Collaborative Approaches to Strengthen the Role of Science in Rangeland Conservation

By Brandon T. Bestelmeyer, Laura M. Burkett, Leticia Lister, Joel R. Brown, and Robert L. Schooley

On the Ground

- The use of science to inform conservation practices is limited by broad generalities generated from limited sampling alongside narrow ecosystem service perspectives.
- Collaborative science approaches featuring ''social-ecological system'' perspectives are being used as a means to improve the utility of science.
- We review our approach to collaborative science to improve brush management outcomes in rangelands in the Chihuahuan Desert.
- Expanding the use and utility of collaborative science requires stable support via targeted funding and technical expertise, as well as web-based tools and mobile applications that link specific locations to science information and conservation practice guidelines.

Keywords: Monitoring, Collaborative adaptive management, Brush management, Ecological sites, State transition models.

Rangelands 41(5):218–226
doi 10.1016/j.rala.2019.08.001

Introduction

"Conservation practices," as used by the US Department of Agriculture (USDA), refer to management interventions in agroecosystems intended to promote the sustainability of production and nonproduction ecosystem services.[1] Historically, "conservation" referred to soil and nutrients, which underpin land potential and options for a variety of land uses, but the goals of conservation practices are now much broader. Current conservation goals in rangelands generally focus on maintaining or restoring a desired ecological state while sustaining the flow of economic benefits.

In rangelands, conservation goals are both individual and societal. There are individual goals because ranchers want to sustain their enterprises and steward the land for future generations. There are societal goals insofar as government agencies, especially the USDA Natural Resources Conservation Service (NRCS), support management via conservation programs and technical assistance to promote public goods, such as wildlife conservation and air and water quality. When public land is involved, conservation actions must additionally serve the multiple-use mission of responsible agencies. Science has been called upon to evaluate and improve the effectiveness of conservation practices, most comprehensively via the NRCS Conservation Effects Assessment Project (CEAP).[2] The role of science in conservation planning, however, has been limited by environmental complexity and the lack of suitable methods and sufficient resources.[1]

In this article, we argue that collaborative science at the landscape scale, supported by developing technologies and stable funding, can mobilize science to improve conservation practice effectiveness. We briefly review the history of science's role in rangeland conservation to provide a background. We then introduce the Restore New Mexico Collaborative Monitoring Program in which we have been applying collaborative science, involving 6M acres of the Chihuahuan Desert of southwestern New Mexico, for the past 10 years. We review steps we have used in the collaborative science process and how we are applying them in the Restore New Mexico program. Our ideas draw from and parallel those of an increasingly rich body of collaborative science examples.[3–6]

The Changing Role of Science in Rangeland Conservation

Science's role in rangeland conservation has evolved over the past century.[7] In the Southwestern United States, early rangeland science (from about 1900 to 1965) focused on improving vegetation conditions for livestock production. The products of this research—often featuring general recommendations based on research at individual study sites—were delivered by scientists in a "top-down" fashion via field days and government publications, influencing outreach to ranchers and government policy.

The dawn of the environmental movement coincided with the rise of ecosystem ecology in the mid-1960s, after which the focus of scientific studies in rangelands broadened to include environmental attributes unrelated to agricultural production, such as nongame animal populations, and development of general ecological theory (see publications from this time period at the Jornada Experimental Range website[i]). Documenting and reducing human impact on nature was a primary motivation for ecosystem ecology beginning in the 1970s.[8] Numerous studies began to highlight negative impacts of livestock production on environmental attributes as a means to influence regulation,[9] whereas other scientists defended ranching land uses.[10] Some of these studies reflected a shift toward an increasing politicization of science[11] that fostered distrust of scientists by some stakeholders and limited the role of science in community decisions.[12]

Analysis of early science-management relationships also point to practical limitations of science for evaluating conservation practices. The narrow spatial and temporal scales of scientific observations in extensive and complex landscapes limit the inferences drawn from many scientific studies in rangelands.[13] Conclusions drawn from one location or time period may be poorly matched to other contexts in which conclusions are applied.[14] Measurements from small plots with specific contexts (e.g., near to or far from livestock watering points or on different soils) can be inappropriately extrapolated to draw conclusions about a conservation practice at a regional scale. Site- or network-level ecological research in the "normal science" tradition[15] is best suited to reveal robust generalities, but the effects of conservation practices are often highly dependent on variations in climate, soils, weather events, and other management actions that are not accounted for.

