ARTICLE

Changing Patterns of Water Availability May Change Vegetation Composition in US National Parks

Acadia National Park, **Agate Fossil Beds National Monument**, **Alibates Flint Quarries National Monument**, **Amistad National Recreation Area**, **Antietam National Battlefield**, ***more »***



Patch of dying junipers with the Abajo Mountains in the background, Cedar Mesa, Utah, 2019. In the two years before this photo was taken, water deficit was higher than at any time since 1980. NPS/Dana Witwicki

Overview

One of the challenges of dealing with climate change is that what it looks like often depends on where you're standing. Humans experience climate mostly through temperature and precipitation. In the US, we're finding our eastern gardens underwater more often—while in the West, water shortages and wildfire, driven by drought and heat, are occurring with unprecedented frequency.

But what if you were a plant? Most plants grow by absorbing water through their roots and releasing it from their leaves during photosynthesis. For those plants to use water, it needs to be stored in the soil. But not all water that falls from the sky ends up being available for plants to use. Some of it runs across the surface of the ground without

ever sinking into the soil, and some drains deeply below rooting zones. Some of it also evaporates, especially as temperatures rise. This means that if you're a plant, a place that received 5 inches more precipitation than normal, but was also 3°F degrees warmer than normal, could actually end up feeling *drier* than normal.

The implications of this are important not only to plants, but also to managers and visitors of national parks. Plants grow where their **traits are best suited** to the climate. When the climate changes, vegetation assemblages change. Shifts in the composition and distribution of vegetation communities (i.e., which plants grow where) can lead to changes in the animal species that live in a park, as well as how visitors experience the landscape.

But climate patterns operate at different scales. Even within the boundaries of a single park, not all areas experience the same climate the same way due to differences in topography, soil type, and other factors. In the past, this has made it hard for park managers to know how to respond and plan for climate change using regional projections. Fortunately, a new dataset developed by the National Park Service, US Geological Survey, and their partners, may help resolve some of those issues.

At a Glance

- Across the US, changes in water availability are affecting vegetation composition and distribution (i.e., which plants grow where). This can lead to changes in the animal species that live in a park, as well as how visitors experience the landscape.
- These changes are evident at a broad scale—but a new dataset can reveal changes at different places within a single park.
- Instead of relying on temperature and precipitation alone, the dataset accounts for interactions between climate and local site conditions.
- This gives park managers a valuable tool for understanding ongoing and potential future changes in vegetation under different scenarios of climate change.

Analyzing Climate through Water Balance

The pre-calculated, gridded dataset looks at climate through **water balance**. Though climate is often thought of in terms of temperature and precipitation, it's important—from the perspective of a plant—to account for the interaction between those two variables through time, as well as their mediation by environmental properties, such as **soil type**. To do this, scientists use a water-balance model. The model calculates climatic water deficit (WD), a measure of unmet water need ("drought stress"), and actual evapotranspiration (AET), a measure of water used by vegetation. Comparing these two variables is a common method of looking at climate in plant ecology. For vegetation, increased WD means that later in the growing season, plants were more likely to wilt than in years past. Increased AET means plants used more water to grow.

What is a “gridded” climate dataset?

On-the-ground measurements of temperature and precipitation from park weather stations are available from only a handful of locations in each park—often, only one. To know about water-balance conditions throughout a park, scientists can create a gridded dataset by interpolating weather-station data following the pattern of a grid, like a checkerboard laid over the park landscape. The resulting dataset accounts for changes in temperature and precipitation caused by elevation differences. This provides a more accurate representation of weather conditions at places far from the actual weather stations, which tend to be located at park headquarters.

Our water-balance model combines these weather grids with information on soil properties and hillslope aspect to derive a local estimate of water use and water need. Without gridded datasets, park managers would have to make management decisions based on temperature and precipitation data from very few locations. But these datasets are now available for every square kilometer in every National Park Service unit in the continental U.S.

Spatial Patterns

Using a water-balance model, agency and partner scientists analyzed spatial patterns in WD and AET across the continental United States from 1980 to 2019. In the West, they found higher WD and lower AET than in the East, indicating drier conditions for plants in the West. The East had generally opposite patterns, indicating wetter conditions for plants. Average annual WD was lower in the North than in the South (Figure 1). As expected, the most desert-like conditions of low AET and high WD occurred in southern California, Texas, and Arizona. The most mesic conditions of low WD and high AET occurred in Florida.

