JRN-LTER VII: Annual Report (Year 1)

Award Number: 2025166
Project Title: LTER; Long-Term Research at the Jornada Basin (LTER VII)

Project/Grant Period: 12/1/2020 - 11/30/2024

Reporting Period: 12/1/2020 - 11/30/2021

ACCOMPLISHMENTS

What are the major Goals of the Project?

We will explore how landscape-level spatial heterogeneity evolves in response to the effects of disturbance triggers, connectivity-mediated feedbacks, and their interactions with the soil-geomorphic template. We will integrate long-term observations and recent theoretical developments to improve a conceptual and predictive framework for drylands. We propose to expand our landscape linkages framework to fill this critical need, and to contribute to emerging ecological theory on: (a) alternative states and transient dynamics, (b) ecosystem sensitivity under global change, and (c) cross-scale interactions.

Obj. 1: Quantify effects of interactions among triggers, connectivity-mediated feedbacks, and soil-geomorphic heterogeneity on the rate and nature of state transitions

Obj. 2: Explain and predict multi-scale spatial heterogeneity in alternative states

Obj. 3: Apply new analytical concepts and tools to broader extents (regional to global) and examine consequences for ecosystem services

What was accomplished under these goals?

Major Activities

Obj. 1: Quantify effects of interactions among triggers, connectivity-mediated feedbacks, and soil-geomorphic heterogeneity on rate and nature of state transitions

A. Grassland to Shrubland Transitions

A1. ThreshEx: Repairs were conducted on infrastructure this year. Experiments will be initiated in 2022.

A2. The NEAT2 Experiment: The NEAT biocrust restoration project intends to restore biocrust and determine interactions with higher plant cover for soil stability against aeolian erosion (**Figure 1**). We characterized crust microbial composition and cultivated biocrust inoculum. Field deployment including the biocrust nursery will occur in Spring 2022.

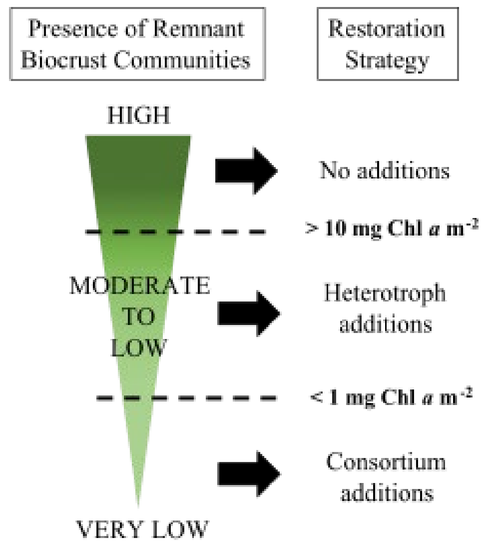

Figure 1: Recommendation for restoration of cyanobacterial biocrusts based on presence of phototrophic biomass at degraded sites.

A3. The Ecotone Study: Long-term sampling of rodents, lagomorphs, and mammalian predators continues to examine trophic cascades during grass-shrub state transitions. We expanded to include investigation of the diet and herbivory of the invasive African oryx relative to native and domesticated mammals. We completed a cross-site study of the responses of species and communities of desert rodents to climate variability using data from the Ecotone Study.

B. Shrubland to Grassland Transitions

B1. The Threshold Responses in Grass Growth, Establishment, and Recovery Experiment (TRIGGER): We manipulate PPT in a mesquite-invaded site at levels representing 100-y and 10-y wet-dry sequences. Plots are divided into 4 replicates with three levels of initial grass cover. At each PPT level, there are plots with ConMods (either present or absent). Weather, ANPP, cover, plant density, and recruitment by species are measured annually.

B2. The Grass Recovery on Wind Eroded Soils Experiment (GROWES): The GROWES experiment is examining alternative succession pathways in the presence or absence of shrubs following major disturbance. The experiment excludes mesquite colonization on half the site and is monitoring long-term vegetation trajectories and grass/forb successional pathways.

B3. Cross-Scale Interaction Study (CSIS): We continued a long-term multi-scale experiment to examine herbaceous recovery while manipulating shrub competition and connectivity across a gradient of shrub and herbaceous cover.

B4. Long-Term NPP and Grass Recovery Trends: We continue the monitoring of NPP at 15 locations across JRN following recent sequences of dry (2000-2003), wet (2004-2008), dry (2009 to 2012), and no trend years (2013-2020). We are examining legacy effects of wet and dry periods, and the spatial-temporal variability in grass response in different shrubland ecosystems.

C. Shrubland to Shrubland Transitions

C1. Long-Term Shrub Monitoring: We are redesigning this experiment to include shrub populations across the full Jornada Basin, including mesquite, tarbush, and creosote adjacent to long-term NPP sites where we have long-term ancillary data (weather stations, soil moisture, etc).

C2. Shrub Demographic Experiment (ShrubDemo): The ShrubDemo experiment targets fundamental demographic processes (germination, growth, and survival rates) controlling shrub expansion and shrub-shrub transitions. During Year 1, a graduate student defended her masters project and the results are in preparation for publication.

QuadCam Development: We piloted a new instrument system to fill the gaps in understanding of high-frequency demographic processes. QuadCam includes a high-resolution camera oriented vertically over a quadrat for automated deep-learning ID of germinations, seedling growth, and mortality/turnover of woody and herbaceous plants.

Plant-Soil Feedbacks: We continue the investigation of rhizosphere microbiomes for four abundant Jornada shrub species to compare rhizosphere microbial diversity and structure with the microbial taxa that associate with each species.

