ARTICLE

Using Remote Sensing to Help Managers Plan for Climate Change at Capitol Reef National Park

Capitol Reef National Park



Crossing over the top of the Waterpocket Fold looking east toward Strike Valley and the Henry Mountains, Capitol Reef National Park. NPS/S. Cotrell.

In fall 2019, National Park Service staff in southern Utah noticed something strange about the landscape. Some of it was the wrong color. The region's dark-green pinyon-juniper communities usually contrast sharply with the red-orange rocks of canyon country. But now, some of the juniper trees were also orange.

They later learned the trees were dying—during one of the driest periods in 1,800 years (Gangopadhyay et al. 2022). Another tree-killing drought had occurred in southern Utah parks in 2002–2003. In combination, these two droughts killed trees that had survived for centuries.

This raised some troubling questions. Should park managers expect more of the same in the future? Could pinyon and juniper trees in other areas be affected? Which other vegetation types might change—and when and where? And what, if anything, could be done about it?

If we had a crystal ball, how might our approach to management change?

We know long-term monitoring creates a record of the past. But it also provides a window into the future. Tracking which kinds of vegetation are changing, where they grow, and which aspects of climate are associated with the

changes can help us understand what, when, where, and why future changes may occur, based on climate projections.

Linking **satellite observations** of vegetation condition with climate data over time can reveal how climate influences plant ***production*** (growth) and ***phenology*** (timing of growth). It can also tell us how sensitive different plant communities are to changes in weather and climate. With information like that, we won't need a fortuneteller.

To see how this might work, **Northern Colorado Plateau Network** scientists used satellite imagery to analyze vegetation condition over time at parks on the northern Colorado Plateau, including Capitol Reef National Park, and explored the relationships between climate and vegetation, using new tools for assessing climate effects. The results help us understand what to expect over the next few decades, and provide park managers with time and tools to plan for a range of scenarios.



In 2019, the death of juniper trees in southern Utah led to questions about whether the same could happen elsewhere on the northern Colorado Plateau. NPS/D. Witwicki.

Phenology and Production

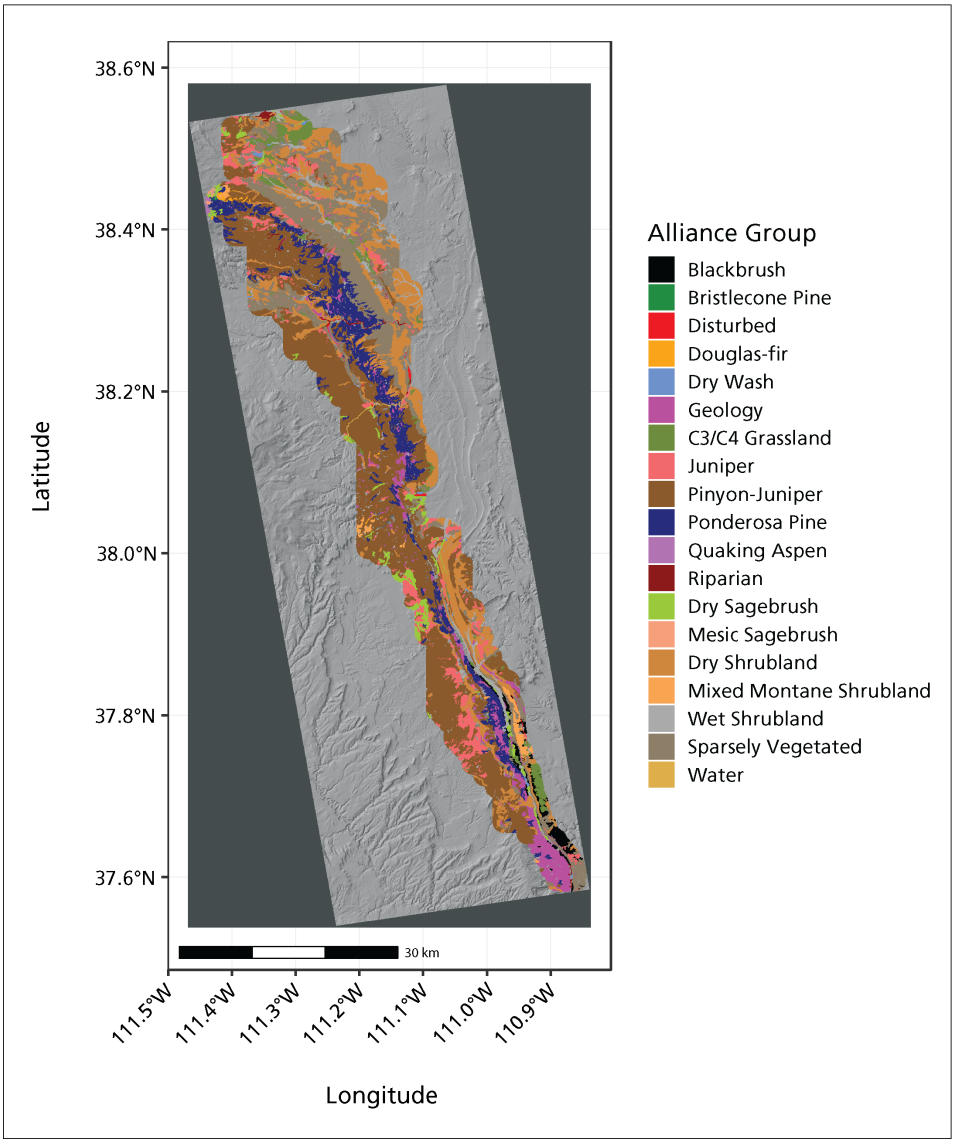
Satellite images collected over time show us when plant growth begins in spring ("greenup")—because the landscape turns green. At the end of the season, it senesces and turns brown ("browndown"). Linking the timing of greenup and browndown to weather provides insight about how weather affects phenology.