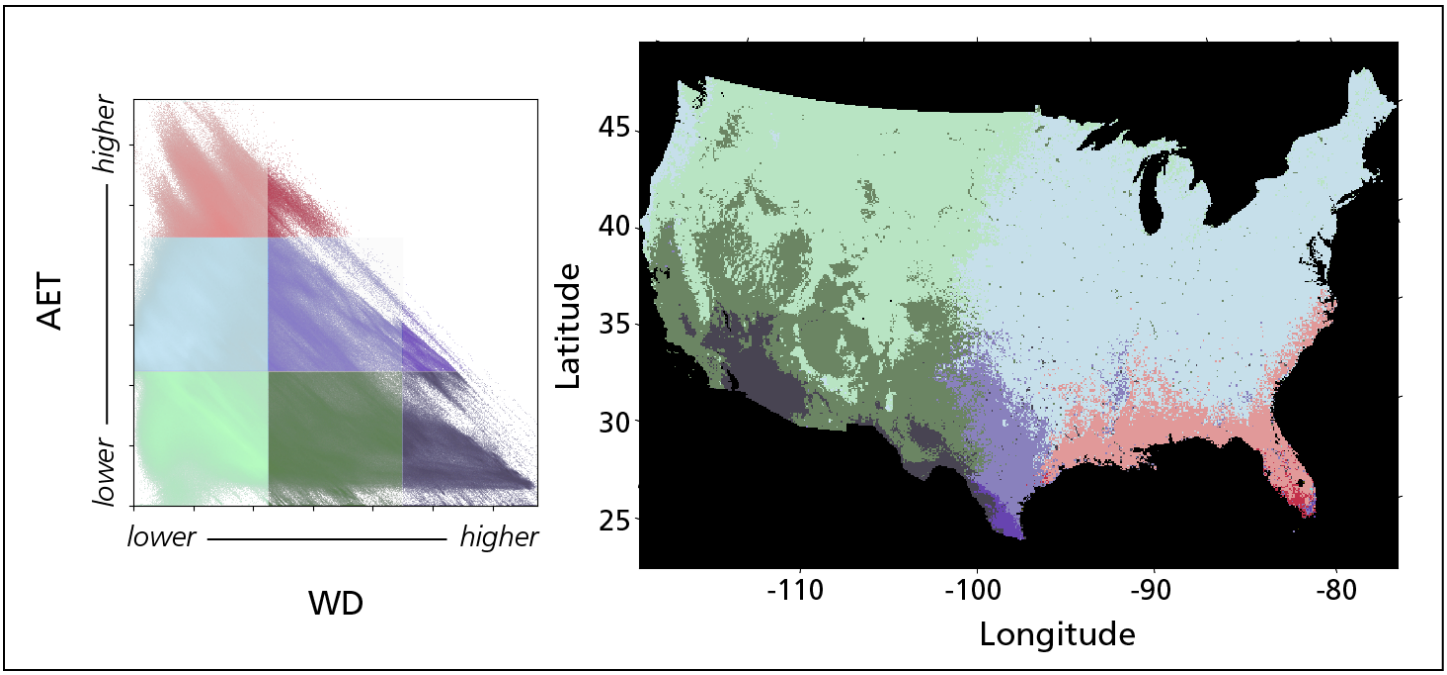
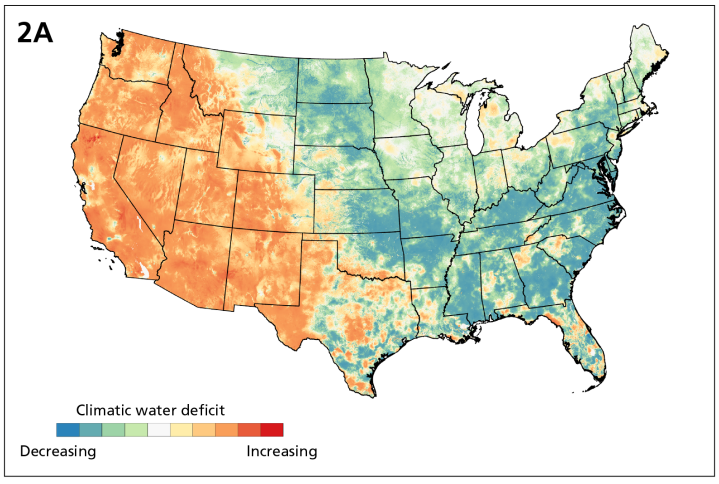


Figure 1. Spatial patterns in climatic water deficit (WD) and actual evapotranspiration (AET). *Left:* Scatterplot of average annual WD and AET for all locations in the continental US, 1981–2019. Colors correlate to zones depicted on the map at right. *Right:* Geographic locations of colored areas in the scatter plot.