C3. Bajada Watershed Studies: We examined rainfall drop-size and kinetic energy at the Jornada and a site in Mesa, AZ as drivers of hillslope runoff and overland flow during winter and summer storm events. Analysis indicates specific runoff thresholds at different scales in the watershed. Long-term eddy covariance measurements were published via AmeriFlux. Analysis of seasonal water, energy, and carbon dioxide fluxes yielded a modified conceptual model of ecohydrological behavior in the watershed.

Carbon and Water Flux Studies: The JRN-LTER leverages collaborations to sample landscape heterogeneity using eddy covariance (2 LTER towers, NEON site, new CZO site, 30+ new ARL towers and 3 new ARS EC systems). The unprecedented JRN coverage provides new opportunities for understanding state-change impacts on landscape carbon, water, and energy exchange.

D. Transition to Novel Ecosystems

D1. How do Rainfall Variability, Grazing, and Competition with Native Grasses Interact to Trigger Non-Native Grass Invasion? Non-native grass *Eragrostis lehmanniana* (Lehmann's lovegrass) is widespread in the Sonoran Desert but less common in the Chihuahuan Desert. Field experiments and models will help predict likely spread with land use and climate change.

Plant-Soil Feedbacks and Lovegrass Invasion: We initiated a study on how 4 biocrust types mediate germination and early establishment of native grasses and *E. lehmanniana*. Data are being prepared for publication. A new nematode genus and species was discovered at the Jornada.

E. Transitions Under Climate Change

E1. Rainfall Manipulation Experiment: We conducted long-term rainfall mean and variability experiments (> 15 y) in a mixed black grama-mesquite dominated ecosystem. We continue to monitor phenology, ANPP, BNPP, plant species composition, and microbial composition. A new experiment will calibrate minirhizotron images using root biomass estimates (root in-growth cores).

Obj. 2: Explain and predict multi-scale spatial heterogeneity in alternative states

Jornada Long-Term Quadrats: A data paper for years 1915-2016 (122 quadrats) was completed and published (Christensen et al., 2021). Digitization is in progress for 33 quadrats. New analyses relating patterns in quadrat data to environmental variables were performed. New pantograph records were collected at 122 quadrats (on a 5-year schedule), which extended this dataset to 106 years.

Spatial Analysis of Jornada Basin State Transitions: Reanalysis of historic vegetation maps from 1858, 1915, 1928, and 1998 was used to quantify basin-scale transitions from grassland to shrubland, transitions between shrub functional groups, and transitions from shrub to grass dominance on contrasting soil-geomorphic units (Archer et al., in press).

Ecohydrological Modeling: Numerical simulations quantified the role of climate change and vegetation state transitions on channel percolation losses. We completed a field experiment that confirmed our concepts for runoff generation through the infiltration excess mechanism. Carbon flux measurements identify model developments needed to depict the role of shrubs in ecohydrological feedbacks in the eastern bajada.

Biocrust Carbon Cycling: We examined carbon exchange rates for five Chihuahuan Desert biocrust types (light, dark cyanobacterial, cyanolichen, chlorolichen, and moss crust). Measurements were taken after biocrust wetting and light incubation for different time-periods. Data analysis for publication is in progress.

Obj. 3: Apply new analytical concepts and tools to broader extents (regional to global) and examine consequences for ecosystem services

Expanding Arid Land Ecological Theory: We adapted the Pulse-Reserve-Paradigm of Noy-Meir for alternative organismal strategies to manage reserves in a manner that can be applied to both plant and microbial communities, and endow it with a solid mathematical treatment for testable predictions.

Restore New Mexico: Additional long-term monitoring records from plots across southwestern New Mexico were gathered and a manuscript based on results was drafted.

Malpai Borderlands Collaborative Research: Analyses comparing the Malpai Borderlands planning area to surrounding areas using spatial data on grassland productivity, vegetation composition, land use, fire, and ownership were conducted and published.

Significant results

Obj. 1: Quantify effects of interactions among triggers, connectivity-mediated feedbacks, and soil-geomorphic heterogeneity on the rate and nature of state transitions

A. Grassland to Shrubland Transitions

A1. ThreshEx: Nothing to report yet.

A2. The NEAT Experiment: Important discoveries include the role of biocrust probiotic bacteria and biocrust pathogens in biocrust systems (**Figure 2**). These results are either published or about to be submitted and are the basis of a complementary NSF award for work at the Jornada.

Figure 2: Image of a biocrust epidemic caused by the pathogen Cyanoraptor togatus.

A3. The Ecotone Study: Shrub encroachment alters the population abundances and community structure of desert rodents. Regionally, species diversity of desert rodents has declined, especially during the dry phase of the Pacific Decadal Oscillation. The species that were winners and losers under drought depended on ecological state. Invasive African Oryx are increasing and concentrating their herbivory on grasslands during dry years, which could affect the extent and rate of grassland-to-shrubland transitions.

B. Shrubland to Grassland Transitions

B1. The Threshold Responses in Grass Growth, Establishment and Recovery Experiment (TRIGGER): Our first two years of field data collection have been completed and preliminary data analysis has been conducted. Analysis and publication await further data.

B2. The Grass Recovery on Wind Eroded Soils Experiment (GROWES): Removal of shrubs facilitates recovery of short-lived grasses (Sporobolus, Aristida) and perennial forbs on this degraded site. As herbaceous cover increases, dust deposition decreases suggesting a reduction in erosion by wind. Results are being prepared for publication.

B3. Cross-Scale Interaction Study (CSIS): Shrub competition and aeolian connectivity interact to control herbaceous recovery in the cross-scale experiment. Results are being prepared for publication.