Because of past measurement limitations, broad-scale assessments of conservation practices' effects have been highly equivocal in rangelands. There are simply not enough site-specific data to draw conclusions that account for highly variable rangeland contexts.[2] Furthermore, the emphasis of science on broad generalities from narrow ecosystem service and societal perspectives limits its ability to improve conservation practices on the ground.[7,16] In response, CEAP has invested in tools and approaches to improve scientific support.

Collaborative science approaches featuring "social-ecological system" perspectives have been proposed as a means to improve the utility of science.[6,17–19] Collaborative science involves the inclusion of scientists as part of a local community of stakeholders who together frame and test questions, rather than scientists going it alone and "transferring" their interpretations to stakeholders. A social-ecological perspective holds that measured attributes should reflect the breadth of ecological and societal processes valued by stakeholders, rather than only those processes of interest to scientists.

[i] https://jornada.nmsu.edu/biblio

Collaborative science additionally relies on two different modes of science that we refer to as "global science" and "local science." Global science is international in scope, creates broad generalizations that can help managers understand potentially important ecological processes, and frame locally relevant questions. Global science relies on the synthesis of many studies across the world from hundreds of scientists. Generalizations about a process or type of management are often based on studies with high levels of control with effects of potential confounding variables minimized. Local (or place-based) science, in contrast, involves collaboration in a single landscape, where ideas from global science are used to generate questions accounting for local context.[20] Local science measures the impacts of conservation practices to make subsequent applications more efficient and effective. Local science also supports adaptive management within specific projects, in which long-term monitoring is used to adjust application of conservation practices over a period of years to decades (e.g., annual adjustments to prescribed grazing).[17] Local studies can also inform the generalizations of global science. Global science is often glamorous: it is reported in widely cited publications and draws news media attention. Local science may not make the news, but directly supports decision-making.

Collaborative approaches hold great promise as tools to increase the utility of science for improving conservation effectiveness, but there are barriers to implementing collaborative science associated with strategies, costs, and expertise.[1,21] It has become clear that we need scientific approaches that: 1) consider stakeholders when selecting variables measured; 2) account for variation in spatial context; 3) are of an adequate duration to reveal slow responses to ecological and social processes; 4) are adaptive and allow for modification of management treatments over time; and 5) are supported by stable funding and technical expertise.

The Restore New Mexico Collaborative Monitoring Program

The RNM Collaborative Monitoring Program was initiated to measure the effects of brush management on the restoration of perennial grasses in the Chihuahuan Desert. The RNM Program, initiated in 2005, is a statewide, multiagency effort led by the Bureau of Land Management (BLM) to control encroaching woody species, improve riparian habitat, and reclaim abandoned oil and gas well pads. The monitoring program described here is focused on the southwestern New Mexico region (Major Land Resource Area 42, largely in the 8–10 inch precipitation zone), where historical episodes of overgrazing during drought events triggered the expansion of shrubs including creosotebush (*Larrea tridentata*) and honey mesquite (*Prosopis glandulosa*) into historical grasslands.[22] Shrub encroachment is a concern for diverse stakeholders because it can diminish multiple ecosystem services, including forage for livestock, habitat quality for grassland-associated wildlife, and air quality. Brush management using selective herbicides to reduce shrub cover has been broadly implemented since the 1980s on public and private lands to sustain or restore perennial grass cover. Rates of brush management increased dramatically after the initiation of RNM in 2005. Over 300,000 hectares of rangeland have been treated in the past 40 years across southwestern NM, and 74% of that area was treated after the initiation of RNM.[22] The outcomes of these brush management treatments, however, have been variable (Fig. 1). Although herbicides are effective at killing shrubs on certain ecological sites, some treatments are highly successful, others moderately so, and others do not appear to result in grass recovery even when shrub reduction targets have been achieved. Consequently, there is broad interest in studying the effects of the recent surge in brush management applications and using that information to improve conservation outcomes.