Trend over time

Examined separately, trends in WD and AET were mirror images of each other across the US. Water deficit (drying) increased in the West and decreased in the East (Figure 2A). Eastern parts of the US often had increasing AET, while western parts often had decreasing AET (Figure 2B). Middle longitudes had mixed trends.



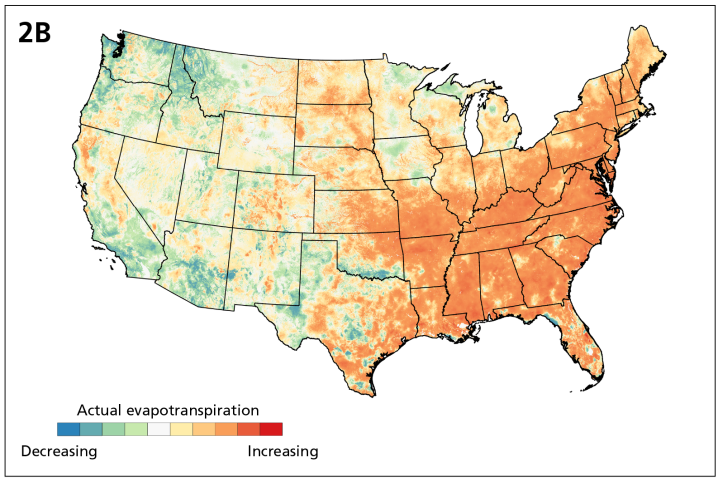
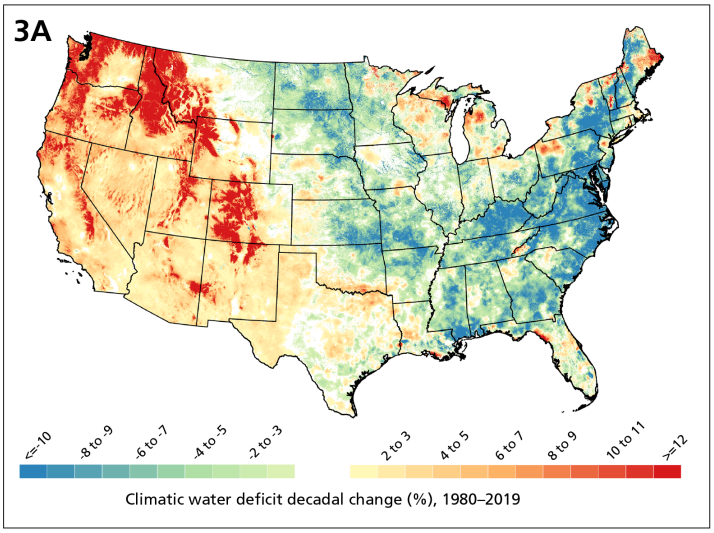


Figure 2A. Change in annual total climatic water deficit (WD) estimated for 1980–2019.

Figure 2B. Change in annual total actual evapotranspiration (AET) estimated for 1980–2019.

Amount of change over time

Water deficit showed more change over time than AET (Figure 3). Again, the patterns tended to be regional, but with some pockets of difference at higher elevations. Some higher-elevation areas in the West (e.g., parts of Wyoming, Colorado, and the Sierra Nevada Range) had large relative increases in AET (wetting). Some of the greatest relative decreases in AET (drying) occurred in desert areas of southern California. These water-limited locations were becoming even more arid.