C. Shrubland to Shrubland Transitions

C1. Long-Term Shrub Monitoring: Nothing to report yet.

C2. Shrub Demographic Experiment (ShrubDemo): Results show that one of the major shrubs of the Jornada Basin (tarbush) is primarily and consistently limited by seed viability (<< 1%), while the other shrubs of the Jornada (mesquite and creosote) germinate readily but have differential responses to the different dominant soils of the Basin, and the varying wet and dry conditions. These results are being prepared for publication.

C3. Bajada Watershed Studies: Ecohydrological modeling revealed that grass-to-shrub state changes induce more change in hydrological processes than anticipated climate change. We found that rainfall intensity was a strong control on runoff generation and connectivity (**Figure 3**) and also the importance of the seasonal carry-over of soil water from summer monsoon to the subsequent cool dry winter and spring period (**Figure 4**).

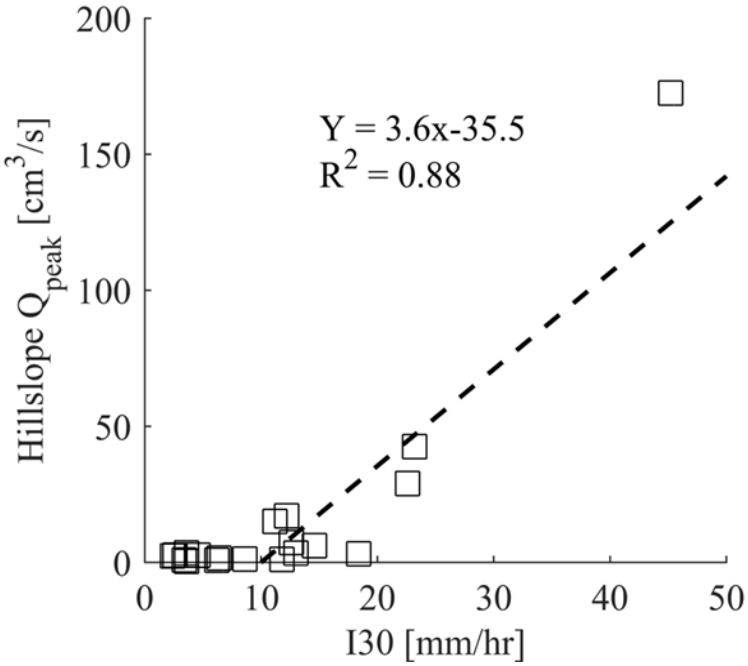

Figure 3: Observed relation between rainfall intensity (I30 is the maximum rate during a 30-minute period) and hillslope plot runoff production (Qpeak is the peak discharge) in the experimental watershed of the eastern bajada at the Jornada Experimental Range. Datasets span the period of October 2019 to September 2021. A threshold behavior is noted with increasing hillslope peak discharge after 10 mm/hr of I30. This implies that only the most intense storms have the capacity to mobilize water laterally within hillslopes. An infiltration-excess runoff mechanism (Hortonian runoff) was identified through this analysis. From Keller (2021): Runoff Connectivity, Controls, and Evolution During the North American Monsoon, Master of Science in Geological Sciences, Arizona State University.

