Final Report

Agreement name: "Development of an applied science tool to help resource managers understand how desert vegetation may be impacted by climate change as a result of changes in the water available in desert soils"

Agreement Number: R12PG80462

Background and context

In the desert Southwest, changes in species composition, abundance, and distribution that may occur with climate change have significant implications for management of natural resources. These changes include: the extirpation or introduction of species, losses of biodiversity, shifts in structure and function of ecosystems and the services they provide, changes in wildlife habitat, invasion of non-native species, and changes in fire regimes. For planning, mitigation, and adaption, land managers would be greatly aided by knowing, in advance, which plant species, functional types, and assemblages will change in response to climate change so that monitoring and mitigation measures can focus on those resources.

The main determinant of plant performance, and the ability of dryland ecosystems to supply services, is the spatial and temporal patterns of water availability (Noy-Meir 1973, Sala et al. 1988, Sala et al. 1997). Climatic conditions, notably precipitation, temperature and potential evapotranspiration, influence general patterns of soil water availability (Rosenzweig 1968, Thomas 2010). However, accurate estimates of plant water availability and potential ecosystem change requires a soil water modeling approach that incorporates landscape variability (Schlaepfer et al. 2012b). Soil (texture, horizon development, depth) and landscape (slope, aspect) properties are highly variable at multiple spatial scales across the southwestern US. These properties often modulate ecosystem water balance significantly and must be accounted for to accurately assess potential climate change impacts on vegetation. For example, the amount of precipitation lost to runoff and evaporation is greatly influenced by surface soil texture. More water is typically lost from fine relative to coarse textured soils, leading to greater plant vulnerability under hot, dry conditions at sites with high clay and silt in the surface horizons (inverse texture hypothesis; Sala et al 1988, Noy-Meir 1973). Similarly, soil depth and subsurface water holding capacity (WHC) are important determinants of wetting depth and timing of plant-water availability. In deeper, coarse soils, infiltrated water can quickly exceed soil WHC and be lost to depths below the root zone for most herbaceous and shallow rooted woody species (>50-100 cm). In contrast, soils with higher near surface WHC or that have a shallow hydrologic restriction (impermeable horizon, bedrock, or hydrologic disconnect) can

retain a much greater amount of infiltrated water in the plant rooting zone for longer periods (Duniway et al. 2010) and thereby impart a greater resilience to drought (Browning et al. 2012). Due to the high variability in soils, incorporating a detailed understanding of soil water availability beyond bioclimatic envelope approaches in the desert Southwest is essential to accurately conduct climate change vulnerability assessments and identify relative risk of vegetation change within and across management units.

Project objectives

Understand how climate change will impact desert vegetation from a ecohydrological perspective. This involved simulating water balance and availability at long-term vegetation monitoring plots from across the Southwest, comparing model output with observed vegetation patterns to identify the features of water availability that are crucial for plant species responses, and assess the vulnerability/sustainability perennial grassland plant communities (a particularly vulnerable ecosystem type in deserts) by simulating site-specific water balance and availability under future climate scenarios.

Project activities

Study sites - We examined the relationships between vegetation dynamics and ecohydrological controls at multiple sites within the desert SW. Co-PIs We utilized measurements of plant species canopy cover at 1128 repeatedly measured vegetation plots from 23 sites across the Sonoran, Chihuahuan, Mojave, and Colorado Plateau Deserts (Fig. 1, Appendix 1). Sites include USFWS (e.g., Sevilleta NWR), NPS (e.g., Saguaro NP, Big Bend NP, Mojave NP), DOD (e.g., White Sands Missile Range, Ft Irwin), USDA (Jornada ER), and universities (Santa Rita ER, Desert Lab) (Munson et al. 2011a, Munson et al. 2011b, Munson et al. 2012). The plots represent dominant grasslands in the desert Southwest. Most measurements were made in the late summer to early fall (August – October) every 1-20 years and many span > 50 years. Importantly, all plots to be included in the analysis are minimally disturbed, which allowed us to isolate the effects of soil water on plant performance. Monitoring vegetation in permanent plots provided a robust approach to assess how plants have changed with respect to soil water availability because it integrates the full suite of environmental conditions that influence plant performance at a site.