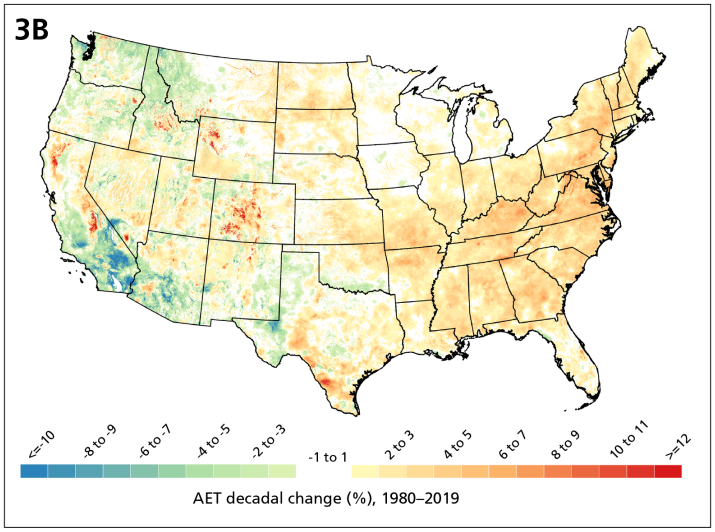


Figure 3A. Normalized change (percent of historical mean per decade) in total annual climatic water deficit, 1980–2019.

Figure 3B. Normalized change (percent of historical mean per decade) in total annual actual evapotranspiration, 1980–2019.

Across the National Park System

In general, the same trends held true for National Park Service units in the continental US: the wettest parks (Eastern Temperate Forests) got wetter and the driest parks (North American Deserts) got drier (Figure 4). The primary driver for AET and WD trends in the West was increasing temperature. Precipitation played a more dominant role in the East. WD generally increased and AET decreased in the West because temperature increases there were steeper than in the East, while precipitation trends were usually flat or declining.