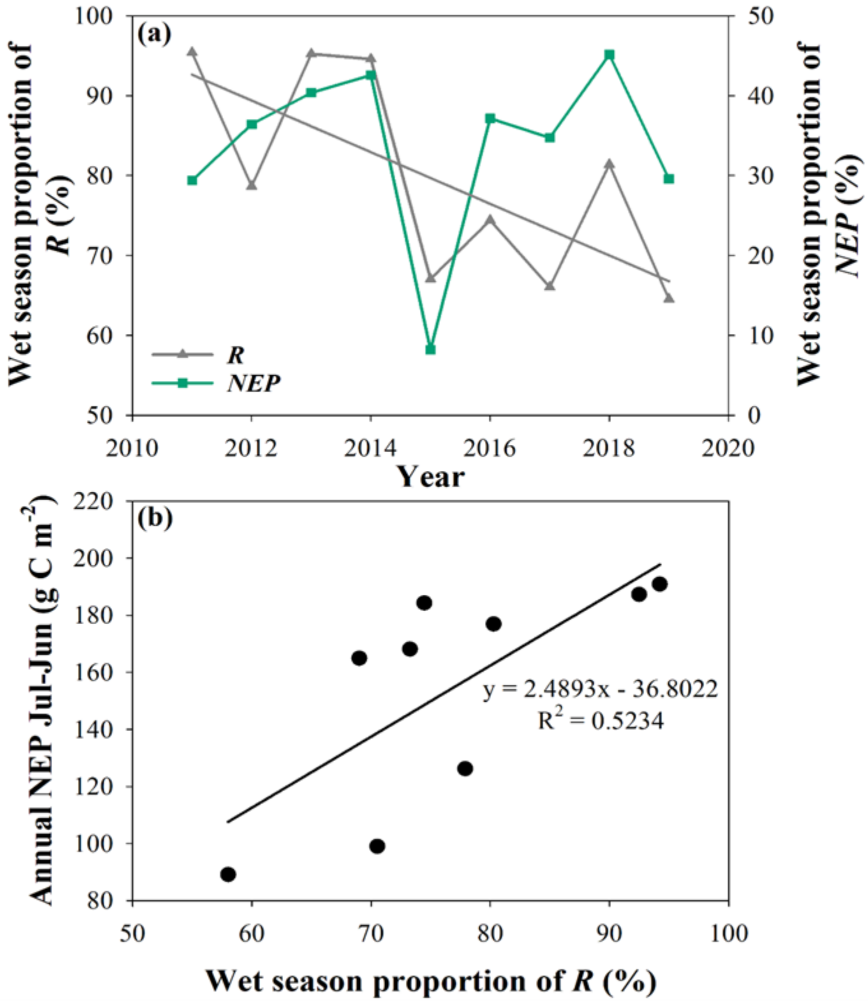

Figure 4: Seasonal contribution of rainfall (R) to net ecosystem production (NEP) in the experimental watershed of the eastern bajada at the Jornada Experimental Range. (a) Wet season proportion of R and NEP to the annual total over the study period (2011-2019). This shows that while wet season (July to December) rainfall declined over this interval, vegetation productivity remained similar. (b) Wet season proportion of R relative to the annual productivity (NEP) in the subsequent period (July to June). This shows that more summer rainfall leads to growth in the annual productivity which results from the carry-over of soil water to the following winter and spring. From Perez-Ruiz (2021): Land Surface Fluxes in Natural and Urban Landscapes in Arid and Semiarid Regions, Ph.D. in Geological Sciences, Arizona State University.

D. Transition to Novel Ecosystems

D1. How do Rainfall Variability, Grazing, and Competition with Native Grasses Interact to Trigger Non-Native Grass Invasion? Grass defoliation promoted emergence, but only when growing season PPT was between 60 and 100 mm. Germination was nil when growing season PPT was <30 mm. Emergence was also promoted in plots with rodent/lagomorph access, suggesting disturbances associated with small mammal activities will promote recruitment. Ants had a negative effect on *E. lehmanniana* recruitment in "wet" years. The presence of small mammals had a positive effect on germination, which is apparently explained by associated soil disturbances.

Plant-Soil Feedbacks and Lovegrass Invasion: A plant-soil feedback study with Lehmann's lovegrass and native Black Grama was published this year (Burdshell et al. 2021). Cover of native and exotic grasses declined in all plots. Both species had similar precipitation sensitivity, indicating a similar response to drought. Two manuscripts were submitted and are in review.

E. Transitions under Climate Change

E1. Rainfall Manipulation Experiment: After 13 years of rainfall manipulation (20%, ambient, and 180%) at the Jornada Basin LTER (NM, USA), N fertilization (+10 g N m^{-2} yr^{-1}) had no effect on ANPP in any of the precipitation treatments. We analyzed the d15N ratios of leaves from *Bouteloua eriopoda* and *P. glandulosa* and soil from five depths suggesting that the flexibility of N sources and the rapidly shifting paths of the N cycle may explain the lack of response to water and N availability. Precipitation controls the timing of grass greenup and senescence while temperature had a modest effect. Deep-rooted woody shrubs showed few effects of variable precipitation or temperature on phenology. While temperatures may extend growing season length for mid and high-latitude ecosystems, precipitation change will be the major driver of phenological change in drylands, with consequences for the global energy, water, and carbon balance.

Key Outcomes or Other Achievements

Obj. 2: Explain and predict multi-scale spatial heterogeneity in alternative states

Biocrust distributions: We studied the temporal and spatial patterns of soil bacteria, fungi, and microfauna from three commonly occurring Chihuahuan Desert biocrust types. Bacteria and fungi were strongly structured by biocrust type, differences in soil, and the chemical and physical properties of vegetation types. In contrast, season had the most influence in microfauna composition and abundances. Our findings highlight that different spatial and temporal drivers may control diversity, function, and interactions in soil biota (Omari et al., 2021).

Jornada Long-Term Quadrats: Multi-model analyses of data from 1916-1979 indicate that the Pacific Decadal Oscillation (PDO) was a stronger predictor of grass cover (**Figure 5**; R^2 =.70) than the more proximate drivers of local precipitation and drought indices, which have generally been considered the mechanisms by which PDO influences vegetation in the Southwestern United States. When extended to recent decades (i.e. post-1990), the PDO model overpredicted grass cover, which can potentially be related to ongoing land degradation and increasing shrub dominance. Thus, while grass cover was historically well-coupled with PDO, more recent changes in dominant species and shrub encroachment appear to have decoupled grass cover from climate teleconnections.

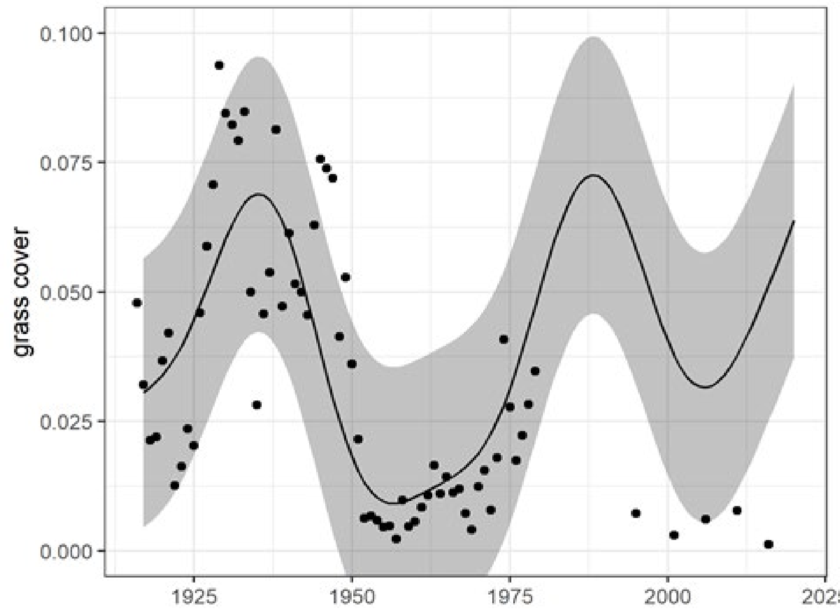

Figure 5: Observed (dots) and predicted (line) grass cover on the Jornada long-term quadrats using a model based on PDO index using data from 1916-1979. More recent measurements (post-1990) are not well predicted by the historical model.