We can use those same satellite images to measure plant production. In combination, phenology and production tell us a lot about plant relationships with climate. And because plants are the biological engines of parks, this analysis tells us a lot about the impacts of **climate change** on park ecosystems.

At Capitol Reef National Park, we used satellite imagery from remote sensing to track phenology and production across 19 vegetation groups in and near the park from 2000 to 2019:

- Blackbrush
- Bristlecone Pine
- Disturbed
- Douglas-fir
- Dry Wash
- Geology
- C3/C4 Grassland
- Juniper
- Pinyon-Juniper
- Ponderosa Pine

- Quaking Aspen
- Riparian
- Dry Sagebrush
- Mesic Sagebrush
- Dry Shrubland
- Mixed Montane Shrubland
- Wet Shrubland
- Sparsely Vegetated
- Water



NCPN alliance groups analyzed for trends in production, phenology, and climate relations at Capitol Reef National Park.

Phenology

- By the end of the study period, the growing season was *starting earlier* for all alliance groups except Quaking Aspen and Mesic Sagebrush. It was also *ending later* for most alliance groups—but ending earlier for Juniper, Quaking Aspen, Mesic Sagebrush, and Bristlecone Pine.
- During the study period, the growing season *lengthened* for all alliance groups except Quaking Aspen and Mesic Sagebrush.

Production

- Multiple indicators suggest annual trends in vegetation production increased 82–86% and decreased 14–18%, depending on indicator, in the area analyzed in and near Capitol Reef National Park between 2000 and 2019.

- Areas that decreased in multiple measures of annual production were in the Sparsely Vegetated, Dry Sagebrush, and Wet Shrubland alliance groups.
- Growing-season production increased in all forested alliance groups (Bristlecone Pine, Douglas-fir, Juniper, Pinyon-Juniper, Ponderosa Pine), and in the Riparian, Mesic Sagebrush, Mixed Montane Shrubland, Geology, and Water alliance groups.

Climate Conditions

We used a **water-balance** model to determine how different aspects of climate and site characteristics affected vegetation phenology and production. To calculate the variables, we used 1-kilometer, gridded, Daymet temperature and precipitation data.

The US Southwest has been in an extended drought over the past 20–30 years. However, even during extended drought there can be periods of increased precipitation. This study, which began in 2000 and ended in 2019, needs to be considered in that context. In 2002, Capitol Reef NP received the second-lowest amount of annual precipitation of any year between 1980 and 2019. This initial extremely dry condition set the stage for subsequent trends in which precipitation increases (from the near-record low in 2000) resulted in increased in vegetation growth relative to conditions at the start of the study. This explains the increase in vegetation growth observed in 80% of the study area in and near Capitol Reef NP during this study.

Taking the long view, an interesting decadal oscillation was evident: peaks in the middle of each decade since 1980 translated to similar peaks in other water-balance variables. If the periodicity of these cycles continues in the future, it could serve as a useful guide for timing restoration efforts that require substantial planning efforts, long-term investments, and multiple years of minimal drought stress for germination and establishment.



Precipitation increased slightly during the study, which began in the midst of a long-term drought. NPS/Ariel Solomon.

Relationships of Climate and Vegetation

With this information about phenology, production, and climate in hand, we explored which climate variables were the most important drivers of phenology and production, which vegetation types were most sensitive to changes in water availability, and which types were most resistant to drought.

