Southwest Biological Science Center
United States Geological Survey

Southern Colorado Plateau Network
National Park Service

Describing Past and Future Soil Moisture in the Clayey Fan Grassland Community in Petrified Forest National Park

In the semi-arid environment of the Colorado Plateau, soil water availability is an important driver of vegetation dynamics. Recent drought-associated tree mortality in the Southwest has highlighted the potential vulnerability of ecosystems to changing water availability. Climate change models predict continued warming and seasonally drier conditions over the next century.

How will changing soil water availability impact vegetation dynamics in these already water-limited ecosystems? To answer this question the U.S. Geological Survey (USGS) and National Park Service (NPS) have teamed up to model soil water availability under projected climate conditions in nine Southern Colorado Plateau Network NPS units where long-term vegetation monitoring is underway.

The resulting projections of soil water availability will allow us to develop hypotheses about how the dominant species in these plant communities will respond to changing soil water conditions. This project will help park managers today by identifying the most sensitive ecosystems and informing strategies to improve long-term ecosystem resistance and resilience. Through continued monitoring over the coming decades we will also be able to compare observed vegetation dynamics to hypothesized responses, thus furthering our understanding of Colorado Plateau ecosystems.



Clayey fan grassland ecosystem in Petrified Forest National Park. NPS photo.

Introduction

For this project, USGS and NPS scientists used the range of variation in historical climate data to provide context for assessing the relative impact of projected future climate on water availability. We used a soil water model, SoilWat2, to translate climate variability into site-specific estimates of soil water conditions that may drive plant responses. One of the valuable outputs of the model is daily soil water potential (SWP), which provides an estimate of water available for plants that reflects soil conditions. We examined SWP at intermediate soil depths (20–50 cm) in relation to site-specific NDVI, a measure of total annual vegetation greenness or productivity, generated for a 15-year period from satellite imagery. For more details, please see the Methods section.

This report provides the results of modeled SWP generated for the clayey fan grassland ecosystem in Petrified Forest National Park, Arizona.

Study Area: Petrified Forest National Park

The Southern Colorado Plateau Network (SCPN) has been monitoring vegetation and soil stability in grasslands, woodlands and forests in network parks since 2007. Clayey fan grassland is one of two upland ecosystems that SCPN monitors at Petrified Forest National Park (PEFO). This open grassland community is primarily dominated by

the grass, alkali sacaton (*Sporobolus airoides*). Four-wing saltbush (*Atriplex canescens*) is the most common shrub. Annual grasses and forbs are well represented in wet years. Soils in this ecosystem are typically classified as sandy clay loam. SCPN also conducts long-term monitoring in the sandy loam upland grassland ecosystem of PEFO, which is addressed in a separate brief. We used data from soil cores from 30 plots in the clayey fan grassland ecosystem as inputs to the SoilWat2 model (Figure 1).

Results

The outputs from our model show SWP for the past, present, and future, and highlight relatively moist and dry periods. These data can be considered in a variety of ways, including climate variability, variability among soil profiles, and relationships with plot-based vegetation monitoring data. Here we present seasonal and temporal patterns in soil water availability in the clayey fan grassland ecosystem at PEFO.

Long term trends in past and future water availability

- Past SWP fluctuations highlight relatively moist and dry periods and allow us to compare the past variability in SWP to future projections (Figure 2A).
- Future projections (Figure 2B) suggest declining water availability, particularly in the fall/winter. By the end of the 21st century (L), average fall/winter SWP is expected to drop to approximately -3.0 MPa, indicating conditions of extreme water scarcity.
- In the future, fall/winter soil moisture will approach conditions observed in the spring now. Spring SWP will likely be less than summer's, a pattern observed intermittently throughout the 20th century.

