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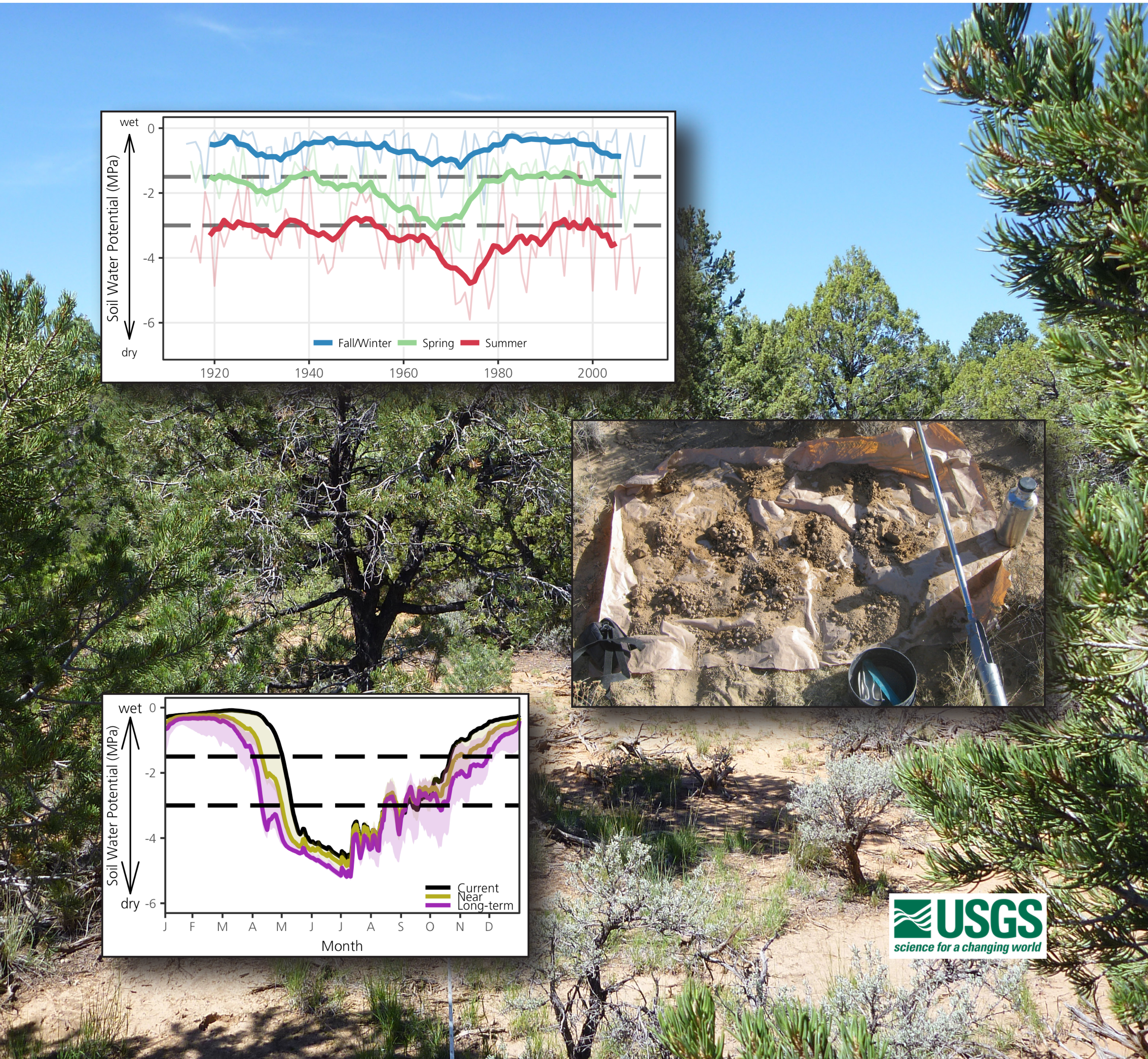
Natural Resource Stewardship and Science

Describing Trends in Past and Future Soil Moisture in the Pinyon-Juniper Woodland Ecosystem in Grand Canyon National Park

Natural Resource Report NPS/GRCA/NRR—2020/2115



ON THE COVER
TOP: Estimated past seasonal soil water patterns at Grand Canyon NP, described in detail in Figure 3.
MIDDLE: Soil samples from different depths of a soil core taken from a long-term monitoring plot. NPS photo.
BOTTOM: Estimated current and future soil water patterns at Grand Canyon NP, described in detail in Figure 4.
BACKGROUND: Photo of Southern Colorado Plateau Network monitoring plot in the Grand Canyon NP pinyon-juniper woodland ecosystem. NPS photo.