Ecohydrological modeling - We used an ecosystem water balance model (SOILWAT), parameterized with soil texture and vegetation composition data for each plot (Fig. 2). SOILWAT is a daily time step, multiple soil layer, process-based, simulation model of ecosystem water balance (Parton 1978, Sala et al. 1992, Bradford and Lauenroth 2006, Lauenroth and Bradford 2006, Bradford et al. 2014b) that we have applied in numerous dryland ecosystems (Lauenroth and Bradford 2012, Schlaepfer et al. 2012a, Bradford et al. 2014a). SOILWAT uses daily weather forcing, mean monthly relative humidity, wind speed and cloud cover data, monthly vegetation (live and dead biomass, litter, and active root profile) and site-specific properties of each soil layer to simulate the daily ecosystem water balance processes. This comprises interception by vegetation and litter, evaporation of intercepted water, snow melt and loss (sublimation and wind redistribution), infiltration into the soil profile, percolation and hydraulic redistribution for each soil layer, bare-soil evaporation, transpiration from each soil layer, and deep drainage (Lauenroth and Bradford 2006, Schlaepfer et al. 2012a). Outputs from SOILWAT are daily, monthly and annual values of each water balance component (Parton 1978). We examined scenarios representing anticipated changes in climate (Maurer et al. 2007).

Data analysis – To determine what aspects of climate and soil water explained variation in perennial grass cover, we used linear mixed-effects models. We used climate, soil water, and bioclimatic variables spanning the entire vegetation sampling interval, which was one year for most sites and dates. Analyses were conducted for each desert region separately, though we expect that inferences would be similar with different sampling schemes (Munson et al. 2011c). To understand the relative contribution of climate and soil water variables in explaining perennial grass cover, we used hierarchical partitioning (HP) analysis (Murray & Conner, 2009). To account for correlated error structures that arise from repeated measures, as well as the effect of perennial grass cover in the previous time step in our HP analyses, we constructed mixed models with transformed cover as the response variable, transformed cover in the previous time step as a main effect, and plot as a random effect and related the residuals from these mixed models (*hereafter* cover residuals) to climate and soil water variables using HP. To compare the relative importance of climate versus soil water variables together, we then summed the independent effects of each category of variables on cover.

Key findings

Our results, as well as methods and implications, are described in detail in the published manuscript identified below (Gremer et al. 2015). Briefly, these results suggest that climate variability has negative effects on grass cover, and that precipitation subsidies that extend growing seasons are beneficial. Soil water

metrics, including the number of dry days and availability of water from deeper (>30 cm) soil layers, explained additional grass cover variability. While individual climate variables were ranked as more important in explaining grass cover, collectively soil water accounted for 40 to 60% of the total explained variance. Soil water conditions were more useful for understanding the responses of C_3 than C_4 grass species. Projections of water balance variables under climate change indicate that conditions that currently support perennial grasses will be less common in the future, and these altered conditions will be more pronounced in the Chihuahuan Desert and Colorado Plateau. We conclude that incorporating multiple aspects of climate and accounting for soil variability can improve our ability to understand patterns, identify areas of vulnerability, and predict the future of desert grasslands.

Specific products

We presented these findings at the Research in Semi-Arid Ecosystems Conference in Tucson, AZ on October 18, 2014. There we engaged with local land managers and researchers across the region to present research findings and discussed the possible consequences for the future management of these systems.

We are also planning to present these results in a webinar to both the Southern Rockies and Desert LCCs on March 29, 2016.

We published these results in a peer-reviewed scientific manuscript:

> Gremer, J. R., J. B. Bradford, S. M. Munson, and M. C. Duniway. 2015. Desert grassland responses to climate and soil moisture suggest divergent vulnerabilities across the southwestern United States. *Global Change Biology* **21**:4049-4062.

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