Climate drivers of production and phenology

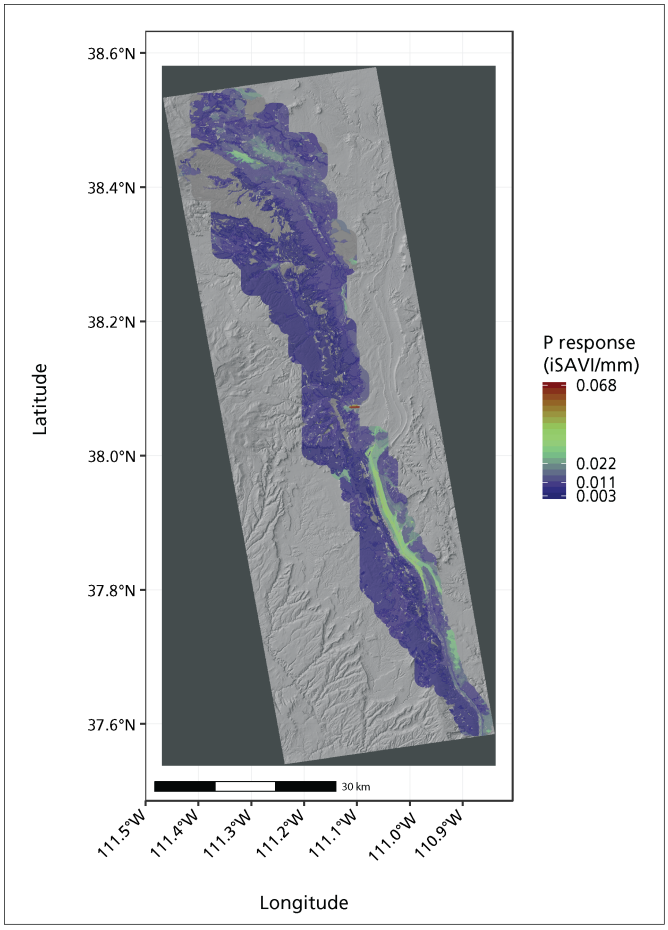
- Annual precipitation and annual production were generally among the most strongly correlated variables, suggesting that increases in annual precipitation may have caused the increase in production over the study period.
- The climate variable most strongly correlated with vegetation production was three years of precipitation.
- The primary determinants of the start of the growing season were growing degree days and precipitation.

Vegetation sensitivity to climate

The way vegetation at Capitol Reef National Park responds to various climate drivers reflects the different plant communities and the site conditions where they grow. The same amount of change in precipitation, for example, may cause different responses from different vegetation types, or even in the same vegetation type growing in different soils.

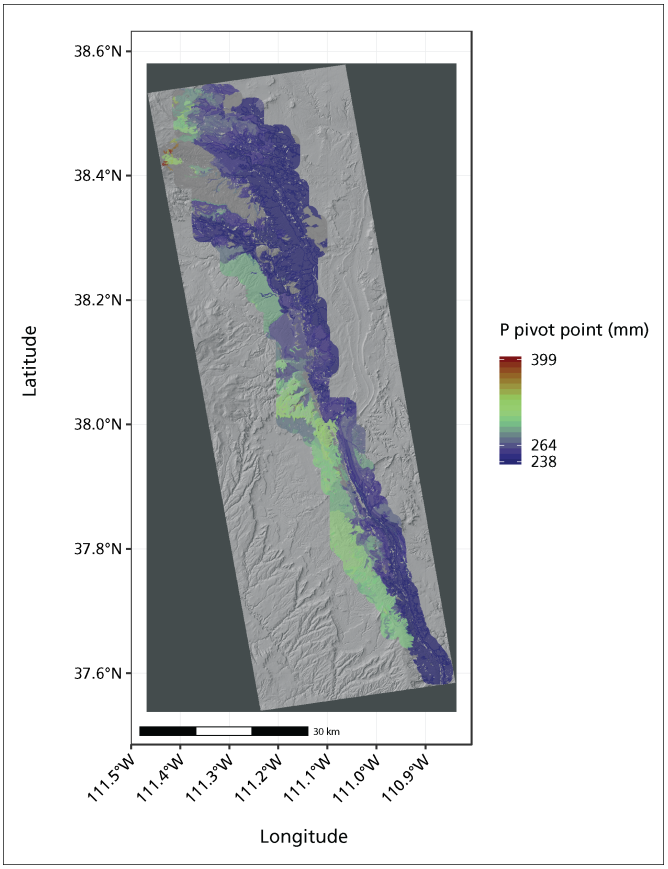
The rate of change in vegetation condition per unit change in a climate variable is known as its climate *sensitivity*. More-sensitive vegetation types respond more quickly or more strongly to changes in climate conditions. Understanding a vegetation type's climate sensitivity is critical to understanding its vulnerability to future climate change.

- Vegetation types at Capitol Reef National Park, ordered from **MOST to LEAST sensitive to precipitation**:
  - Disturbed areas (including road corridors and agricultural areas just outside the park boundary)
  - Wet Shrubland
  - Dry Sagebrush
  - Blackbrush
  - Dry Wash
  - C3/C4 Grassland
  - Dry Shrubland
  - Sparsely Vegetated
  - Riparian
  - Mixed Montane Shrubland
  - Juniper
  - Pinyon-Juniper
  - Douglas-fir
  - Ponderosa Pine
  - Bristlecone Pine



Vegetation types responded differently to precipitation, according to their sensitivity. Vegetation types in areas not shaded purple tended to be more sensitive to precipitation changes.

