholders including Tribal communities, interdisciplinary researchers, farmers, ranchers, and rural citizens.

Peer-reviewed Publications:

1. **Reyes, J.J.**, Tague, C.L., Evans, R.D., Adam, J.C. 2017. Assessing the impact of parameter uncertainty on modeling grass biomass using a hybrid carbon allocation strategy. Journal of Advances in Modeling Earth Systems.

Appendix 2D: **PAST ACCOMPLISHMENTS OF SHAWN W. SALLEY, POST DOCTORAL RESEARCH ASSOCIATE – 2014-2017**

Education

2015	Colorado State University, Pedology, Ph.D.
2007	Emporia State University, Physical Science, M.Sc.
2003	Emporia State University, Earth Science, B.Sc.

Work Experience

2014-present	Post-Doctoral Research Associate, Range Management Research Unit USDA, ARS, Las Cruces, NM
2010- 2014	Doctoral Research Assistant, Department of Soil & Crop Sciences Colorado State University, Fort Collins, CO
2007- 2010	GIS Specialist, Jornada Research Unit New Mexico State University, Las Cruces, NM

Accomplishments:
Dr. Salley developed concepts and protocols for the (USDA Natural Resources Conservation Service [NRCS]) Land Resource Hierarchy to be used with the development of Ecological Site Descriptions. Dr. Salley further helped update agency policy documents such as the NRCS Soil Survey Handbook regarding the land resource hierarchy and Ecological Site Descriptions. Dr. Salley also led analysis on improving field estimates of soil texture for the federal agencies (NRCS and Bureau of Land Management, [BLM]) and citizen scientists as part of the Land Potential Knowledge System (LandPKS), a smart phone app which serves as the access and delivery point for free, simple to use, and locally appropriate tools and knowledge so land managers can ultimately make sustainable land management decisions based on the best information.

Peer-reviewed Publications:
1. Brown, J., Angerer, J., **Salley, S.W.**, Blaisdell, B., Stuth, J.W. 2010. Improving estimates of rangeland carbon sequestration potential in the U.S. Southwest. Rangeland Ecology & Management. 63:147–154.
2. **Salley, S.W.**, Talbot, C.T., Brown, J.R. 2016. The Natural Resources Conservation Service Land Resource Hierarchy and Ecological Sites. Soil Science Society of America Journal. 80:1-9.
3. **Salley, S.W.**, Sleezer, R.O., Bergstrom, R.M., Martin, P.H., Kelly, E.F. 2016. A Long-term analysis of the historical dry boundary for the Great Plains of North America: Implications of climatic variability and climatic change on temporal and spatial patterns in soil moisture. Geoderma. 274:104-113.
4. **Salley, S.W.**, Monger, H.C., Brown, J.R. 2016. Completing the land resource hierarchy. Rangelands. 38:313-317.

Appendix 2E: PAST ACCOMPLISHMENTS OF SHERI SPIEGAL, POST DOCTORAL RESEARCH ASSOCIATE – 2015-2017

Education

2015	University of California, Berkeley, Environmental Science, Policy, and Management, Ph.D.
2010	University of California, Berkeley, Range Management, M.S.
2000	Connecticut College, Environmental Studies, B.A.

Work Experience

2015-Present	Post-Doctoral Research Animal Scientist
2009-2010	Range Conservationist Student Trainee, USDA, Natural Resources Conservation Service, Petaluma, CA
2000-2008	Fundraiser, National Audubon Society, New York, NY, San Francisco, CA

Accomplishments: Dr. Spiegal advanced the collaborative research of the Long-Term Agroecosystem Research (LTAR) network, both at the Jornada Experimental Range and network-wide. Dr. Spiegal helped to refine the experimental design of the LTAR "common experiment" at the Jornada Experimental Range, with the "business-as-usual" treatment representing cow-calf production using Angus crossbreds and feedlot finishing in Texas and Oklahoma, and the "aspirational" treatment representing cow-calf production with a grass-finishing option using a little known cattle biotype, Raramuri Criollo, which has undergone >500 years of natural selection in shrub-dominated landscapes. To inform the long-term comparison, Dr. Spiegal supported the collaborative research program led by Dr. Richard Estell to understand the ecology and production potential of Raramuri Criollo cattle. To this end, Dr. Spiegal developed methodology to evaluate and compare landscape use and resource utilization of Raramuri Criollo and Angus crossbreds in large, heterogeneous rangeland pastures across multiple seasons. Preliminary results suggest that overall, Raramuri Criollo utilize heterogeneous desert pastures more evenly than conventional Angus crossbreds, particularly during periods when forage quality is lower. In addition, Dr. Spiegal developed a method to interpret dietary DNA metabarcoding data from fecal samples of the two breeds. Working across the LTAR network, Dr. Spiegal co-led, with Dr. Brandon Bestelmeyer, the Long-Term Agroecosystem Research network Common Experiment Synthesis Project. Drs. Spiegal and Bestelmeyer administered two questionnaires to scientists at the 18 biogeographically diverse LTAR sites over the course of a year, to improve understanding about the rationale and design of the sites' local LTAR research. Scientists from the 18 LTAR sites collaborated to synthesize questionnaire results and identify commonalities among the goals and strategies for sustainable intensification shared among the sites. Dr. Spiegal led the development of a manuscript summarizing questionnaire and synthesis results, with 32 co-authors (i.e., questionnaire respondents) representing all LTAR sites. Dr. Spiegal concurrently served as second author on a review of the sustainability of U.S. agriculture and the need for networked research about sustainable intensification, with co-authors representing most of the 18 sites. As a doctoral student, Dr. Spiegal managed the collection of data on soils, vegetation, and grazing effects at 57 permanent plots across 100,000 acres of grasslands at Tejon Ranch, CA during five years. Dr. Spiegal developed a method to classify ecological sites and develop state-and-transition models using plot data and expert knowledge. The models are being used to inform adaptive grazing management of the extensive grasslands, tailored toward natural resource conservation and ranching profitability.