Beginning in 2007, the BLM initiated a collaboration with the USDA Agricultural Research Service (ARS) Jornada Experimental Range (JER) in order to: 1) estimate the average effects of brush management treatments on vegetation across the southwestern New Mexico area; 2) identify environmental factors explaining variations in treatment outcomes; and 3) determine which brush management treatments are not performing as expected and identify strategies to maximize future benefits (adaptive management). We embedded true experiments in planned brush management treatments. Treated and untreated site pairs were established at randomly selected locations within targeted ecological sites. Untreated "control" sites were programmed into the global positioning system (GPS) of the aircraft applying herbicides, and treated sites occurred in adjacent areas featuring similar soils and initial vegetation. Monitoring of plant cover using standardized methods[23] was conducted before shrub mortality and periodically (at least every 5 years) thereafter. We plan to follow the treatments for at least 20 years given the slow responses of arid ecosystems. This effort has been supported by a portion of the restoration funds obtained by BLM, other related BLM programs, NRCS CEAP, and staff contributions of the JER.

In June 2018, we held our first partner meeting to review the results from study sites with vegetation responses measured 5–10 years posttreatment, focused on the use of tebuthiuron treatments within creosotebush shrublands, which were most common. The formal analysis of these data will be presented in another paper, but here we will describe our general conclusions to date and describe our collaborative science process. We disseminate our results to ranchers via their direct interactions with BLM range staff and participation at coordination meetings.

A Strategy for Collaborative Science to Improve Conservation Outcomes

Below, we describe eight steps in a general approach to a collaborative science program and how we have applied each step in RNM (Fig. 2). The primary goal of this approach is

Figure 1. Variations in effects of historical brush management on gravelly to loamy ecological sites in southern New Mexico. The top panel is a typical shrub-dominated state, and the lower panels depict varying degrees of grass cover in treated sites (which may partly reflect differences in inherent productivity).