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from the Southern Colorado Plateau Network, and the Natural Resource Publications Management Web. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

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Executive Summary

Variation in the structure and function of Colorado Plateau ecosystems is driven by seasonal moisture availability in the soil profile; however, the availability of soil moisture is expected to change in the coming decades as a result of climate change. To understand how ecosystems will be affected by this, we need to understand in more detail how these soil moisture patterns relate to plant productivity, and what changes in soil moisture are expected, both seasonally and at the range of soil depths that plants are adapted to use.

We used a soil water model (SOILWAT2) to estimate historical, current, and future soil water availability in 300 vegetation monitoring plots in 13 ecosystems in the Southern Colorado Plateau Network of the National Park Service. In Grand Canyon National Park, this included 29 vegetation monitoring plots within the pinyon-juniper woodland ecosystem. The SOILWAT2 model used plot-specific vegetation and soil core data collected as part of the Southern Colorado Plateau Network's long-term upland vegetation monitoring program to represent the environment.

Model simulations were run using climate data from the past (1916–2011) to provide historical context, the present (1980–2015) to create a current baseline for comparison. Model simulations were also run for two time periods in the future: a near-term period (2020–2059) and a long-term period (2060–2099). The future projections were made using nine general circulation models under two possible greenhouse gas emissions pathways: the 8.5 representative concentration pathway (RCP), and the 4.5 RCP. Results of the 8.5 RCP simulations are presented here; this pathway corresponds to a comparatively high greenhouse gas emissions scenario.

The soil-water model results provide a detailed look at historical patterns of soil water availability, and how soil water availability is projected to change in the future, both seasonally and at different soil depths. Model output included daily soil water potential estimates at multiple depths within the soil profile. This report describes results at intermediate (20–50 cm) soil depths.

A second goal of this work was to better understand how changes in seasonal soil water availability might affect vegetation. To do this, we initially examined how vegetation today is affected by seasonal differences in soil moisture by calculating correlations of annual NDVI (2001-2014) with soil water potential averaged over a range of moving windows. However, recent work (Norris and Walker, in review) has shown that the NDVI values in most pinyon-juniper ecosystems do not correspond with vegetation greenness. Therefore those analyses were discarded.

Key findings for the Grand Canyon NP pinyon-juniper woodland ecosystem include the following:

- All of the climate models predicted increases in mean monthly and annual temperature in the near-term future (+2.5°C on average), and further increases in the long-term future (+5.0°C on average). Models had greater variation in their predictions of both the direction and the amount of future precipitation, except for the late spring months, for which low precipitation is consistently predicted.
- Future soil water availability is projected to decline in the fall/winter and spring. By the end of the 21st century, average spring soil water potential is expected to drop below -3.0MPa, indicating conditions of extreme water scarcity.
- The drying of soils in spring is predicted to occur earlier in both near and long-term scenarios, and will shorten the period when soils are wet during the spring growing season. This will likely have a substantial impact on plant species that rely on spring soil moisture.

Acknowledgements

This report benefited from editorial improvements from Jean Palumbo and from reviews by David Thoma and Kathryn Thomas. Thanks to multiple years of Southern Colorado Plateau Network upland monitoring crews for vegetation and soils data collection. This work was supported by the National Park Monitoring Program of the U.S. Geological Survey and by the National Park Service Inventory and Monitoring Program, Southern Colorado Plateau Network.

Introduction

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 national park 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 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.

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.

This report provides the results of modeled SWP at intermediate soil depths (20–50 cm) generated for the pinyon-juniper woodland ecosystem in Grand Canyon NP, Arizona (Figure 1).

Figure 1. Pinyon-juniper woodland ecosystem in Grand Canyon NP. NPS photo.