Peer-reviewed Publications:

1. Bartolome, J.W., Allen-Diaz, B.H., Barry, S., Ford, L.D., Hammond, M., Hopkinson, P., Ratcliff, F., **Spiegal, S.**, White, M.D. 2014. Grazing for biodiversity in Californian Mediterranean grasslands. Rangeland. 36:36–43. 2014.
2. **Spiegal, S.**, White, M.D., Bartolome, J.W. 2016. Applying ecological site concepts to adaptive conservation management on an iconic Californian landscape. Rangelands. 3:365–370. 2016.
3. Brown, J., Alvarez, P., Byrd, K., Deswood, H., Elias, E., **Spiegal, S.** 2017. Coping with historic drought in California rangelands: Developing a more effective institutional response. Rangelands. 39:73–78.
4. Browning, D.M., **Spiegal, S.**, Estell, R.E., Cibils, A.F. and Peinetti, H.R. Integrating space and time: A case for phenological context in grazing studies and management. Frontiers of Agricultural Science and Engineering. *In Press*.
5. **Spiegal, S.**, Bestelmeyer, B.T., Archer, D.W., Augustine, D.J., Boughton, E.B., Boughton, R.K., Cavigelli, M.A., Clark, P.E., Derner, J.D., Duncan, E., Hapeman, C., Harmel, D.H., Heilman, P., Holly, M., Huggins, D.R., King, K., Kleinman, P.J.A., Liebig, M.A., Locke, M.A., McCarty, G.W., Millar, N., Mirsky, S.B., Moorman, T.B., Pierson, F.B., Rigby, J.R., Robertson, G.P., Steiner, J.L., Strickland, T.C., Swain, H., Wienhold, B.J., Wulfhorst, J.D., Yost, M.A., Walthall, C.L. Evaluating strategies for sustainable intensification of U.S. agriculture through the Long-Term Agroecosystem Research network. Environmental Research Letters. *In Press*.
6. **Spiegal, S.**, Estell, R., Cibils, A.F., James, D.K., Peinetti, R., Browning, D.M., Romig, K., Gonzales, A. Seasonal divergence in foraging behavior of heritage and conventional cattle on a heterogeneous desert landscape. Rangeland Ecology & Management. *In Revision*.
7. Kleinman P.J.A., **Spiegal, S.**, Rigby, J.R., Goslee, S., Baker, J., Bestelmeyer, B.T., Boughton, R., Bryant, R.B., Cavigelli, M., Derner, J., Duncan, E.W., Goodrich, D.C., Huggins, D., King, K., Liebig, M., Locke, M., Mirsky, S., Moglen, G.E., Moorman, T., Pierson, F., Robertson, G.P., Sadler, J., Shortle, J., Steiner, J.L., Strickland, T.C., Swain, H., Williams, M.R., Walthall, C.L., Advancing sustainable intensification of U.S. agriculture through long-term research. Bioscience. *Submitted* September 27, 2017.
8. Browning, D.M., Crimmins, T., James, D.K., **Spiegal, S.**, Levi, M., Anderson, J., Peters, D.P.C. Synchronous species responses reveal phenological guilds – Implications for management. Ecosphere. *Submitted* October 5, 2017.
9. Ratcliff, F., Bartolome, J.W., Macaulay, L., **Spiegal, S.**, White, M.D. Applying ecological site concepts and state-and-transition models to a grazed riparian rangeland. Ecology and Evolution. *Submitted* November 30, 2017.

Appendix 2F: PAST ACCOMPLISHMENTS OF CAITRIANA M. STEELE, COLLEGE ASSISTANT PROFESSOR

Education

2000	Kings College, University of London, Geography, Ph.D.
1994	Kings College, University of London, Geography, B.Sc. Hons

Work Experience

2015-present	USDA SW Climate Hub Coordinator, Range Management Research Unit USDA, ARS, Las Cruces, NM
2004-present	College Assistant Professor, New Mexico State University, Las Cruces, NM
2000-2003	Postdoctoral Research Fellow, University of Southampton, Southampton, UK

Accomplishments:

Dr. Steele developed a classification scheme based directly on vegetation dynamics described in the Ecological Site Description / State and Transition model framework used by the Natural Resources Conservation Service (NRCS). The classification scheme and associated mapping protocol has been used to create a spatial resource for the U.S. Bureau of Land Management Las Cruces District Office. It has also been applied on other federal and private lands to inform rangeland health assessments and restoration activities. As part of the New Mexico Experimental Program to Stimulate Competitive Research (EPSCoR) team (2008 – 2013), Dr. Steele discovered and quantified problems with remote sensing algorithms for mapping snow cover in the Upper Rio Grande and identified alternative approaches for improved snow cover estimates. Dr. Steele calibrated empirical streamflow simulation models for 25 sub-basins of the Upper Rio Grande that are significant producers of runoff from melting snow. These simulation models have since been used to estimate changes in snowmelt runoff under changed climate conditions, providing insight into the effects of increasing temperatures and decreased precipitation on snowmelt runoff. Dr. Steele also supports colleagues' research through expertise in optical remote sensing of vegetation, for example helping to develop a method for radiometric correction of UAV imagery, and train others in data collection to support this method. Dr. Steele works closely with colleagues at New Mexico State University, serving on multiple graduate student committees, and between 2008 and 2016, providing training in geographical information systems to over 200 undergraduates and graduate students. Dr. Steele currently works in the role of Coordinator for the USDA Southwest Climate Hub, maintaining partnerships and collaborations with other climate hubs, Federal and State partners, and other stakeholders; collaborating in primary and secondary research on climate change vulnerability in agricultural systems; translating science for a wider audience; building a regional Cooperative Extension climate network in the Southwest.

Peer-reviewed Publications:

1. Smith, A.M.S, Strand, E.K., **Steele, C.M.**, Hann, D.B., Garrity, S.R., Falkowski, M.J., Evans, J.S. 2008. Production of vegetation spatial-structure maps by per-object analysis of juniper encroachment in multitemporal aerial photographs. Canadian Journal of Remote Sensing, 34, 2, S268-S285.
2. Rango, A., Laliberte, A., Herrick, J., Winters, C., Havstad, K., **Steele, C.**, Browning, D. 2009. Unmanned aerial vehicle-based remote sensing for rangeland assessment, monitoring, and management. Applied Remote Sensing 3, 033542.
3. Smith, A.M.S., Falkowski, M.J., Hudak, A.T., Evans, J.S., Robinson, A.M., **Steele, C.M.** 2009. A cross-comparison of field, spectral, and lidar estimates of forest canopy cover. Canadian Journal of Remote Sensing, 35(5): 447-459.