Spatial Analysis of Jornada Basin State Transitions: An analysis of long-term changes in shrub community compositions for the entire Jornada Basin over the last ~150 years is in the advanced stage of publication (Archer et al., in press).

Regional Hydrologic Connectivity: A detailed LiDAR digital elevation model provides the opportunity to accurately delineate watersheds in the Jornada Experimental Range, including those draining to playa systems. Playa rain gauge, water level, and Planet (daily, 3m) data will be used to quantify the dynamics of surface inundation in the playas and the large channels draining to them. These datasets will support analysis of the surface hydrologic connectivity in the Jornada Basin and provide the basis for subsequent hydrologic model applications.

Obj. 3: Apply new analytical concepts and tools to broader extents (regional to global) and examine consequences for ecosystem services

Malpai Borderlands Group Collaborative Research: We integrated landscape-scale spatial data to demonstrate that collaborative landscape management applied by the Malpai Borderlands Group created desired outcomes for ecological states and processes in desert grasslands, including sustained grassland productivity and widespread use of managed fire.

Expanding Arid Land Ecological Theory: A manuscript with the new theoretical framework has been submitted and is under review.

Experimental Watershed Comparison: Long-term flux observations from two watershed networks (the Jornada and Santa Rita Experimental Ranges) were compared revealing differences in seasonal cycle and the composition of the woody plant encroachment process occurring at both sites. Long-term datasets at the monthly scale were released through Zenodo (Vivoni et al. 2021) to facilitate catchment studies in semiarid and arid regions globally.

Shrub Encroachment in the Southwestern USA: Woody-plant encroachment is a global phenomenon with major environmental and socio-economic ramifications and there is active debate as to the causes (climate, CO_2, disturbance). We separated the effect of climate and land-use change on woody-plant encroachment at the continental scale, using herbarium and climate records, to reconstruct mesquite expansion in the Southern Great Plains and Hot Deserts and predict future distributions using GCM scenarios. Results suggest that 33% of the 1900-2000 expansion was caused by climate change, while the rest was due to land-use change. Mesquite cover will likely increase in KS, NV, OK, and UT by an additional 1 million km^2 by the year 2100, with climate change accounting for 67 % of the predicted expansion by the year 2100. The improved understanding of underlying causes provides a basis for anticipating change and developing region-specific management adaptations.

Drylands in a Carbon Neutral World: We reviewed literature on dryland systems and their role in future carbon sequestration and climate management (Hanan et al, 2021). Global drylands cover around 40% of the Earth's land surface and contain ~30% of global terrestrial carbon stocks, demonstrating the significance of dryland carbon reserves and importance for global carbon management plans. Dryland carbon storage capacity is correlated with water availability and future aridity patterns (**Figure 6**). JRN-LTER long-term measurements of carbon dynamics support our understanding of carbon dynamics in dryland vegetation and soils and the changes associated with shrub encroachment and soil degradation. Future management of dryland carbon should consider local ecological contexts, while ensuring ecological integrity of dryland systems and provision of critical services to dryland populations.

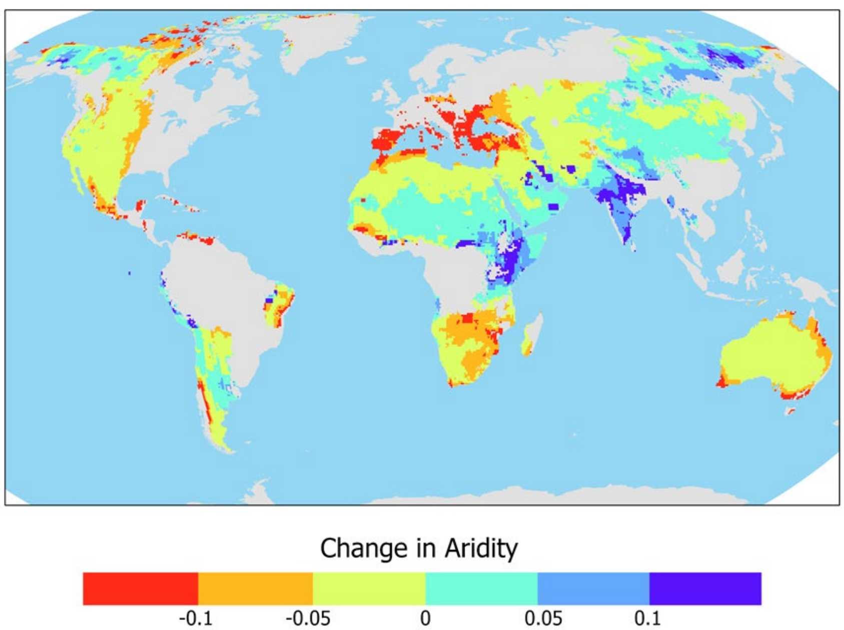

Figure 6: Change in aridity (P/PET) projected for 2076-2100 relative to 2006-2025 averaged across 22 GCM participating in the climate model inter-comparison project (CMIP5) for continued greenhouse gas emissions and a cumulative 8.5W additional radiative forcing (RCP 8.5). Hanan et al., 2021.

What opportunities for training and professional development has the project provided?