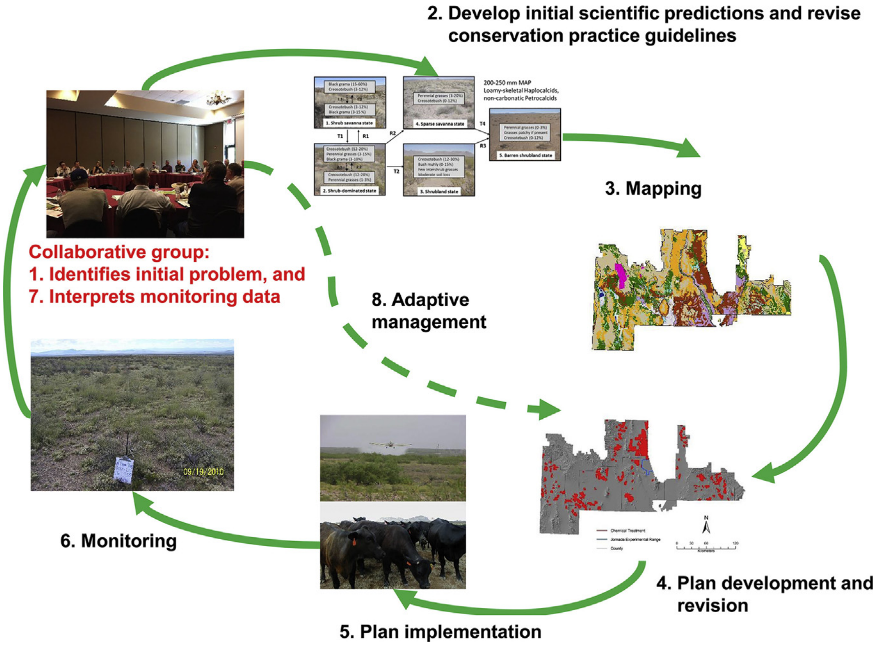

Figure 2. Steps in collaborative science with the Restore New Mexico Collaborative Monitoring Program. The dashed line indicates adaptive management after initial results are interpreted.

not to contribute to a general determination of the value of conservation practices across the United States,[2] but rather to better manage the local application of practices that are already known to produce benefits in at least some circumstances.

Establish a Collaborative Group that Identifies Critical, Landscape-level Problems (Step 1)

Collaborating stakeholders that represent the varied interests in a particular landscape are assembled and are often guided by a team leader or "boundary spanner" that can connect people and is trusted.[16] The group identifies and prioritizes natural resource problems and restoration goals for a project area, typically a specific landscape sharing a common institution and defined by shared interests.[24]

In some cases, agreement on a management strategy can be difficult. Twidwell and others[25] describe efforts of landowner-led prescribed burn cooperatives to manage the encroachment of Ashe juniper (*Juniperus ashei*) and Eastern red cedar (*Juniperus virginiana*). The use of prescribed fire is complicated by societal resistance to fire based on health and safety concerns. In such cases, education and gradual acceptance of a conservation practice may be required in order to expand collaborative groups.

In the case of RNM, shrub encroachment has been a long-standing resource concern for many rangeland users. The collaborative group to address this issue was formed around RNM funding, and brush management using herbicides is broadly regarded as an effective practice in the region.[26] The group comprises land management agencies that fund and execute brush management and supporting practices (NRCS, BLM, New Mexico Department of Fish and Game, among others) across multiple land ownerships (private, state, and federal). These efforts are coordinated with ranchers by the New Mexico Association of Soil and Water Conservation Districts (NMACD) via Coordinated Resource Management Plans. Leaders from NMACD effectively serve as "boundary spanners" that connect agencies, ranchers, and science activities.

Develop Predictions for Conservation Effects (Step 2)

Existing science information is used to identify assumptions and develop predictions that guide conservation actions (Fig. 2). This has been accomplished via participatory mapping exercises, interviews, and workshops[27,28] and can be centered on conceptual models of ecosystem change and restoration options for a region.[29] In the United States and elsewhere, synthesis products called "Ecological Site Descriptions" (ESDs) are used to guide conservation investments in rangelands. Land classes called "ecological sites" differentiate land areas according to the soil and climatic factors that control vegetation composition and its responses to management.[30] State-and-transition models (STMs) for each ecological site describe the possible ecosystem states, the mechanisms of transitions, and the mechanisms preventing or promoting recovery of desired states.[31] The STMs link science to resource concerns and conservation practices using narratives. The details in STMs form the scientific basis for "conservation practice specifications" that tailor general "conservation practice standards" (i.e., why and where a