4. 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(11), 2529-2551.
5. **Steele, C.M**., Bestelmeyer, B., Smith, P., Burkett, L., Yanoff, S. 2012. Spatially-explicit representation of state-and-transition models in arid rangelands of southern New Mexico. Rangeland Ecology and Management 66: 213-222.
6. Al-Kofahi, S., **Steele, C.**, VanLeeuwen, D., St Hilaire, R. 2012. Mapping land cover in urban residential landscapes using very high spatial resolution aerial photographs, Urban Forestry and Urban Greening, 11(3):291-301.
7. Fernald, A., Tidwell,V., Rivera,J., Rodríguez, S., Guldan, S., **Steele, C.**, Ochoa, C., Hurd, B., Ortiz, M., Boykin, K., Cibils, A. 2012. A Model for Sustainability of Water, Environment, Livelihood, and Culture in Traditional Irrigation Communities and Their Linked Watersheds, Sustainability 4(11):2998-3022.
8. Browning, D.M., **Steele, C.M**. 2013. Vegetation index differencing for broad-scale assessment of productivity under prolonged drought and sequential high rainfall conditions, Remote Sensing 5, 327-341.
9. Rango, A., Fernald, A., **Steele, C**., Hurd, B., Ochoa, C. 2013. Acequias and the effects of climate change. Journal of Contemporary Water Research and Education. 151:84-94.
10. Othman, Y., **Steele, C.,** VanLeeuwen, D., Heerema, R., Bawazir, S., St. Hilaire, R. 2014. Remote Sensing to detect moisture status of pecan orchards grown in a desert environment, International Journal of Remote Sensing: 35:949-966.
11. Elias, E., **Steele, C.**,Havstad, K., Steenwerth, K., Chambers, J., Deswood, H., Kerr, A., Rango, A., Schwartz, M., Stine, P., Steele, R. 2015. Southwest regional climate hub and California subsidiary hub assessment of climate change vulnerability and adaptation and mitigation strategies. Washington, DC: U.S. Department of Agriculture. 76 p.
12. Fernald, A., Guldan, S., Boykin, K., Cibils, A., Gonzales, M., Hurd, B., Lopez, S., Ochoa, C.G., Ortiz, M., Rivera, J., Rodriguez, S., **Steele, C.M**. 2015. Hydrological, ecological, land use, economic, and sociocultural evidence for resilience of traditional irrigation communities in New Mexico, USA, Hydrological and Earth System Sciences, 19, 293-307.
13. Elias, E., Rango, A., **Steele, C.M.,** Mejia, J.F., Baca, R., James, D., Schrader, S., Gronemeyer, P. 2016. Simulated impact of climate change on hydrology of multiple watersheds using traditional and recommended snowmelt runoff model methodology. Journal of Water and Climate Change 7 (4):665-682.
14. Elias, E., Rango, A., Smith, R., Maxwell, C., **Steele, C.**, Havstad, K. 2016. Climate change, agriculture and water resources in the Southwestern United States. Journal of Contemporary Water Research & Education, 158(1):46-61.
15. Havstad, K.M., Brown, J.R., Estell, R., Elias, E., Rango, A., **Steele, C**. 2017. Vulnerabilities of Southwestern US Rangeland-based animal agriculture to climate change. Climatic Change, pp.1-16. https://doi.org/10.1007/s10584-016-1834-7.
16. **Steele, C.M.,** Dialesandro,J., James, D., Elias, E., Rango, A., Bleiweiss, M. 2017. Evaluating MODIS snow products for modelling snowmelt runoff: case study of the Rio Grande headwaters. International Journal of Applied Earth Observation and Geoinformation. 63: 234-243.
17. Harpold, A. A., Kaplan, M.L., Klos, P.Z., Link, T., McNamara, J.P., Rajagopal, S., Schumer, R., **Steele, C.M.** 2017. Rain or snow: hydrologic processes, observations, prediction, and research needs. Hydrology and Earth System Sciences, 21(1):1-22.
18. Elias, E., Marklein, A., Abatzoglou, J.T. Dialesandro, J., Brown, J., **Steele, C**., Rango, A. Steenwerth, K. 2017. Vulnerability of field crops to midcentury temperature changes and yield effects in the Southwestern USA. Climatic Change, pp.1-15. https://doi.org/10.1007/s10584-017-2108-8.

Appendix 2G: PAST ACCOMPLISHMENTS OF NICHOLAS P WEBB, RESEARCH ASSOCIATE PROFESSOR

Education

2008	University of Queensland, Geomorphology, Ph.D.
2004	University of Queensland, Geographical Sciences, B.Sc. (Hons. Class 1)
2003	University of Queensland, Earth Science and GIS, B.Sc.

Work Experience

2017-present	Research Associate Professor, Jornada Experimental Range, New Mexico State University, Las Cruces, NM
2012-2017	Research Assistant Professor, Jornada Experimental Range, New Mexico State University, Las Cruces, NM
2012	Visiting Research Fellow, Atmospheric Environment Research Centre, Griffith University, Brisbane, Australia
2009-2011	Postdoctoral Research Fellow, Ecosystem Sciences and Climate Adaptation Flagship, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Townsville, Australia

Accomplishments:

Dr. Webb led the establishment of a National Wind Erosion Research Network in collaboration with the USDA LTAR network, NRCS, BLM, Department of Defense (DoD), and US Geological Survey (USGS). Dr. Webb developed standard methods protocols for the Network, coordinated participation of 16 sites across a variety of cropland and rangeland ecosystems, oversaw site installation, training and implementation of protocols, and coordinated development of a database system to store and manage big data that is compatible with the BLM Terrestrial Assessment, Inventory and Monitoring Database (TerrADat). Dr. Webb led the development of an all-lands wind erosion model that has been adopted by the NRCS and conceived multi-scale applications to national monitoring data across public and private lands. Dr. Webb led empirical research to improve understanding of aeolian sediment transport mechanics to support wind erosion modeling. Research linking aeolian processes with Ecological Site Descriptions (ESD) has produced a conceptual framework for assessing accelerated soil erosion across land uses and supports establishment of benchmarks for wind erosion management by the BLM and NRCS. Dr. Webb conceived the first national assessment of wind erosion impacts on Australian soil carbon stocks and carbon accounting.