Study Area

The Southern Colorado Plateau Network (SCPN) has been monitoring vegetation and soil stability in grasslands, woodlands and forests in network parks since 2007. In Grand Canyon NP, SCPN monitors the pinyon-juniper woodland ecosystem. The plant community in this ecosystem is characterized by dense pinyon-juniper overstory with understory shrubs including Stansbury cliffrose (*Purshia stansburiana*) and big sagebrush (*Artemisia tridentata*). Perennial grasses, forbs and cacti are also represented. Soils in this ecosystem are typically classified as clay loam. We used data from soil cores taken from 29 plots in this ecosystem as inputs to the SOILWAT2 model (Figure 2).

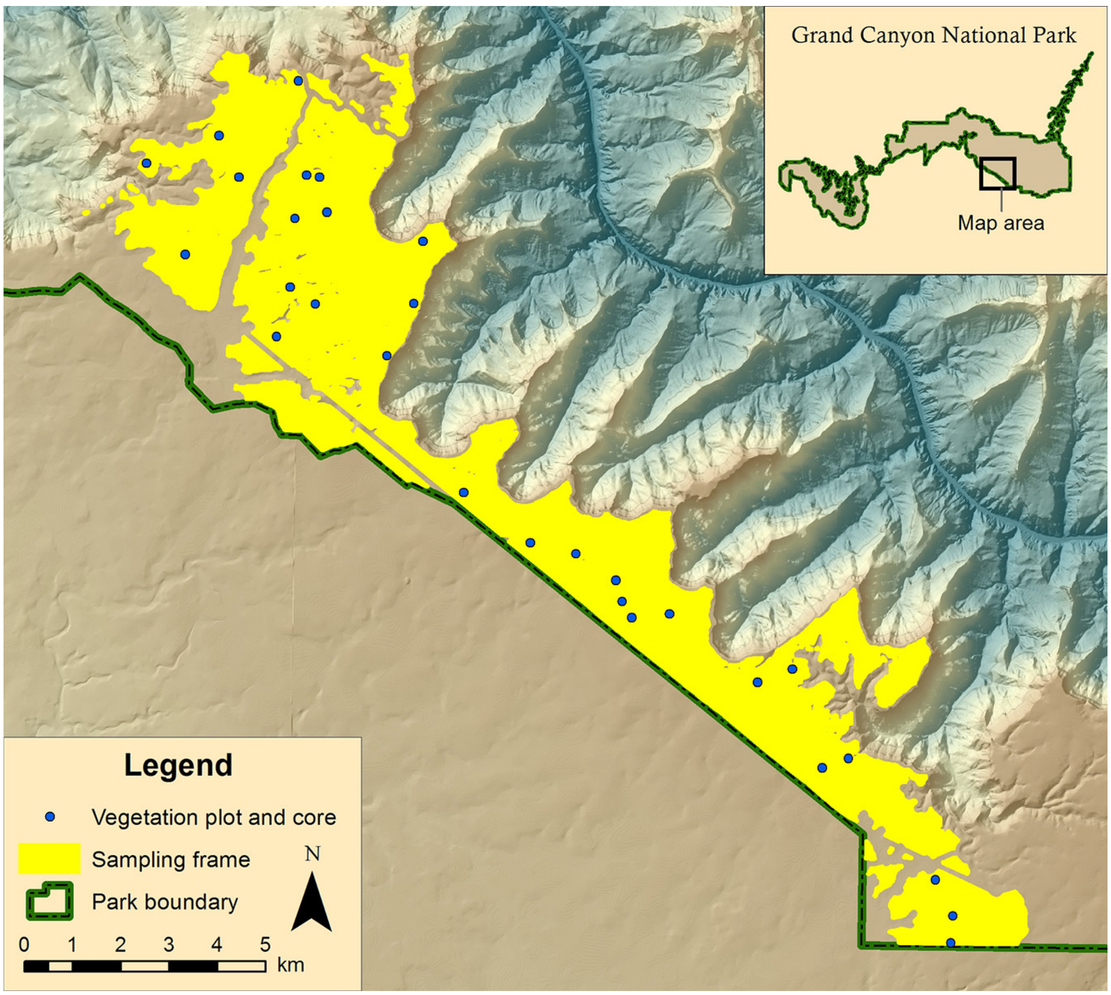

Figure 2. Map of Grand Canyon NP showing Southern Colorado Plateau Network monitoring plots in the pinyon-juniper woodland ecosystem. Plots from which soil cores were used are indicated as solid blue dots. NPS map.