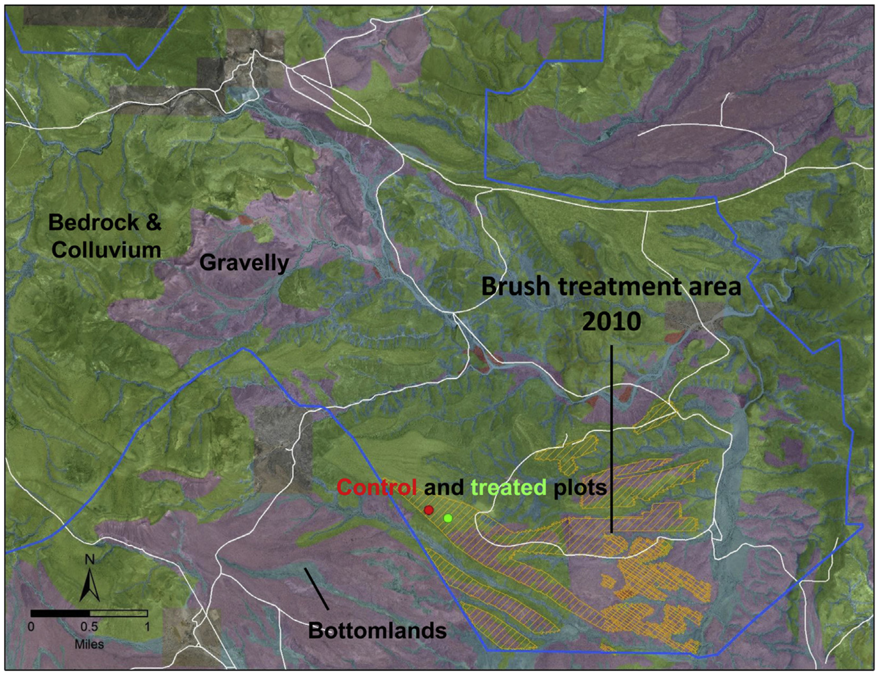

Figure 3. Map of ecological site groups, treated area (hatched pattern), and the locations of treatment and untreated (control) plots on an individual ranch in southern New Mexico.

practice should be applied) for local contexts[ii]. The narratives ideally reflect a blend of scientific and local knowledge.[32]

Within a collaborative project, the ESD documents can be used to initiate discussions about goals, assumptions, and hypotheses for specific parts of a landscape and how to design conservation effectiveness studies. In the RNM case, ESDs and their associated soils and topographic information were used to: 1) determine application rates for herbicides (the amount of herbicide needed for creosotebush treatments depends on soil clay content); 2) identify states that are unlikely to experience substantial grass recovery following shrub mortality (highly eroded shrubland states are least likely to benefit from treatment); and 3) specify monitoring strategies and indicators of treatment success (perennial suffrutescent and bunchgrasses characteristic of the reference state of target ecological sites). Monitoring plans were finalized with a BLM technical group in 2008.

Develop Maps Based on Predictions (Step 3)

Spatial data on ecological sites and states are essential to connect predictions to areas on the ground. Aerial photography and other GIS layers (e.g., digital elevation models, soil maps) can be used to produce maps of ecological sites and states by hand or using automated procedures (Fig. 3).[33] Because the ecological state of an area is often difficult to ascertain from remotely sensed data, rapid field assessments based on indicators in ESDs can be used to verify state identity. The potential for spatial interactions with adjacent states (e.g., offsite effects) can also be evaluated using imagery, field observations, and process-based (e.g., hydrology) models. The mapping effort delineates land units according to their responses as predicted in STMs, rather than to arbitrary vegetation classes. The map units can also be used to store data about restoration actions in a database.

[ii] https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps/

Development of Landscape Management Plans (Step 4)

Maps of ecological sites and states are used to specify the goals and management interventions needed to achieve them in different parts of the project area. The selection of objectives and interventions depends upon the ecosystem services being managed for and either the risk of degradation or the nature of restoration thresholds that must be overcome to achieve the objective, such as the need for altered stocking rates or more intensive efforts such as seeding or channel stabilization. In this way, the scientific and local knowledge synthesized in STMs can be used to produce derived "management maps" to guide conservation plans. In the RNM case, maps for particular project areas are based on the ecological sites being targeted for brush management with a particular herbicide. For example, tebuthiuron targeting creosotebush is focused on shrub-dominated states of Gravelly and Loamy ecological sites. Drainages featuring woody plants that are desirable for wildlife (e.g., little-leaf sumac; *Rhus microphylla*), areas that are dominated by woody plants in the reference state (rocky outcrops), and erodible areas with high slopes or already eroded states are avoided for treatment.