Peer-reviewed Publications:

1. **Webb, N.P.**, Strong, C.L. 2011. Soil erodibility dynamics and its representation for wind erosion and dust emission models. Aeolian Research, 3:165-179.
2. **Webb, N.P.**, Chappell, A., Strong, C.L., Marx, S.K., McTainsh, G.H. 2012. The significance of carbon-enriched dust for global carbon accounting. Global Change Biology, 18:3275-3278.
3. **Webb, N.P.**, Strong, C.L., Chappell, A., Marx, S.K., McTainsh, G.H. 2013. Soil organic carbon enrichment of dust emissions: magnitude, mechanisms and its implications for the carbon cycle. Earth Surface Processes and Landforms, 38:1662-1671.
4. Chappel, A., **Webb, N.P.**, Butler, H.J., Strong, C.L., McTainsh, G.H., Leys, J.F., Viscarra Rossel, R. 2013. Soil organic carbon dust emission: an omitted global source of atmospheric CO_2. Global Change Biology. 19:3238-3244.
5. **Webb, N.P.**, Stokes, C.J., Marshall, N.A. 2013. Integrating biophysical and socio-economic evaluations to improve the efficacy of adaptation assessments for agriculture. Global Environmental Change. 23:1164-1177.

6. Marshall, N.A., Stokes, C.J., **Webb, N.P.**, Marshall, P.A., Lankester, A. 2014. Social vulnerability to climate change in primary producers: a typology approach. Agriculture, Ecosystems and Environment. 186:86-93.
7. **Webb, N.P.**, Okin, G.S., Brown, S. 2014. The effect of roughness elements on wind erosion: the importance of surface shear stress distribution. Journal of Geophysical Research: Atmospheres, 119:6066-6084.
8. **Webb, N.P.**, Herrick, J.E., Duniway, M.C. 2014. Ecological site-based assessments of wind and water erosion: informing accelerated soil erosion management in rangelands. Ecological Applications. 24:1405-1420.
9. Chappell, A., **Webb, N.P.**, Viscarra-Rossel,R., Bui, E.N. 2014. Australian net (1950s-1990) soil organic carbon erosion: implications for CO_2 emission and land-atmosphere modelling. Biogeosciences, 11:5235-5244.
10. Li, J., Okin, G.S., Tatarko, J., **Webb, N.P.,** Herrick, J.E. 2014. Consistency of wind erosion assessments across land use and land cover types: a critical analysis. Aeolian Research, 15:253-260.
11. Aubault, H., **Webb, N.P.**, Strong, C.L., McTainsh, G.H., Leys, J.F., Scanlan, J.C. 2015. Grazing impacts on the susceptibility of rangelands to wind erosion: the effects of stocking rate, stocking strategy and land condition. Aeolian Research, 17:89-99.
12. Shao, Y., Bergametti, G., Chappell, A., Findlater, P., Gillies, J., Ishizuka, M., Klose, M., Kok, J., Leys, J., Lu, H., Marticorena, B., McTainsh, G., McKenna-Neuman, C., Nickling, W., Okin, G., Strong, C., **Webb, N.P**. 2015. A Tribute to Michael R Raupach for Contributions to Aeolian Fluid Dynamics. Aeolian Research, 19:37-54.
13. **Webb, N.P.**, Galloza, M.S., Zobeck, T.M., Herrick, J.E. 2016. Threshold wind velocity dynamics as a driver of aeolian sediment mass flux. Aeolian Research, 20:45-58.
14. Herrick, J.E, Beh, A., Barrios, E., Bouvier, I., Coetzee, M., Dent, D., Elias, E., Havstad, K.M., Hengl, T., Karl, J.W., Liniger, H., Matuszak, J., Wangui Ndungu, L., Obersteiner, M., Shepherd, K.D., Urama, K.C., van den Bosch, R., **Webb, N.P**. 2016. The Land-Potential Knowledge System (LandPKS): mobile apps and collaboration for optimizing climate change investments. Ecosystem Health and Sustainability, 2:1-7.
15. **Webb, N.P.**, Herrick, J.E., Van Zee, J.W., Courtright, E.M., and others. 2016. The National Wind Erosion Research Network: Building a standardized long-term data resource for aeolian research, modeling and land management. Aeolian Research, 22:23-36.
16. Chappell, A., **Webb, N.P**. 2016. Using albedo to reformulate wind erosion modelling, mapping and monitoring. Aeolian Research, 23:63-78. 2016.
17. **Webb, N.P.** Van Zee, J.W., Karl, J.W., Herrick, J.E., Courtright, E.M., Billings, B.J., Boyd, R., Chappell, A., Duniway, M.C., Derner, J.D., Hand, J.K., Kachergis, E., McCord, S.E., Newingham, B.A., Pierson, F.B., Steiner, J.L., Tatarko, J., Tedela N.H., Toledo, D., Van Pelt, R.S. 2017. Enhancing wind erosion monitoring and assessment for US rangelands. Rangelands, 39:85-96.
18. **Webb, N.P.**, Marshall, N.A., Stringer, L.C., Reed, M.S., Chappell, A., Herrick, J.E. 2017. Land degradation and climate change: building climate resilience in agriculture. Frontiers in Ecology and the Environment, 15:450-459.
19. Mayaud, J.R. and **Webb, N.P.** 2017. Vegetation in drylands: effects on wind flow and aeolian sediment transport. Land, 6:64.
20. Chappell, A., **Webb, N.P.**, Guerschman, J.P., Thomas, D., Mata, G., Handcock, R.N., Leys, J.F., Butler, H. 2017. Improving ground cover monitoring for wind erosion assessment using MODIS BRDF parameters. Remote Sensing of Environment, 204:756-768.