Methods

Data were collected from the following sources for input into the SOILWAT2 model:

- texture and depth data from core samples that were taken during the 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).

SOILWAT2 integrated these climate data, along with the soils and vegetation data, to generate the following simulations:

- 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. 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.

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 pinyon-juniper woodland ecosystem in Grand Canyon NP.

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 3A).
- Future projections (Figure 3B) suggest declining water availability in the fall/winter and spring. By the end of the 21st century (L), average spring SWP is expected to drop below -3.0MPa, indicating conditions of extreme water scarcity.
- Future soil moisture in the summer will remain relatively unchanged. However, spring SWP will likely be lower than summer, a pattern not observed in the 20th century.

Historical and future climate patterns

- Currently, mean annual temperature (MAT) is 11.5°C. In the future, MAT is expected to increase under all climate models (near future +2.5°C, long-term future +5.0°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 4A).
- Mean annual precipitation (MAP) is 430 mm. The precipitation is bimodal, falling during the monsoon and in winter (Figure 4A). 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 4B).
- Periods of meteorological drought occur when the precipitation line is below the temperature line in Figure 4A. The current period of meteorological drought spans from mid-April to mid-July. In the future, the duration of these dry conditions will likely start earlier and last longer, primarily as a result of rising temperatures.

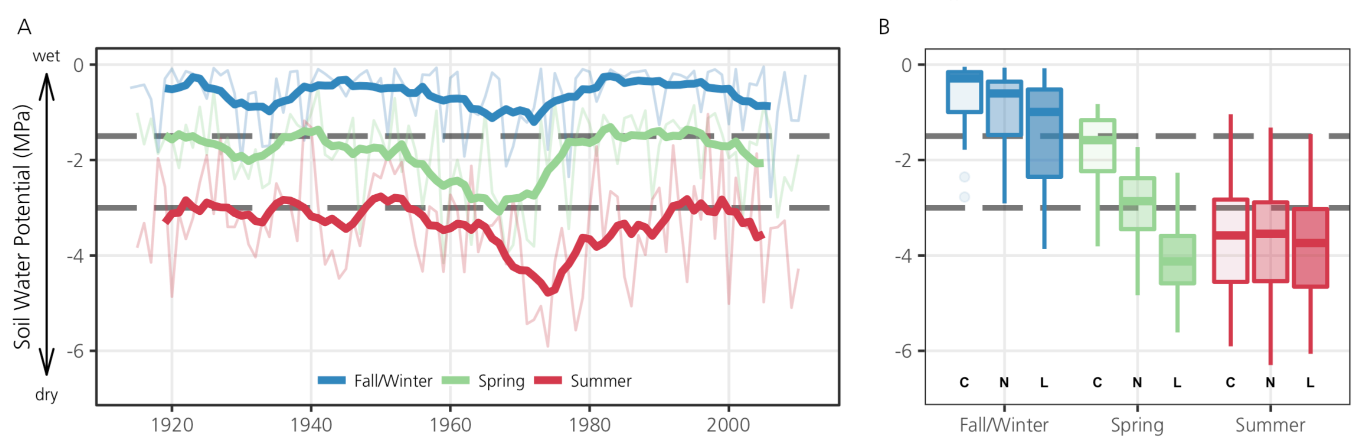

Figure 3. Historical (A) and future projections (B) of soil water potential (SWP) at intermediate soil depths (20–50 cm) in the pinyon-juniper woodland ecosystem in Grand Canyon NP for three seasons: fall/winter (October–February), spring (March–June), and summer (July–September). Panel A shows historical 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. Boxplot 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).

Future soil moisture

- Future soil moisture is predicted to be lower in the early part of the year, particularly in March through June (Figure 4B).
- Soil moisture from July to October will remain relatively unchanged or increase, but will decrease from October onwards.
- This earlier seasonal onset of dry soils will shorten the period when soils are wet during the fall/winter growing season, with likely substantial impacts on vegetation reliant on this soil moisture.