Table 1. Strategy for collaborative interpretation of monitoring data in the Restore New Mexico program

1. Focus on interpretation of patterns in the data, not on causality (for which we have scant data).
2. Highlight the different directions of the multiple responses (e.g., some species increase, others decrease in response to brush management).
3. Give time to let the multiple responses "sink in" and be comprehended.
4. Let discussion of possible causes emerge from group members, respond to questions they direct to scientists.
5. Let group members identify the next round of hypotheses.

Management Plan Implementation (Step 5)

Management agencies or landowners implement the management plans. For RNM, this is a collaborative effort with various partners depending on the project (BLM, NRCS, State Lands Office, private landowners). In recent years, the boundary spanner (NMACD) has taken on the role of hiring contractors to apply chemical treatments and executing projects across land-ownership boundaries (e.g., via Coordinated Resource Management Plans and multiple sources of funding) to make treatments more efficient.

In testing the effects of a conservation practice, it is essential that the practice is implemented according to clearly defined practice specifications. If the practice is not implemented according to specifications, then long-term monitoring will not provide a valid evaluation of practice efficacy. For example, if a prescribed grazing plan is based on the hypothesis that 30% utilization with 2 years of growing-season deferment will lead to recovery of key grass species, but the practice as applied results in 50% utilization and occurs throughout the growing season, then a lack of recovery does not reject the management hypothesis. For RNM, we ensure that tebuthiuron applications result in > 75% of shrubs having > 50% leaf loss before initiating monitoring tests. This target for shrub mortality can readily be achieved and it allows us to avoid confusing a poor grass response given high shrub mortality (which we want to understand) with poor grass response owing to errors in herbicide application and low shrub mortality (which we understand already).

Monitor and Interpret Ecosystem Responses (Steps 6, 7)

Precise, repeatable monitoring stratified to different parts of a landscape and linked to key explanatory variables (e.g., elevation, soil texture) can test for the effectiveness of management to achieve desired outcomes. In designing the monitoring, there should be careful consideration of the choice of response variables, their anticipated sensitivities to the management actions, and timelines for detectable change. Modeling exercises can help to link ground-based monitoring of certain indicators (such as vegetation cover and height) to other processes and ecosystem services that cannot be measured directly in most circumstances (such as wind erosion and air quality).[34] New interpretations can be used to update predictions, conceptual models, and conservation practice specifications.

We have been careful to discuss monitoring data with stakeholders using a deliberative process (Table 1) before offering interpretations into the public domain because the effects of brush management are influenced by short-term climate variability and other events that are not reflected in available data. The limitations of available data are highlighted: interpretations can evolve with additional data, hence the need for long-term monitoring and periodic meetings when new analyses are available. Furthermore, interpretation of a given result may vary among stakeholders. Thus, "jumping the gun" on interpretations can engender distrust, disrupt social learning, and ultimately compromise the utility of science to improve conservation. However, participants in collaborative groups should also be made aware that scientists must produce peer-reviewed publications and deliver formal presentations to their scientist peers in order to validate scientific results and for scientist's careers to advance.

Adaptive Management (Step 8)

The interpretation of monitoring data can point to one of two options. The data may indicate desired responses to conservation practices in an acceptable proportion of cases, supporting continuation of management strategies with minimal adjustment. Alternatively, the data may indicate no change or negative change in key indicators of interest to stakeholders. In these cases, the potential causes of negative outcomes can be evaluated and discussed, alternative management strategies considered, and additional data needs identified. Uncertainty in data interpretations should always be acknowledged, owing to the limitations of the duration of monitoring and spatial coverage of sampling.