1. K-12 Education and Outreach Accomplishments: The Jornada LTER K-12 education and outreach program is spearheaded by our partner, the nonprofit Asombro Institute for Science Education. The program's primary goals are to increase students' ecological understanding, decrease their perceived stereotypes about scientists and science, and encourage them to consider STEM careers. Since 1998, we have created flexible programs for K-12 students, which include (1) classroom/schoolyard lessons, (2) field trips, (3) the Desert Data Jam, (4) teacher workshops, (5) a book for the LTER children's book series, and (6) graduate student interaction with the K-12 students.

The pandemic tested the flexibility of our K-12 programs in 2020 and 2021. Schools were closed due to the COVID-19 pandemic from March 2020 through April 2021, so our team created science education opportunities (detailed below) to allow students to continue learning from home. Schools have been mostly open again starting in August 2021, so in-person programming has resumed. However, we have continued to provide remote-learning options that were developed in 2020. Between December 1, 2020 and September 30, 2021, we provided science education opportunities for 11,012 K-12 students and 489 teachers. Details of these programs are listed below.

Classroom and Schoolyard (Backyard) Science Lessons - A total of 10,003 PreK-12th grade students participated in classroom, schoolyard, and backyard science activities provided by JRN educators. This included 4,357 students who participated in remote learning lessons and 5,646 students who participated in face-to-face lessons delivered by Asombro educators. Remote learning lesson modules were delivered via education management platforms used by school districts (mostly Canvas and Google Classroom). Many lessons include individual kits of supplies provided to students when they came to the schools to pick up meals.

Field Trips - In-person field trips were forbidden until late June 2021, when some elementary schools reopened for extended learning programs. In June, we provided two full-day field trips for 109 students.

Desert Data Jam - We converted the 2021 Desert Data Jam from a series of in-person classroom lessons and an in-person competition to an online program with video-conference lessons, online access to all project materials, data visualization, exploration using CODAP, and an online judging of projects. Thirty-six classes (900 6th-8th grade students) participated in the Desert Data Jam. The top 49 projects were entered in the final competition and judged at least three times each. Winning projects can be seen on the "2021 Winners" tab from the Desert Data Jam website (https://asombro.org/desert-data-jam/).

Teacher Workshops - We provided 29 hours of online professional development workshops for 174 teachers from June to September 2021.

One Day in the Desert - In response to school closures, we created a three-video series associated with our LTER children's book, One Day in the Desert (www.asombro.org/onedayinthedesert). Each video includes a guided reading of the story and hands-on activities that students can do in their own backyards or neighborhoods. The videos were featured on the local school district's YouTube channel and remain available online.

2. Graduate Student Integration in K-12 Education: Beginning in LTER VI, all graduate students who receive fellowships from the LTER are required to participate in 2-10 hours of K-12 education activities. They choose from a menu of flexible options that can be done in-person or from afar (e.g., assisting with education programs or providing science review for new science education lessons).

Between December 2020 and September 2021, seven graduate students contributed 61 hours to help with the K-12 program.

3. LTER-VII Graduate Fellow Report: The JRN-LTER solicits graduate proposals for summer (3 month) and annual (12-month) fellowships that are reviewed by an ad-hoc committee of JRN investigators each Spring. In 2021, we supported 10 summer fellowships and 2 12-month fellowships for graduate students pursuing both master's and PhD research focused on dryland ecology at the Jornada LTER site.

4. LTER-VII REU Report: The JRN-LTER also supported summer research experiences for two undergraduate (REU) fellows this year, including a student from NMSU and a student from UTEP. Both students were paired with faculty mentors and presented their research projects during the Desert Ecology Short-Course. Two additional REU students conducted guided research projects at the Jornada with separate support from UCLA and ASU mentors, Okin and Sala respectively.

5. Jornada Desert Ecology Short-Course: The Jornada Desert Ecology Short-Course takes place during late June or early July each year. In 2021, the short-course was converted to an in-person/online hybrid event, featuring field excursions, guest speakers, student talks, and posters, as well as professional development, networking, and social/team-building elements. The 2021 short-course sessions were attended by 30-45 participants (including undergraduate students, graduate students, postdocs, technical staff and project investigators).

How have the results been disseminated to communities of interest?

JRN-LTER results have been communicated through scientific meetings, and publications in high impact journals (see Products).

NRCS and BLM continue to apply a common set of national rangeland assessment and monitoring protocols based in part on JRN research, with support from JRN scientists. As of 2021, the Land-Potential Knowledge System (LandPKS; https://landpotential.org) has been used to collect data and provide access to soil information at over 25,000 locations globally. Development of the LandPKS system is based in part on JRN research, with support from JRN scientists. LandPKS now includes direct links to the new “Ecosystem Dynamics Interpretive Tool” (EDIT), developed by the Jornada (https://edit.jornada.nmsu.edu/). We also share updated LTER results with US land management agencies and other natural resource managers through our co-leadership of the “Interpreting and Managing Indicators of Rangeland Health” (IIRH) course that is conducted three times/year in locations throughout the western US, and also in additional 4+ annual BLM “Assessment, Inventory and Monitoring” (AIM) trainings.

Outreach activities included the Jornada Virtual Symposium (11/12/2020, with ~100 participants; https://jornada.nmsu.edu/symposium), the Malpai Borderlands Group Science Meeting webinar (4/16/2021; 120 participants), a Restore New Mexico Coordination Meeting (2/11/2021, with 30 participants), and a plenary presentation to the International Rangeland Congress (10/25/21).

JRN personnel provided AIM Crew Training in Biological Soil Crust for the BLM Las Cruces Office, incorporated JRN research and soil sample/characterization in an undergraduate Soil Science curriculum (SOIL476L), and hosted both LTER and Critical Zone (CZ) REU students for soil microbial research projects.