Appendix 3. Existing Cooperative Agreements and Specific Cooperative Agreements

Project #	Accn / Log #	Start Date	End Date	Agree. #	Title	Cooperative Agency
	57478	10/15/15	10/14/20	58-3050-6-001	Trust Fund Coop Agreement – Recycling/Rebate	
	57566	10/13/15	09/30/18	60-3050-6-001	Southwest Climate Hub/Sub Hub Workshop; The USDA Greenhouse Gas Mitigation Strategy	Office of the Chief Economist, USDA
	59504	08/10/16	12/31/17	60-3050-6-008	Climate Variability, Water and Land Use Meetings	Office of the Chief Economist, USDA
	61414	07/01/17	06/30/22	58-3050-7-009	Trust fund Coop Agreement - Adm. Services	Oryx Hunts
3050-11210-008-12J	432784	07/01/17	06/30/18	58-3050-7-006	Acquisition of Goods and Services	New Mexico State University
3050-11210-008-03I	432817	08/15/17	08/14/22	60-3050-7-006	CEAP-Grazing Lands Wind Erosion, Economics & Modeling Project	Natural Resources Conservation Service (NRCS)
3050-11210-008-06I	432856	06/08/17	09/30/18	60-3050-7-004	Engaging Southwestern Commodity Groups in Knowledge Co-production Using RMA Cause of Loss Data	Office of the Chief Economist, USDA
3050-11210-008-08A	432693	05/15/17	10/18/18	59-3050-7-008	DIMA: Enhancements for MCC Mongolia Implementation	Barry Lavine
3050-11210-008-09S	432719	06/01/17	09/30/18	58-3050-7-005	Application of Assessment and Monitoring Tools for Adaptive Management of Large Ranch Landscapes	Malpai Borderlands Group
3050-11210-008-11R	433112	04/21/17	09/20/18	58-0210-7-002	Land Potential Knowledge Systems (LandPKS)-Phase II	US Agency for International Development (USAID)
3050-11210-008-13I	433198	09/25/17	12/31/18	60-3050-7-005	Ecological Site Development 2017 and 2018	Natural Resources Conservation Service (NRCS), USDA
3050-11210-008-17S	424317	02/01/13	01/31/18	58-6235-3-001	Management Technologies for Western Rangelands	New Mexico State University
3050-11210-008-28R	425330	09/30/13	09/29/18	58-0210-3-005	Land-Potential Knowledge System-LandPKS	US Agency for International Development (USAID)
3050-11210-008-33A	425840	09/25/13	08/31/18	59-6235-3-004	CEAP-Grazing Lands	Resource Management Systems, LLC
3050-11210-008-34A	425455	03/01/14	02/28/19	59-6235-4-001	Database for Inventory, Monitoring and Assessment Feature Enhancement	Barry Lavine
3050-11210-008-36R	426632	08/01/14	02/28/19	58-6235-4-006	Field and Laboratory Analysis of Soil Samples for the Terrestrial Observation System of NEON	National Ecological Observatory Network, Inc. (NEON, Inc.), NSF

3050-11210-008-37A	426548	04/16/14	04/15/19	59-6235-4-005	Science Education Curricula Development and Outreach Programs	Asombro Institute for Science Education
3050-11210-008-40A	426799	05/26/14	12/31/18	59-6235-4-003	Supporting Climate-Smart Decision Making in New Mexico, USDA Southwest Climate Hub	New Mexico State University
3050-11210-008-41S	426812	05/26/14	12/31/18	58-6235-4-007	Supporting Climate-Smart Decision Making in Arizona, USDA Southwest Climate Hub	University of Arizona
3050-11210-008-42S	426915	06/01/14	09/30/18	58-6235-4-010	Supporting Climate-Smart Decision Making in Utah, USDA Southwest Climate Hub	Utah State University
3050-11210-008-43S	426919	06/01/14	12/31/18	58-6235-4-011	Supporting Climate-Smart Decision Making in Nevada, USDA Southwest Climate Hub	University of Nevada
3050-11210-008-47I	427324	06/16/14	12/31/18	60-6235-4-006	Validate ARS Wind Erosion Model	Bureau of Land Management (BLM), DOI
3050-11210-008-48S	427164	07/01/14	12/31/18	58-6235-4-013	Supporting Climate-Smart Decision Making in Hawaii, USDA Southwest Climate Hub	University of Hawaii
3050-11210-008-51N	432809	06/01/17	05/31/22	58-3050-7-007-FN	Collaboration on Development of State-and transition Models to Guide Sustainable Land Management in the Americas	INTA, Buenos Aires, Argentina
3050-11210-008-53S	428768	05/01/15	12/31/18	58-3050-5-005	Long-term Abiotic Data Measurements for Jornada Long-term Agricultural Research (LTAR)	University of Texas
3050-11210-008-58I	428923	09/15/15	9/14/20	60-3050-5-009	Scientific Support and Partnership for Renewable Resources programs in BLM NM	Bureau of Land Management (BLM), DOI
3050-11210-008-65A	433553	08/28/17	08/31/18	59-3050-7-006	Central Great Plains Ecosystem Service Economics and Index Valuation Project	Earth Economics
3050-11210-008-68A	430839	08/15/16	07/01/18	59-3050-6-001	Enhancement of a Land-Potential Knowledge System (LPKS)	University of Colorado
3050-11210-008-69M	430880	05/02/16	05/01/19	58-3050-6-007M	Collaborative Research in Atmospheric Modeling and Sensing	US Army Research Laboratory
3050-11210-008-70I	430981	09/06/16	09/30/18	60-3050-6-006	Development and Support of Ecological Site Description Research	Natural Resources Conservation Service (NRCS), USDA
3050-11210-008-71I	431227	10/01/15	09/30/18	60-3050-6-007	CEAP-Grazing Lands Plant Community & Wind Erosion Support for Modeling	Natural Resources Conservation Service (NRCS), USDA
3050-11210-008-72N	431252	06/14/16	06/13/21	58-3050-6-001N	Collaborative Animal Research between New Mexico State University (NMSU) and ARS	New Mexico State University
3050-11210-008-73A	431334	07/01/16	09/30/18	59-3050-6-002	Assessment and Monitoring Technical Support	New Mexico State University
3050-11210-008-77S	430620	09/01/16	06/30/18	58-3050-6-012	Selecting & Managing Practices for Agri Landscapes	New Mexico State University

3050-11210-008-79A	430657	08/01/16	07/14/18	59-3050-6-003	Scientific Support and Partnership for Renewable Resource Programs in BLM	New Mexico State University
3050-11210-008-81A	431896	01/01/17	07/01/18	59-3050-7-001	Development of an All-Lands Wind Erosion Model	New Mexico State University
3050-11210-008-85A	432272	02/01/17	07/01/18	59-3050-7-003	Scientific and Local Knowledge for a Land Potential Knowledge System (LandPKS)	New Mexico State University
3050-11210-008-89A	429602	04/01/17	06/30/18	59-3050-7-004	Ecological Site Description (ESD) Research	New Mexico State University
3050-11210-008-97I	432138	04/01/17	03/31/22	60-3050-7-001	Implementation and Expansion of the BLM's Assessment, Inventory, and Monitoring Strategy to Support Multiple Resource Management Decision Making	Bureau of Land Management (BLM) (DOI)
3050-11210-008-98I	432549	01/17/17	01/16/22	58-0210-7-001	MCC Mongolia Rangeland Assessment and Monitoring 2017	Millennium Challenge Corp.
3050-11210-008-99O	428604	02/01/15	12/31/18	60-3050-5-002	NRCS Project – Data for NEON Sites	NRCS

Appendix 4. Jornada Project and Data Documentation Forms

Jornada Information Management System Project Documentation Form

Project ID: *<to be completed by information manager>*

*** **Begin entry on __first line after__** each section title or subsection title.
*** **Do not format text** (e.g., bold, italics, underline, color) as this will be lost during processing.
*** **Use tabs** rather than extra spaces when alignment is important.
*** **Enter N/A** or **<NONE>** when applicable.