To date, the RNM data provide a complicated "report card" on brush management practices. Responses of vegetation in both recent (as yet unpublished) and historical treatments[35] indicate that, on average, perennial grasses benefit from treatments, but grasses that are characteristic of the reference state may not recover to their historical abundance. There is also considerable variation in the degree of grass recovery that is related to variation in soils, climate, and unmeasured factors. Treatments also benefit some grassland-associated wildlife species, but not all of them, and some shrubland-associated species decline.[35–37]

Adaptive management can occur at programmatic and enterprise/site levels. With regard to programs, statistical patterns from the whole monitoring program will inform restoration investments and prioritization by the BLM and NRCS. For use at the level of individual ranchers, we developed an automated report that compares the response of an individual brush management treatment to a population of treatment responses from similar environmental contexts (i.e.,

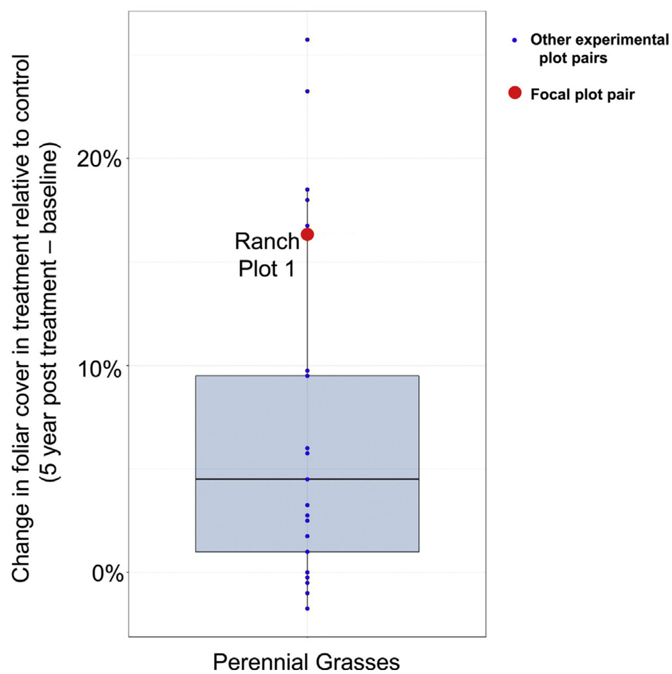

Figure 4. A box-and-whisker plot of the change in foliar cover of perennial grasses in treatments relative to controls over a 5-year monitoring period (2010–2015) in all monitoring plot pairs below 5,000 feet (1,500 m) elevation. The red point indicates the change value for an individual ranch. Values above zero indicate that treatments gained cover (over 5 years) at a greater rate than controls.

a form of benchmarking). In our example (Fig. 4.), we showed a rancher that her treatment response was among the best responses observed in her climatic zone, in spite of the fact that her soils had comparatively low water holding capacity. This result initiated discussions of grazing management history and future possibilities. Most important, this effort made the monitoring data relevant to her.

Fostering Collaborative Science

Our experiences with collaborative science suggest two critical challenges that must be overcome to expand such approaches as part of CEAP and rangeland science more generally.

Resources and Widely Available Expertise

Significant investment from government agencies or other organizations is required to initiate and sustain long-term collaborative science programs.[1] Our work with RNM is possible because of sustained funding from BLM and NRCS partners, in-kind support from the ARS-JER, and competitive USDA National Institute of Food and Agriculture (NIFA) funding. Similar support is hard to obtain and sustain in most landscapes. Furthermore, long-term involvement of science technical staff in local communities would need greater support. Research institutions, including universities and government labs, are spread throughout the United States and support interactions with stakeholders. The number of the research institutions and scientists, however, is likely insufficient to serve all those who might benefit from direct interactions. We see two options to scale up the technical expertise needed to make science tools available to numerous, distinct communities: 1) funding to involve federal science agencies, university extension, and private contractors (e.g., technical service providers that work on behalf of NRCS) in collaborative projects, and 2) appropriately trained scientists embedded within the offices of NRCS, BLM, Forest Service, or landscape collaborative organizations (e.g., the Malpai Borderlands Group). Rangeland and ecology programs at universities are well positioned to develop and deliver the needed training for early career scientists,[38] including interdisciplinary and collaboration skills that are emphasized in "translational ecology."[39] Local scientists can be continually supported (in, for example, data analysis) via collaborations with national science programs at federal research laboratories and universities.