What do you plan to do during the next reporting period to accomplish the goals?

Obj. 1: Quantify effects of interactions among triggers, connectivity-mediated feedbacks, and soil-geomorphic heterogeneity on the rate and nature of state transitions

A. Grassland to Shrubland Transitions

We will continue long-term monitoring of vegetation structure changes across the Jornada Basin using combinations of field sites and long-term quadrats, airborne, and satellite measurements. With renewed access to the field, we will continue work on the NEAT experiment to examine interactions between biocrust, rainfall, and erosion-based feedbacks in the shrub encroachment process. On the Ecotone Study, we will continue long-term monitoring of mammalian consumers and predators, precipitation, plant cover, and net primary production. We will examine trophic cascades across shrub gradients with a focus on canid predators and lagomorph prey. We will also contrast diets of African Oryx to those of cattle using metabarcoding of fecal and gut samples, and then we will design a herbivory exclosure experiment that leverages long-term data sets. We will initiate the ThreshEx 2 experiment in 2022.

B. Shrubland to Grassland Transitions

We are continuing our long-term experiments; (1) to examine rainfall and connectivity as triggers of grass recovery, (2) to evaluate the effects of shrub presence or absence on grass recovery, and (3) monitor the cross-scale effects of shrub mortality, patch-scale redistribution of sediments and other resources, and cover of grasses or shrubs on grass recovery. (4) We will continue to monitor ANPP at 15 locations for 5 ecosystem types at 3 sites each. These seasonal data have been collected since 1989 and remain a critical part of our long-term data.

C. Shrubland to Shrubland Transitions

In the next year, we will initiate new monitoring sites for long-term shrub community monitoring and assessment of directional changes in density and species to complement earlier analysis of long-term shrub-shrub transitions. Shrub demographic (ShrubDemo) experiments will be analyzed and submitted for publication, and new experiments will be designed to fill gaps in our understanding of the demographic processes underlying long-term shifts in both density and species. To complement our new data on shrub demographic bottlenecks, we will also continue the development of our new QuadCam hardware and analysis systems for gradual deployment at the existing long-term NPP sites. These will add to our understanding of the role of rapid herbaceous turnover in herbaceous demographics and community dynamics. At our detailed ecohydrology research site, we will address the linkage between drop size distribution and the kinetic energy of rainfall with hillslope runoff generation to understand the differences between winter and summer periods. The soil moisture network, including the cosmic-ray neutron sensor, will be used to further investigate the occurrence and dynamics of deep subsurface water storage. A wireless radio network will be refurbished to provide near real-time data from the bajada watershed to web users. We will analyze the long-term water, energy, and carbon flux measurements from the perspective of rainfall events (intensity, duration, distribution, and frequency) to understand triggers for vegetation productivity and the role of shrub phenology interacting with these precipitation characteristics.

D. Transition to Novel Ecosystems

We will continue our experiments exploring the invasion dynamics of the exotic Lehman's lovegrass in the Jornada Basin in response to varying climate, herbivory, and nutrients. We will also explore how the soil microbiomes of Lehman’s lovegrass and Black Grama may shift across a toposequence.

E. Transitions Under Climate Change

For the rainfall manipulation experiment, we will continue monitoring all the long-term experiments including those in which we manipulated precipitation amount and variability. In addition, we will deploy a new experiment in which we will manipulate N and P in combination with rainfall in an attempt to address the question of the lack of response to N fertilization that has puzzled scientists for a long time. We will continue the rainfall manipulation to calibrate the minirhizotron method.

Obj. 2: Explain and predict multi-scale spatial heterogeneity in alternative states

We are analyzing long-term vegetation dynamics and state-changes across the Jornada Basin using estimated shrub, grass, and bare-soil cover derived from the long-term Landsat archive. These analyses are being designed to diagnose thresholds in cover that lead to the subsequent more rapid state changes (e.g. shrub encroachment) associated with the interactive effects of connectivity, soils, and climate. We will process the LiDAR DEM data to obtain watersheds, channels, and playa features and overlay them with high-resolution shrub cover estimates. Catchments draining into playas will be characterized with respect to their land surface properties and rainfall amounts, and data will be obtained from rain gauges and weather radar estimates. The dynamics of playa inundation will be studied using the Planet Cubesat data and the water level measurements will be related to the rainfall data to understand runoff production and connectivity thresholds. We will identify a playa with active hydrologic dynamics so we can install a cosmic ray neutron sensor and an eddy covariance tower for a short-term deployment (one summer season).

Obj. 3: Apply new analytical concepts and tools to broader extents (regional to global) and examine consequences for ecosystem services

In 2022 we will publish research on regional (Restore NM) monitoring of shrub control efforts and will analyze long-term (10 yr) trends of ecological state change in drylands of Mongolia. In addition, we will continue to gather monitoring data for the Restore NM program.

What is the impact on the development of the principal discipline(s) of the project?

The Jornada Basin LTER project (JRN-LTER) continues to advance understanding and theory of dryland ecosystem functioning, relevant to applied range management and broader ecological theory. In particular, JRN-LTER advances the application of ecological understanding of state transitions and alternative stable states in drylands, and the development of ecological theory on state change and ecosystem dynamics in temporally and spatially complex environments.

What is the impact on other disciplines?

Jornada Basin LTER results are directly relevant to livestock, range management, and dryland ecosystems across the southwestern USA and other arid and semi-arid lands globally. JRN collaboration and outreach impacts a variety of US and international, tropical, and temperate drylands.

What is the impact on the development of human resources?