0) Jornada Study Number (from researcher's Jornada Notification of Proposed Research form)

1) Project title (descriptive title including 'what, when, where' information)

2) Responsible Investigator

3) Data contact person (for data queries and data requests)

4) Date research commenced (mm/dd/yyyy or UNKNOWN)

5) Date research terminated (mm/dd/yyyy, ONGOING, or UNKNOWN)

6) PI funding the research

7) Additional investigator(s) (examples: a graduate student's primary adviser; others with significant roles)

8) Funding agency (examples: EPA, NSF, USDA)

9) Funding cycle (examples: LTER II, FY2001, N/A)

10) Informative abstract (Describe research project completely. Include project Objectives and Hypothesis.)

11) Dataset(s) associated with project

Dataset(s) associated with project ***(add rows as needed:** click **outside** right edge of last cell & press Enter key)*	
Filename of dataset documentation	Dataset title (from dataset documentation form)

12) Publications resulting from project research

13) Comments (Include any comments here that more fully describe this project)

Comments		***(add rows as needed)***
mm/dd/yyyy Date	Comments by	Comments

History of Responsible Investigator(s)		***(add rows as needed)***
mm/dd/yyyy Start date	mm/dd/yyyy End date	Name (first last)

14) **Document Change Log** (history of changes made to this document)

Document Change Log		***(add rows as needed)***
mm/dd/yyyy Date	Log entry by	Log entry

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END OF PROJECT DOCUMENTATION FORM
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Jornada Information Management System
Dataset Documentation Form

Dataset ID: *<to be completed by information manager>*
Project ID: *<to be completed by information manager>*

*** **Begin entry on <u>first line after</u>** each section title or subsection title.
*** **Do not format text** (e.g., bold, italics, underline, color) as this will be lost during processing.
*** **Use tabs** rather than extra spaces when alignment is important.

0) Jornada Study Number (from researcher's Jornada Notification of Proposed Research form)

1) Dataset access (RESTRICTED or UNRESTRICTED)

2) Dataset title (descriptive title including 'what, when, where' information)

3) Project title (from Project documentation form)

4) Responsible Investigator

5) Data contact person (for data queries and data requests)

6) Date data collection commenced (mm/dd/yyyy or UNKNOWN)

7) Date data collection terminated (mm/dd/yyyy, ONGOING, or UNKNOWN)

8) Expected duration of study

9) Frequency of measurement

10) Associated researchers
(personnel who will be collecting data and would need to be contacted directly if there is a problem in the raw data)

11) Methods of recording (field data sheets, instrumental, digital voice recorder, etc.)

12) Site location
(Describe in sufficient detail that the site can be relocated. State that Jornada spatial manager has GPS coordinates for all associated research sites OR list GPS coordinates for associated research sites and include datum (WGS84 should be used where possible), projection and coordinate system)

13) Dataset overview
(include the hypothesis and/or objectives <u>that the dataset addresses</u>; list the measured variables)

14) Data description (define each field of data file)

Help section to complete Data description table located below Example table. **Each column of dataset must be described.** ***To add or insert a table row, place cursor outside of rightmost cell and press Enter key.*** ***Use "n/a" in a table cell if the Descriptor does not apply.***		
Descriptor	**Explanation**	**Examples**
field name	must match field name used in data file	date, site, plot, dry-sample-wt
format	1. D# = date (mm/dd/yyyy) 2. C# = alphanumeric character field 3. I# = integer [whole number] 4. F#.# = floating point [number with decimal fraction], where 1st digit = total places including decimal point (ex: F5.# for #.###) 2nd digit = number of digits to right of decimal point (ex: F#.3 for #.###)	1. **D10** example: 11/17/2013 2. **C3** for max of 3 alphanumeric **C**haracters [xxx] 3. **I2** for **I**nteger with 2 places [##] 4. F5.3 [for ex: 2.**327**]
measured units	units of measure	1. milligrams per liter 2. N/A *(not applicable)*
field code	1. List acceptable values (e.g., a list or range) 2. Name a separate file that lists the variable codes (file needs to accompany this document)	1. E, M, Q *(list)* 10-36 *(range)* 2. plantcodes.txt
missing value	Code(s) used for missing value	1) -9 2) "." without the quotes
field description	Fully describe field and variable code(s)	1) Air-dry weight of soil 2) Data quality flag, where M=missing data; E=estimated data; Q=questionable data

Example					
Field name	Format	Measured units	Field code	Missing value	Field description
date	D10	n/a	n/a		Collection date (mm/dd/yyyy)
site	C2	n/a	G1, G4, M1-M4		Site, where G1 & G4 = grassland sites; M1 through M4 = mesquite sites
quad	I2	n/a	1-36		Quad ID: 1 to 36
species	I4	n/a	*	"."	Plant species code. See plantcode.txt.
cover	F5.2	percent	n/a	"."	Percent species cover
dry-weight	F2.3	grams	n/a	"."	Oven-dry plant weight

Data description					***(add rows as needed)***
Field name	Format	Measured units	Field code	Missing value	Field description

15) Methodology
(Provide sufficient detail such that an unaware reader could repeat the described data collection procedures.)

16) Key literature (Citations that describe sampling procedures, [reference of a published paper, thesis, etc.])

17) Keywords (keywords that describe dataset; maximum of 10, comma-delimited)

18) QA/QC (Quality assurance/Quality control) Steps taken to check accuracy of data.
Examples: visual verification; graphing for outliers; outliers checked programmatically;
data entry program validates entries for species code and acceptable range for cover.