Web and Mobile Technologies

Technology can link science resources to collaborative groups and, to some degree, mitigate the lack of local science expertise. Web and mobile applications are being developed that increase accessibility of data, analytical, and visualization resources to local scientists and managers (e.g., the Rangeland Analysis Platform).[40] Mobile tools in development will also facilitate a land manager's ability to provide data to scientists and community groups (e.g., LandPKS).[41] Finally, web-based conservation planning platforms, such as the NRCS Conservation Desktop[iii] can be designed to link science information in ESDs to conservation planning activities. In turn, modeling efforts linked to ESDs can expand the variables considered in setting conservation objectives, including wind erosion and a wide range of ecosystem services (which is a current emphasis of NRCS CEAP-supported research). Recent advances in the databasing of ESD information via the Ecosystem Dynamics Interpretive Tool (EDIT) can facilitate web and mobile-based information access.[42] Such web-based and mobile tools can be used to communicate how conservation practice efficacy varies across a landscape, and how practices might be locally adjusted to increase efficacy.[43]

Conversely, ESDs could be redesigned to more directly link ecological processes to conservation planning and practice guidelines. Results from monitoring data, such as those we have produced, can be used to update generalizations and considerations for local efforts. Agencies can also help to manage data resulting from tests and link them to ESDs (e.g., the BLM's Assessment, Inventory, and Monitoring Program). Careful attention to information management is critical. The involvement of federal or state government agencies should ensure the durability, integrity, and availability of data and science knowledge, but the inspiration, organization, and technical expertise for projects is necessarily a local, community-level effort.

Conclusions

As global change accelerates, the need for conservation investments will increase. Yet funding to support conservation programs is likely to remain limited. Learning and adaptation will be increasingly important to increase efficiency and sustain the value of conservation investments. Expanding collaborative science as part of CEAP activities could promote learning and adaptation and help land managers to avoid the pitfalls of rigid, overgeneralized science interpretations and weakly supported claims. The development of a broadly applicable and flexible methodology for collaborative science, taking advantage of tools such as ESDs and technologies such as mapping, web-accessible databases, and mobile applications[43] could increase the frequency and success of collaborative science efforts in rangelands.

Acknowledgments

We thank the staff and leadership of the BLM Las Cruces District Office for supporting this collaboration, especially Jack Barnitz, Lane Hauser, Don McClure, Ray Lister, and Phil Smith. We also thank the NMACD for their support of the interactions with stakeholders, especially George Chavez, Don Ellsworth, and Ken Leiting. We also thank our scientific collaborators John Coffman, Brad Cosentino, Neeshia Macanowicz, and Darren James for support of the Restore New Mexico studies. Finally, we thank the NRCS CEAP Grazinglands program, Leonard Jolley, and Lori Metz for their support of this and related programs.

[iii] http://www.wikiagro.com/en/Conservation_Delivery_Streamlining_Initiative

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Authors are Research Leader, United States Department of Agriculture, Agricultural Research Service, Jornada Experimental Range, Las Cruces, NM, USA; Ecologist, United States Department of Agriculture, Agricultural Research Service, Jornada Experimental Range, Las Cruces, NM, USA; Supervisory Rangeland Management Specialist, United States Department of the Interior, Bureau of Land Management, Las Cruces District Office, Las Cruces, NM, USA; Rangeland Ecologist, United States Department of Agriculture, Natural Resources Conservation Service, Jornada Experimental Range, Las Cruces, NM, USA; Professor, Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana, IL, USA.