Student training and mentoring opportunities in dryland ecology this year included direct support for 10 graduate students and 2 REU students, and participation of a larger number of students attending the Desert Ecology short-course and conducting research at the JRN with support from their JRN advisors, home universities, and independent research fellowships. This year, the JRN-LTER also initiated a new graduate networking and professional development forum (the "Desert Discourse" Series). The Desert Discourse series aims to enhance opportunities for research and career advancement, learning, and peer networking for JRN-LTER graduate students. It is designed as a monthly online forum gathering graduate students, PIs, postdocs, and staff for networking and team-building, mentoring, co-mentoring and professional development, and also serves as a mechanism for retention and the promotion of a diverse next generation of ecological and STEM researchers.

What is the impact on teaching and educational experiences?

K-12, undergraduate, and graduate students from our host communities and neighboring institutions (K-12, Community and 4-year Colleges) benefit from field research opportunities and education/outreach activities.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

In 2020, the successful renewal of the JRN's LTER award ended a 2-year probationary cycle that was in-part attributable to information management (IM) deficiencies. Since that time, the JRN IM team has focused on increasing the efficiency and sustainability of its data management systems, while continuing to publish high-quality datasets to open-access data repositories. Notable improvements include the implementation of two new databases (one for annotating datasets with metadata and one for research project management), the creation of an R package that handles key steps in our data publication workflow, and other numerous improvements in the documentation, security, and redundancy of our IM system. Data publication has continued at a steady pace in parallel with IM management improvements, with 10 new published datasets and new updates to 228 unique existing datasets published this year in our primary data catalog at the EDI repository (Figure 7, top). JRN's datasets at EDI are well used, averaging over 34 public downloads per day (Figure 7, bottom). We are also making significant strides in raising the discoverability and accessibility of Jornada datasets held outside of EDI, and are planning outreach and training activities to support discovery, analysis, publication, and citation of Jornada datasets by Jornada students and researchers.

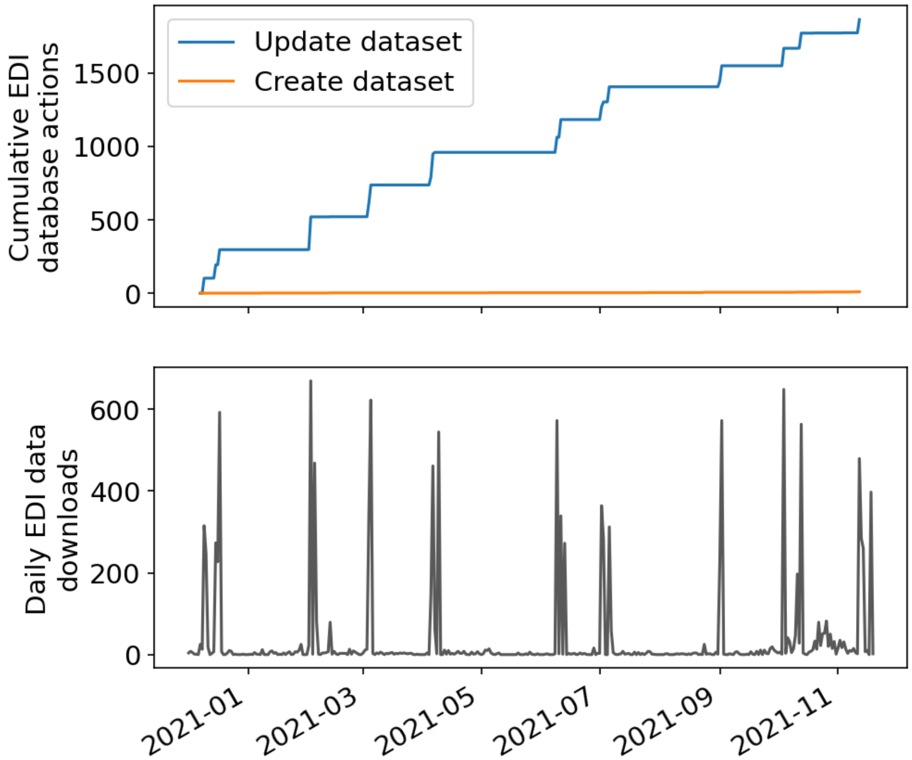

Figure 7: Information management activity by the Jornada LTER at the [EDI data repository]() for the period from 1 Dec. 2020 to 20 Nov. 2021. The top panel shows cumulative updates and creation of Jornada datasets at EDI, while the lower panel shows daily public user downloads of Jornada datasets.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

Our K-12 outreach program reaches every child in the local school districts and many children in school districts across southern New Mexico and west Texas. Field and classroom programs increase awareness and understanding in the general public with major long-term benefits for environmental and STEM literacy. The JRN-LTER has been working towards making its outreach programs more inclusive and accessible for marginalized communities. Participants in the K-12 programs for JRN include underrepresented and underserved groups. 80% of program participants are economically disadvantaged, and 75% are Hispanic, as defined and classified by the New Mexico Public Education Department. Jornada's K-12 outreach works with entire classes, schools, and sometimes districts. This helps promote equity by ensuring that all students are exposed to these enriching opportunities, not just those who have the resources to sign up for voluntary science education opportunities. To formalize our consideration of DEI in education and outreach programming, the Asombro Institute for Science Education created a DEI lesson screener in 2020. The screener includes nine criteria that are formally evaluated in the early stages of lesson development. For example, we ensure that each lesson contains stories of diverse people and careers in STEM, that it includes connections to Spanish and Native languages when possible, and that Spanish versions are available for all worksheets and video captions. We have shared this tool with the LTER Network Education and Outreach Committee.

PRODUCTS (12/2020-11/2021)

Peer Reviewed Journal or Conference Proceeding

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