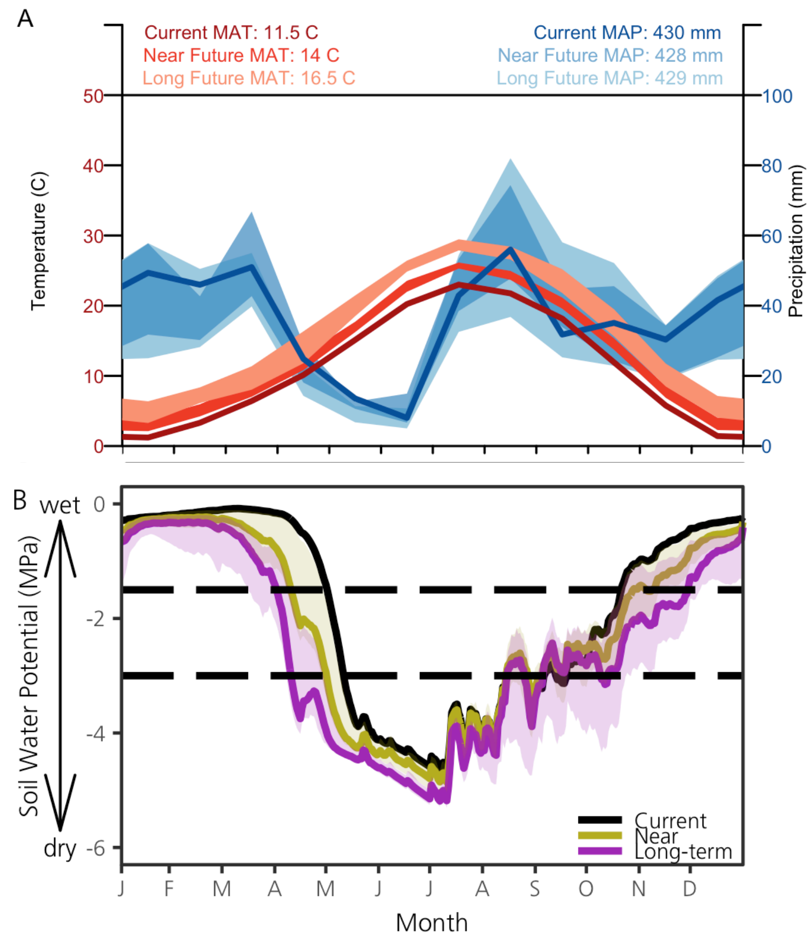

Figure 4: Panel A. Average seasonal patterns of climate in the pinyon-juniper woodland ecosystem in Grand Canyon NP. Climate diagram (Walter and Leith 1967) shows mean monthly temperature (°C) and precipitation (mm) in dark red and blue lines, respectively, in the current period (1970–2010). Shaded red 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. 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 from the 11th to 89th percentile, removing both the highest and lowest model values.

Discussion

These results present a long-term historical and future perspective on soil moisture in the pinyon-juniper woodland ecosystem in Grand Canyon NP. Predicted changes in SWP are likely to affect vegetation community dynamics in the future. Future dry spring-season periods are expected to become drier and longer as winter precipitation decreases and snowmelt events occur earlier. This change in the timing of soil moisture will leave this community vulnerable to declines as a result of climate change. When compared to other woodland ecosystems examined in the SCPN, Grand Canyon receives the most overall precipitation, as well as winter precipitation. Understanding how winter moisture will change is critical to understanding this community's future.

The projections of future soil moisture provided here can be used in conjunction with species-specific vegetation monitoring data collected by the SCPN to (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. Furthermore, the SWP estimates here have been published as a data release (Andrews and Bradford 2017) and can be used to inform future research. A recent example of this is a study by Gremer and others (2019) that used these SWP values to model the balance between grasses and shrubs in SCPN parks. The model created in that study predicted that in the future, climate change will favor greater relative abundance of shrubs across most Southern Colorado Plateau Network parks, including for the long-term future predictions (2060–2099) for the Grand Canyon NP pinyon-juniper woodland ecosystem described in this report.

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, and projections of change in SWP are robust. The variation among climate projections displays the uncertainty in the magnitude of SWP change, but modeled SWP patterns consistently point to earlier and drier spring periods. These changes in both the timing and amount of soil moisture are certain to affect the communities that rely on them.

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