Historical and future climate patterns

- Current mean annual temperature (MAT) is 12.5°C. Future MAT is expected to increase under all climate models (near future +2.3°C, long-term future +4.9°C), underscoring the consistency of these projected rising temperatures across climate models (variation in temperature projections among models is reflected by the variation in orange and red values in Figure 3A).
- Mean annual precipitation (MAP) is 240 mm, with rainfall concentrated during the monsoon (Figure 3A). While future changes in precipitation are less consistent across models than temperature, the substantial projected increases in temperatures will likely result in decreased soil moisture, especially during spring, and longer summer dry periods (Figure 3D).

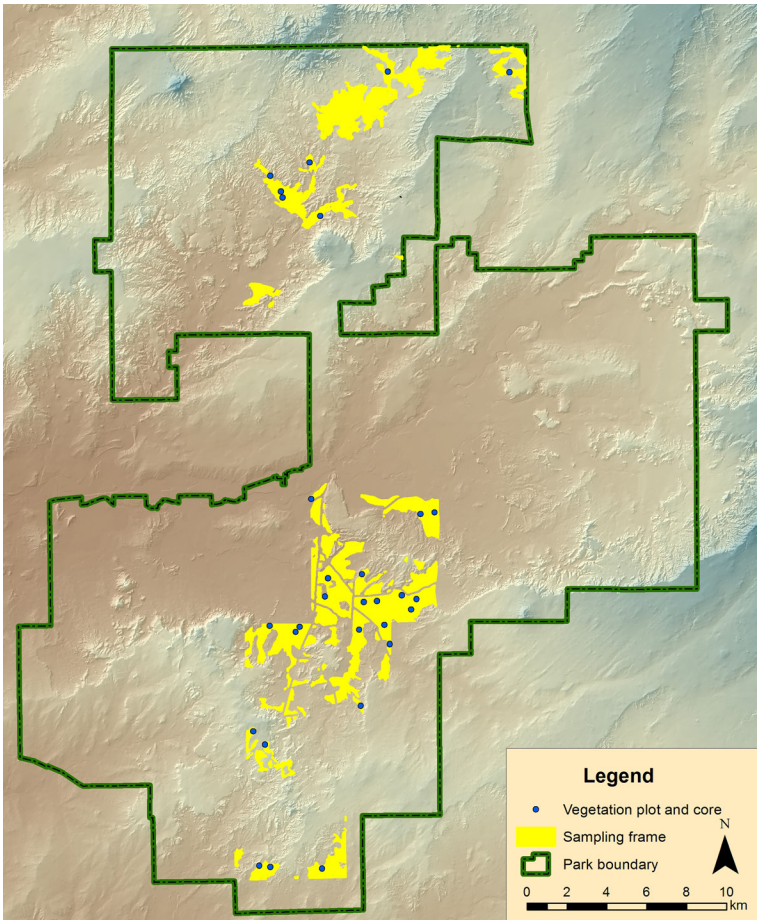
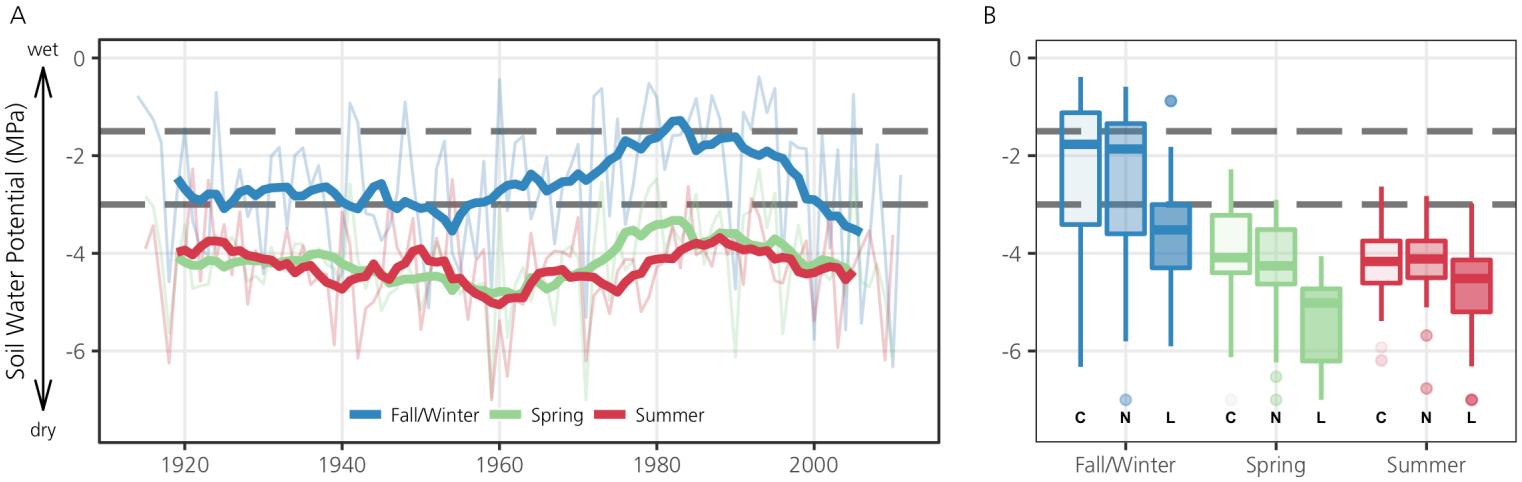