19) Preliminary treatment of data
(If a variable is derived from data originally collected, describe how it was derived. Provide programs or formulas used to generate the value described. List separate program files in the section below, "Files associated with this dataset"

20) Files associated with this dataset

This is Help for completing Associated Files table located below the example table.
To add or insert a table row, place cursor at end and outside of rightmost cell and press Enter key.
Use "N/A" in a table cell if the Descriptor does not apply.

Descriptor	**Valid code**	**Definition**	**Examples**
File type	**MD**	**m**eta**d**ata (project & dataset documentation forms)	*Use for both project & dataset documentation files.*
	DS	data (described by Section 14)	study32_ecotoneBiomass_data.xls
	DE	data entry, verification, and analysis file	SAS file; data entry data filenames
	OT	other (any other supporting file)	protocols; species lists filenames
Filename	1. **Begin** filenames with "study#_" from your Jornada Research Notification form. 2. **End** project and dataset metadata and data filenames with _prj,_dsd, and _data, respectively, immediately before the filename extension. 2. Filename should be descriptive of the contents, but not excessively long. 3. Do no use spaces, periods, or special characters other than underscore and dash.		1. & 2. **study32_**ecotone_**prj**.docx **study32_**ecotoneBiomass_**dsd**.docx **study32_**ecotoneBiomass_**data**.docx 1. **study32_**biomass-calc.sas **study 32_**plantcodes.txt
File format	This provides information relative to opening and reading the file.		1. text file 2. Microsoft Word 2010 document
Description	Describe file		1. Data entry program 2. SAS program: calculates dewpoint

Example

File type	Filename	File format	Description
MD	study123_Ecotone_**prj**.docx	Microsoft Word 2010	**Proj**ect documentation for Study 123
MD	study123_EcotoneBiomass_**dsd**.docs	Microsoft Word 2010	**D**ata**s**et **d**ocumentation for Study 123
DS	study123_EcotoneBiomass_**data**.xls	Microsoft Excel 2010	Ecotone quad biomass data

DE	study123_EcotoneBiomass-2008-analysis.xls	Microsoft Excel 2010	Analysis of Ecotone quad biomass data from quad field data for 2008
OT	study123_plantcodes.txt	text file	List of plant species with associated codes used in data

Files associated with this dataset			***(add rows as needed)***
File type	Filename	File format	Description

21) **Comments** (Include any comments here that more fully describe this project or provide clarification)

Comments		***(add rows as needed)***
mm/dd/yyyy Date	Comments by	Comments

History of Responsible Investigator(s)		***(add rows as needed)***
mm/dd/yyyy Start date	mm/dd/yyyy End date	Name (first last)

22) **Document Change Log** (history of changes made to this document)

Document Change Log		***(add rows as needed)***
mm/dd/yyyy Date	Log entry by	Log entry

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END OF DATASET DOCUMENTATION FORM
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Appendix 5. Letters of Support*

Dr. Lisandro Blanco
Research Range Management
Instituto Nacional de Tecnologia Agropecuaria
INTA EEA La Rioja
Argentina

Dr. Andres Cibils, Professor, Range Sciences
Dept. of Animal and Range Sciences
New Mexico State University

Dr. Felipe A. Rodríguez Almeida
Head of the Research and Graduate Studies Division
Universidad Autonoma de Chihuahua
Chihuahua, Mexico

C. Alan Rotz, Agricultural Engineer
USDA ARS
North Atlantic Area
Pasture System & Watershed Management Research Unit
University Park, PA

Jason Neff, Director
The Sustainability Innovation Lab at Colorado (SILC) & Professor, Environmental Studies
University of Colorado
Boulder, CO

*Note that letters of support are provided to indicate critical support that is not yet explicitly recognized via formal cooperative agreements. Most collaborations on Objectives in this plan are linked to cooperative agreements (Appendix 3).

Instituto Nacional de Tecnología Agropecuaria

December 18, 2017

Dr. Rick Estell
Research Animal Scientist
USDA-ARS Jornada Experimental Range
Las Cruces, NM 88003

Dear Dr. Estell,

We are writing to express our commitment to collaborate with you, Dr. Andrés Cibils, and Dr. Sheri Spiegal on your study comparing productivity and environmental impacts of Raramuri Criollo cattle vs. conventional livestock production systems in the arid southwest. My institution has agreed to provide support to conduct a long term grazing experiment in Argentina that will be modeled after the study at the Chihuahuan Desert Research Center (CDRRC) described in your proposal.

Our specific role will be to conduct a sister grazing study in four rangeland pastures (approximately 1200 ac each) at our Campo Anexo Los Cerrillos in the province of La Rioja, Argentina. We will follow similar protocols to those used at the CDRRC to measure the impacts of Argentine Criollo vs. desert-adapted Aberdeen Angus cattle on vegetation and soils of the arid Chaco ecosystem. In its initial phase, a doctoral student, whom we have already identified, will be in charge of conducting this study with full logistical and academic support from our institution.

We are excited to have the opportunity to join this network of Criollo cattle grazing studies and look forward to a fruitful exchange of experimental results, scientists, and students. With best regards,

…………………………………
Dr. Lisandro Blanco
Research Range Management
INTA EEA La Rioja

College of Agricultural, Consumer and Environmental Sciences
Animal & Range Sciences, MSC 3I
New Mexico State University
P.O. Box 30003
Las Cruces, NM 88003
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December 15, 2017

Dr. Rick Estell
Research Animal Scientist
USDA-ARS Jornada
Experimental Range Las Cruces,
NM 88003

Dear Dr. Estell,

I am writing to express my unambiguous commitment to collaborate with you and Dr. Spiegal on your study comparing productivity and environmental impacts of Raramuri Criollo cattle vs. conventional livestock production systems in the arid southwest. My home department of Animal and Range Sciences (ANRS) at New Mexico State University has approved the use of four pastures of its Chihuahuan Desert Rangeland Research Center (CDRRC) to conduct the long term grazing experiment described in your five-year plan.

My specific role will be to help oversee the execution of this study, to act as a liaison between the USDA- ARS Jornada Experimental Range and ANRS/CDRRC, and to serve as academic advisor for graduate students involved in conducting the research. I will allocate a portion of my USDA-AFRI Hatch grant funds (pending renewal in 2018) to partially cover the cost of operating this study. A considerable portion of my research time will be allocated to this project. My collaboration efforts will also involve serving as a liaison with sister studies at research sites in Mexico and Argentina; I will help coordinate study network activities including exchange of data, students, and researchers. Letters of support from Argentine and Mexican collaborators will be sent to you under separate cover.