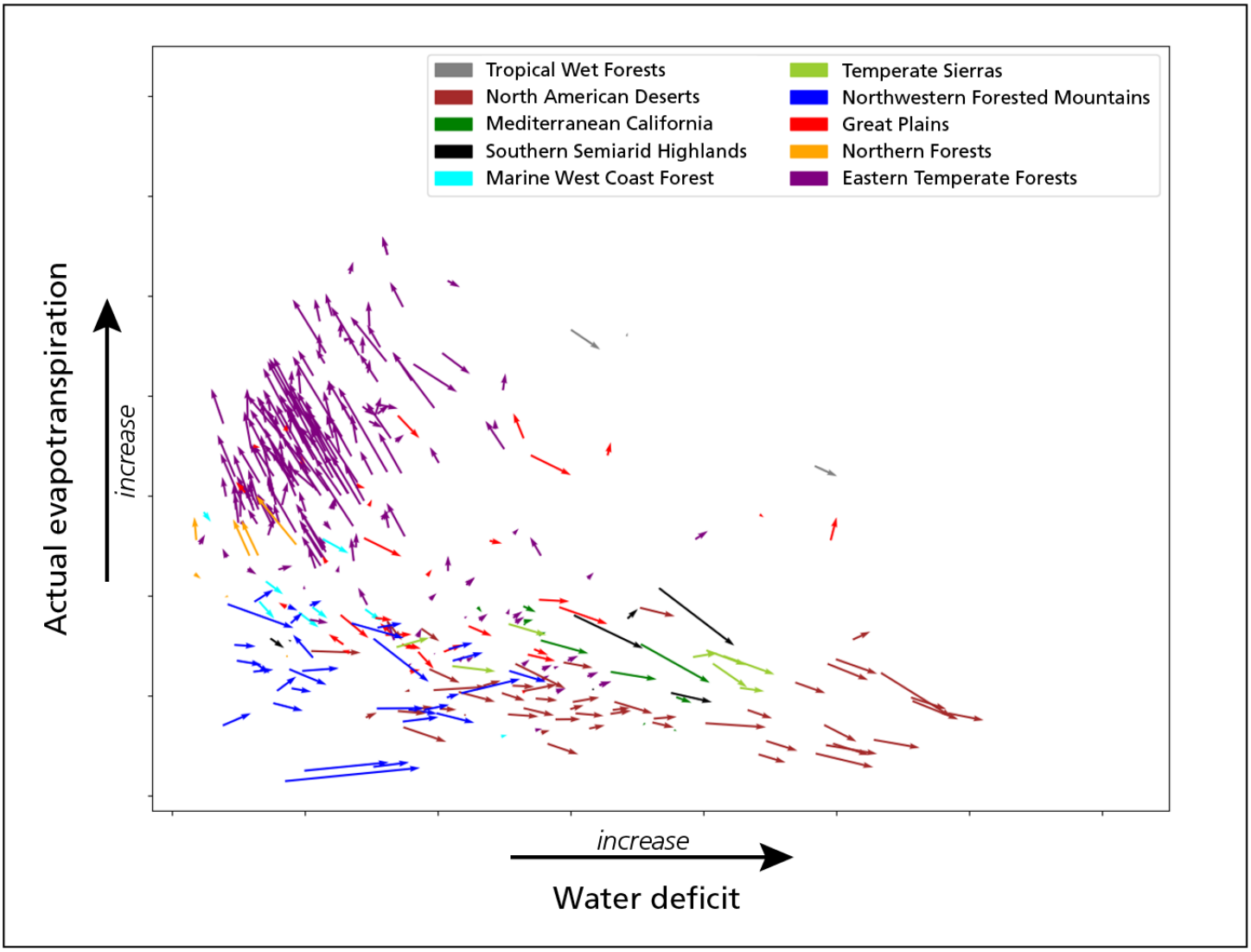


Figure 4. Combined change in climatic water deficit and actual evapotranspiration (“climate space”) for all National Park Service units in the continental US, calculated from means for 1980–1999 and 2000–2019. One centroid point for each park was selected, creating one vector for each park. Due to the strong relationship between plant distributions and climate space, any directional movement favors some species over others. The shift quantifies the central climate forces experienced by plants, which can help explain why different species grow where they do and how shifts in species composition might occur over time.

Within-park Trends

But what about a single park with a broad ecological range? The dataset developed by the NPS and its partners makes it possible to rapidly conduct park-specific analyses that would have been difficult and time-consuming in the past. For example, Sequoia and Kings Canyon National Parks showed broad diversity in trends within a relatively small (~1,500 square kilometer) area.



With their diverse topography and ecotones, Sequoia and Kings Canyon National Parks also showed diverse responses to climate within a relatively small area. NPS photo.

The parks straddle the boundary between two ecoregions (Northwestern Forested Mountains and Mediterranean California). Vegetation types range from chaparral, to montane forests, to giant sequoia groves, to high alpine communities.

Park areas experienced a broad range of WD and AET during the study period, with changes varying along an elevation gradient of 500–4,300 meters.

- The greatest changes occurred at higher elevations, where increasing trends in temperature were greatest and average annual precipitation increased during the study period. These areas (>2,000 m) generally saw increases in WD and little change in AET.
- Middle elevations (1,000–2,000 m) generally experienced moderate increases in both AET and WD.
- Lower-elevation locations, where average annual precipitation was lowest and the least amount of temperature increase occurred, generally had the smallest changes, with WD increases and little change in AET.

Ecological Implications

In the plant world, AET is tightly linked to plant growth, while WD is a good indicator of drought stress. These two variables determine the “climate space” where plants grow. When drought exceeds the stress tolerance of a particular species, then that species may decline. A drying West, expressed by increasing WD, portends shifts in plant distribution, as species better-suited to drier conditions (sometimes non-natives) replace current species. Elsewhere, increasing AET can benefit species that rely on abundant moisture and high growth rates to compete, causing concomitant shifts.

Vegetation responses to changes in water availability can be abrupt or gradual. Gradual vegetation shifts are already taking place in eastern forests, while abrupt, disturbance-driven events are altering treeline forests in the West. In the Southwest, increases in aridity suggest that more drought-tolerant species may have competitive advantage in the future.



Long-term monitoring by the NPS Inventory & Monitoring Division is capturing changes in vegetation composition. Here, staff from the Northern Colorado Plateau Network take repeat measurements on plants that were alive during previous visits.

Value to Park Managers

These findings help explain how the same temperature and precipitation patterns can have different effects over short distances due to local interactions between climate and site characteristics. At a coarse scale, ecosystems across the western US are drying while becoming wetter in the East. But at the park scale, environmental variability drives a range of local responses. When interpreted in the context of high-priority resource issues, such as **vegetation dynamics, freshwater flows, wildfire ignitions**, and dynamics of **water-sensitive species**, water-balance trends can serve as important indicators of ecological change that can inform management decisions.

The dataset used for this analysis is available for use by park managers seeking to understand how plant communities may shift under **different scenarios of climate change**. For instance, the vectors in Figure 4 point in the direction that plant-relevant climate space is moving. In response to the driving force of climate change, vegetation will adapt, move, or perish. Understanding the vulnerability of vegetation to climate change is the key to **helping managers decide** whether to **resist, accept, or direct** change to achieve management goals.

Information in this article was summarized from "**Historical changes in plant water use and need in the continental United States**," by MT Tercek, D Thoma, JE Gross, K Sherrill, S Kagone, and G Senay. PLOS ONE, September 2, 2021.

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