Figure 1. Map of Petrified Forest National Park showing Southern Colorado Plateau Network monitoring plots in the clayey fan grassland ecosystem. Plots from which soil cores were used are indicated as solid blue dots. Map by NPS.



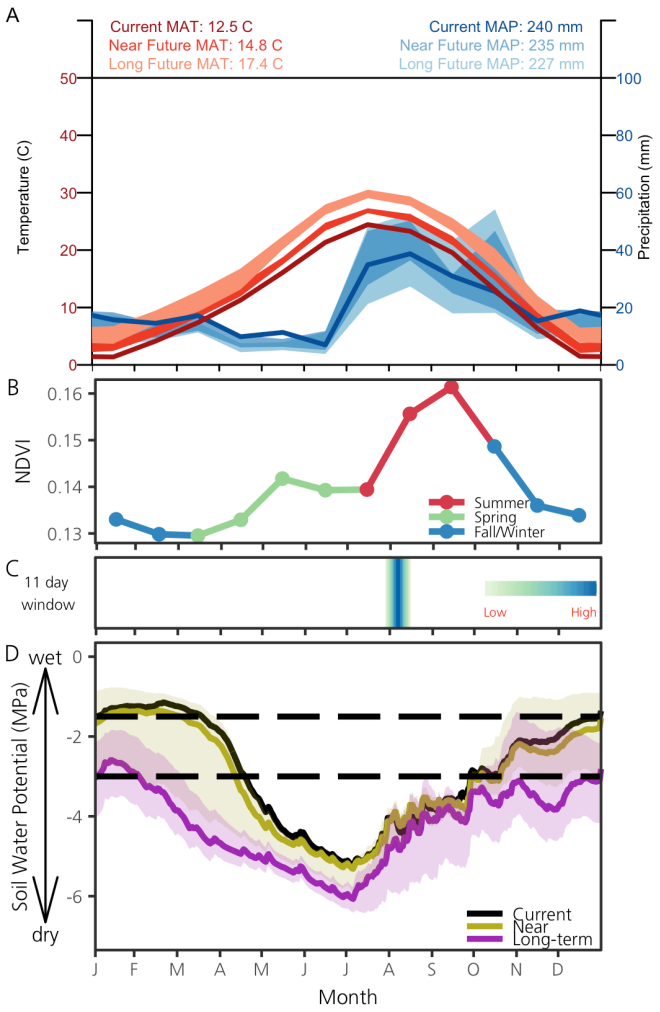


Figure 3: **Panel A**. Average seasonal patterns of climate in the clayey fan grassland ecosystem in Petrified Forest NP. Climate diagram (Walter and Leith 1967) showing mean monthly temperature (°C) and precipitation (mm) in dark red and blue lines, respectively, in the current period (1970–2010). Shaded red and blue areas indicate the range of potential values in the near (darker area; 2020–2059) and long-term (lighter area; 2060–2099) future periods. Mean annual temperature (MAT) and mean annual precipitation (MAP) are derived from the mean monthly values. **Panel B**. Monthly mean for normalized difference vegetation index (NDVI, 2001–2014). **Panel C.** Seasonal periods when soil moisture is related to fluctuations in vegetation productivity, depicted by correlations between NDVI and soil water potential (SWP) 2001–2014. Colors indicate the sum of significant correlations ($p < 0.1$) that overlap with each day of the year based upon window length (11 days identified as the most significant interval length). Darker blue indicates periods of greater cumulative correlation between NDVI and SWP. **Panel D**. Average daily SWP for the current period (1970–2010; black), near future (2020–2059; yellow), and long-term future (2060–2099; purple). For future time periods, thick lines represent the median value among climate models, while shaded areas represent the range of values across different climate models.

Figure 2 (left): Historical (A) and future projections (B) of soil water potential (SWP) at intermediate soil depths (20–50 cm) in the clayey fan grassland ecosystem in Petrified Forest NP for three seasons: fall/winter (October–February), spring (March–June), and summer (July–September). **Panel A** shows historical annual variability (fine lines) and moving 10-year averages (thick lines) of drying and wetting from 1915–2010. **Panel B** compares variability amongst years for three time periods, current (C; 1970-2010), near future (N; 2020-2059), and long-term future (L; 2060-2099), grouped by season. Box plot whiskers are 1.5 times the inter-quartile range of values, while dots are values outside this range. Dashed lines in both panels highlight plant-relevant SWP levels: traditional wilting point (-1.5 MPa) and a drylands wilting point (-3.0 MPa; Kolb and Sperry, 1999a, 1999b).