Needless to say I am thrilled to have the opportunity to work with you and Dr. Spiegal on this cutting- edge research. I am convinced that it will have tremendous impact on southwestern ranching systems.

With best regards,

Andrés F. Cibils
Professor of Rangeland Science

UNIVERSIDAD AUTÓNOMA DE
CHIHUAHUA

December 18, 2017

Dr. Rick Estell
Research Animal Scientist
USDA-ARS Jornada Experimental Range
Las Cruces, NM 88003

Dear Dr. Estell,

We are writing to express our commitment to collaborate with you, Dr. Andrés Cibils, and Dr. Sheri Spiegal on your study comparing productivity and environmental impacts of Raramuri Criollo cattle vs. conventional livestock production systems in the arid southwest. Our department has agreed to provide support to conduct a long term grazing experiment in Mexico that will be modeled after the study at the Chihuahuan Desert Research Center (CDRRC) described in your proposal.

Our specific role will be to conduct a sister grazing study in four rangeland pastures at the Rancho Experimental Teseachic, state of Chihuahua, Mexico. We will follow similar protocols to those used at the CDRRC to measure the impacts of Mexican Criollo vs. British crossbred cattle on vegetation and soils of semiarid oak woodlands. In its initial phase, a doctoral student, whom we have already identified, will be in charge of conducting this study with full logistical and academic support from our institution.

We are excited to have the opportunity to join this network of Criollo cattle grazing studies and look forward to a fruitful exchange of experimental results, scientists, and students.

With best regards,

Dr. Felipe A. Rodríguez Almeida
Head of the Research and Graduate Studies Division

c.c.p. Dr. Carlos Ortega Ochoa – Director de la Facultad de Zootecnia y Ecología, UACH.

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United States Department of Agriculture

Research, Education and Economics
Agricultural Research Service

August 31, 2018

Dr. Sheri Spiegal, Research Animal Scientist
USDA, Agricultural Research Service
P.O. Box 30003, MSC 3JER, NMSU
2995 Knox Street
Las Cruces, New Mexico 88003

Dear Dr. Spiegal:

This letter supports my interest and willingness to collaborate with you on your new USDA-ARS funded CRIS project. Specifically, I will work with you in modeling and life cycle assessment of traditional Angus and alternative Criollo beef cattle production systems. We will study the environmental and economic impacts of these systems to determine the most sustainable cattle production practices for this region of New Mexico. I look forward to working with you on this project.

Sincerely,

C. Alan Rotz

C. Alan Rotz
Agricultural Engineer

North Atlantic Area • Pasture Systems & Watershed Management Research Unit
Building 3702, Curtin Road • University Park, PA 16802-3702, USA
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SILC - Sustainability Innovation Lab at Colorado
UNIVERSITY OF COLORADO BOULDER

Sustainability Energy and Environment Complex
4001 Discovery Drive
Boulder, CO, 80309

January 17, 2018

Dear Dr. Bestelmeyer,

I am writing to confirm the commitment the Sustainability Innovation Lab at Colorado (SILC) to a continued and expanded collaboration with the USDA-ARS Jornada Experimental Range. I believe our ongoing collaboration adds value and impact to current ARS projects by leveraging CU's significant expertise in modeling, remote sensing, and social sciences. Our students and researchers also benefit from regular interaction with high level ARS and NRCS research scientists.

SILC was established in 2015 as an "innovation space" where a wide variety of individuals and organizations can interact. Our current projects include the U.S. Global Hub of the Future Earth Secretariat, the Global Sustainability Scholars program, and collaborative research in areas that include detailed analysis of the interactions between wind/water erosion, climate change and agricultural and rangeland sustainability. Our work with the Jornada's "Land-Potential Knowledge System" (LandPKS) has proven highly synergistic with these and other research efforts and opened the door to a wide diversity of new collaborative opportunities.

During the past several years, SILC has:

- Provided a collaborative space for the LandPKS team to work in a technology development environment modeled after best practices in the private sector
- Recruited and retained key staff, including a very successful (developed 2 of Top 10 i-Phone health apps) private sector software engineer to work on the LandPKS project and contractors to provide rapid, high-quality input to app design, cloud computing capacity, and database management.
- Hosted multiple formal and informal work sessions with collaborators located within commuting distance of Boulder including, the NRCS Colorado State Office, the Bureau of Land Management National Operations Center, and several groups at Colorado State University, among others.
- Hosted an international USAID digital agricultural innovation workshop where LandPKS was featured prominently
- Provided technical leadership for LandPKS model development.
- Acquired over $450,000 in in private foundation funding to support LandPKS model development.
- Facilitated collaboration with a team of CU-based social scientists, which acquired a $50,000 seed grant to support research designed to improve the development of LandPKS.
- Facilitated collaboration with CU's Computer Science program, which resulted in the no-cost development of a soil color identification module that is being added to the LandPKS app.

SILC - Sustainability Innovation Lab at Colorado
UNIVERSITY OF COLORADO BOULDER

Sustainability Energy and Environment Complex
4001 Discovery Drive
Boulder, CO, 80309

- Introduced ARS scientists to the broader community by hosting seminars, scheduling meetings with CU administration, and by including them in several high-level conferences and workshops hosted at CU.
- Connected LandPKS staff and developers to the dynamic software and start up communities in the Boulder-Denver region.
- Promoted adoption of the LandPKS app, including a tentative commitment from a partner organization to translate it into Urdu and deploy it on 100,000 phones.

During the next 5 years, we welcome the opportunity to continue the types of collaborations described above, and to further explore opportunities to leverage the respective strengths of SILC and the Jornada to support Sustainable Agricultural Systems Research. We are particularly interested in working together on research and technology development to better support farmer and rancher decision making. CU is widely recognized for its expertise in the earth and space sciences with rapidly growing capacity in machine learning, systems modeling and other key areas.

During the first half of 2018, SILC will create a new innovation community for 25 graduate students drawn from a range of fields including engineering in a new community focused on innovative problem solving leveraging recent advances in sensor and mobile technology. This expansion of SILC will further increasing opportunities to build on the unique opportunities that a non-land grant university with a very progressive, flexible and innovative administration has to offer.

Sincerely,

Jason Neff
Director, The Sustainability Innovation Lab at Colorado (SILC) & Professor, Environmental Studies