- Periods of meteorological drought occur when the precipitation line is below the temperature line in Figure 3A. The current period of meteorological drought spans from mid-March to mid-November. In the future, the duration of these dry conditions will likely increase, starting earlier and lasting longer, primarily as a result of rising temperatures.

Relationship between water availability and vegetation dynamics

- In the clayey fan grasslands of PEFO, mean annual peak NDVI is variable, but typically highest in summer (Sep, 0.161) and lowest in spring (Mar, 0.13) (Figure 3B).
- Annual NDVI is most strongly related to SWP over 11 day windows in early-summer (Figure 3C), underscoring the importance of soil moisture during this time period.
- The correlation between soil moisture during this time of year and NDVI suggests a positive impact of short-term water availability during mid-summer on inter-annual variability in plant growth (Figure 3C).

Future soil moisture

- Future soil moisture in the first half of the year is to remain relatively unchanged in the near-term, but to decrease significantly under the long-term scenario (Figure 3D).
- Soil moisture from August to October is to remain relatively unchanged or to increase, but to decrease from October through the end of the year.
- The drying of soils in spring is predicted to occur earlier in the long-term scenario and will shorten the period when soils are wet during the winter and spring growing season. This will likely have a substantial impact on vegetation reliant on this soil moisture.

Discussion

These results present a long-term historical and future perspective on soil moisture in the clayey fan grassland ecosystem in Petrified Forest NP. Predicted changes in SWP are likely to affect vegetation community dynamics in the future. Results indicate that variation in annual productivity in this ecosystem is associated with short-term soil moisture in the early summer. In the future, summer soil moisture is expected to remain relatively unchanged. This primary reliance on the summer monsoon may buffer this ecosystem against some of the adverse effects of climate change. However, spring reliant vegetation may be vulnerable to declines. When compared to other grassland communities in the SCPN, the soil moisture at PEFO is expected to remain relatively unchanged in the near-future, but will be impacted by the end of the century. Similar conditions were observed in the sandy loam grassland ecosystem of PEFO.

The modeled soil moisture values are influenced by both

the logic embedded within the SoilWat2 model and site-specific weather, soil, and vegetation. This approach provides a consistent, process-based framework for assessing climate change impacts on soil moisture. Projections of change in SWP should be robust to many modeling assumptions.

The relationships between soil moisture and interannual plant growth identified here can (1) contribute to hypotheses about how individual species within an ecosystem may respond to changing soil water availability and (2) inform future management decisions in the face of changing and increasingly variable climate. The variation among climate projections creates uncertainty in the magnitude of SWP change, but modeled SWP patterns consistently point to earlier and drier spring periods.

Literature Cited

Kolb, K. J., and J. S. Sperry. 1999a. Differences in drought adaptation between subspecies of sagebrush (*Artemisia tridentata*). Ecology 80:2373–2384.

Kolb, K. J., and J. S. Sperry. 1999b.Transport constraints on water use by the great basin shrub, *Artemisia tridentata*. Plant, Cell and Environment 22:925–935.

Livneh B., E. A. Rosenberg, C. Lin, B. Nijssen, V. Mishra, K. M. Andreadis, E. P. Maurer, and D. P. Lettenmaier. 2013. A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions. Journal of Climate 26:9384–9392.

Walter, H., and H. Leith. 1967. Climate diagram world atlas. Fischer Verlag, Jena, Thuringia, Germany.

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Methods

1. Data were collected from the following sources for input into the SoilWat2 model:

- texture and depth data from core samples that were taken during establishment of SCPN upland monitoring plots (supplemented with NRCS SSURGO soil texture data when the soil cores did not extend to the full depth of the soil profile)
- vegetation species and functional group cover data from SCPN monitoring plots
- daily weather data estimates from 1920 to the present
  - Livneh (long-term historical weather; 1916–2011; 1/16th resolution)
  - DayMet (near-term historical weather; 1980–2015; 1 km × 1 km resolution)
- projected daily weather for 9 General Circulation Models (GCMs) for the periods 2020–2059 and 2060–2099, under representative concentration pathways (RCP) 8.5. RCPs, adopted by the International Panel on Climate Change, characterize potential future climate based on the hypothetical trajectories in the concentrations of greenhouse gases, with 8.5 demonstrating the highest potential concentrations. All projected climate data were downloaded from the Green Data Oasis (https://hpc.llnl.gov/data-vis/green-data-oasis).

2. SoilWat2 integrated these climate data, along with the soils and vegetation data, to generate the following simulations (presented in Figure 2):

- long term historical daily soil water potential (1915-2010)
- near term historical daily soil water potential (1980-2015)
- near term future daily soil water potential (2020-2059)
- long term future daily soil water potential (2060-2099)

We used box plots to represent annual variation in each of the seasonal soil moisture projections for the respective time periods (Figure 2B). For future time periods, we used the mean projected soil moisture from the median ranked GCM.

The SoilWat2 model, along with the soil moisture simulation for this report, is available at https://doi.org/10.5066/F7D50K6S.

3. NDVI was generated on a bi-weekly frequency from 2000–2014 using a neighborhood analysis of MODIS data. NDVI is an indicator of productivity and represents phenological timing in vegetation communities. NDVI ranges from 0 (low productivity) to 1 (high productivity). Average monthly values are presented in Figure 2B.

4. Annual NDVI was calculated by integrating the area under the NDVI curve, as a representative measure of total annual productivity. Annual NDVI was then correlated with SWP averaged over windows ranging from 10 to 365 days throughout the year. This method of analysis allows for the consideration of both the impact of timing and duration of water availability on annual NDVI.

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