Drought tolerance



Vegetation groups in purple areas are less tolerant of drought than other areas.

Understanding drought tolerance helps park managers determine which vegetation types may persist or perish if water stress increases due to climate change. Vegetation that requires less water is more drought-tolerant.

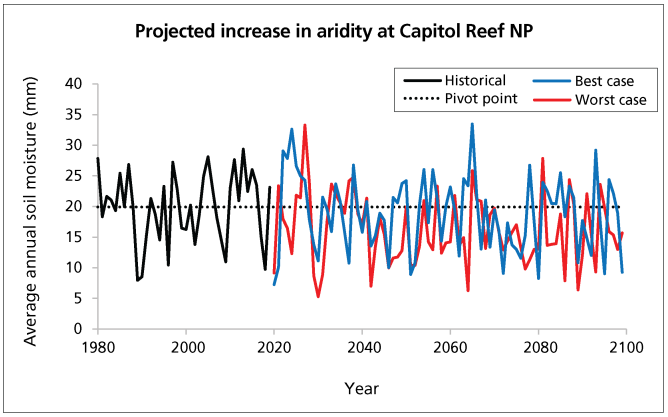
- If the landscape gets drier, then the amount of area suitable for drought-tolerant species will likely increase. Under this scenario, there will likely be less area available for less drought-tolerant species.
- Vegetation types at Capitol Reef National Park, ordered from **MOST to LEAST drought-tolerant**:
  - Blackbrush
  - Riparian
  - Disturbed areas
  - Sparsely Vegetated
  - Wet Shrubland
  - Dry Wash
  - Dry Shrubland
  - C3/C4 Grassland
  - Ponderosa Pine
  - Dry Sagebrush
  - Juniper
  - Pinyon-Juniper
  - Mixed Montane Shrubland
  - Douglas-fir
  - Bristlecone Pine

What Lies Ahead for Capitol Reef National Park?

Potential vegetation transitions

Though our science-based findings are more reliable than the musings of a fortuneteller, they have limits. We can't know exactly how vegetation change will play out at Capitol Reef National Park. But change is coming. The cause of juniper mortality seen by park managers in southern Utah in 2018 was acute drought stress (Kannenberg 2021)—a surprising finding, given the relative insensitivity of juniper to interannual precipitation changes. And even under a range of scenarios, projections trend toward more aridity in the future (see figure).

In the figure, "average annual soil moisture" represents the amount of moisture stored in the top meter of soil at a single Ponderosa Pine polygon at the park's center. The "**pivot point**" represents how much drought stress a vegetation type can tolerate and still persist over time. Soil moisture at levels below the pivot point restricts plant



Under best-case and worst-case scenarios, Capitol Reef National Park is projected to become more arid in the future.

growth and survival. Combined with climate projections of increased aridity, the vegetation sensitivity to soil moisture reported in this study can help guide the time and place for management actions at Capitol Reef National Park.

Under a best-case (warm-and-wet) future scenario, annual soil moisture will remain near the historic range of variability, but multiple years of drought below the soil-moisture pivot point may exceed the adaptive capacity of the Ponderosa Pine alliance group, leading to transition due to acute drought or fire disturbance. Under a worst-case (warm-and-dry) scenario, soil moisture will be lower than the best-case scenario in most years. This will result in more intense and prolonged drought stress that will likely make transitions happen sooner. It may also result in more dry-adapted vegetation composition than in the best-case scenario. Either way, the time to start planning for change is now.

Informed planning

Managers can use information from studies like this one in a powerful planning framework. **Climate Smart Conservation** (CSC) is a roadmap for managing natural resources as the climate changes. Ultimately, the CSC process helps managers decide whether to **resist, accept, or direct** vegetation change and identify management options for each approach. One of its key inputs is a resource's sensitivity and *vulnerability* to climate change, which this study provides. The report associated with this web article offers a step-by-step application of this kind of information for Climate Smart Conservation planning.



The success of restoration projects improves when growing conditions are more likely to promote establishment of desirable plant species.

Information in the report can also be used to identify optimum restoration windows. Restoration projects are an indispensable resource-management tool. They are also expensive and time-consuming. If park managers can anticipate how different vegetation types are likely to respond to projected climate conditions, then they can adjust the species mix and timing of restoration projects to optimize seed germination and establishment of desirable species most likely to survive new climate conditions.

Other potential questions—and answers

The information provided in this research can also help managers anticipate and plan for cascading ecological effects, such as effects on pollinators, or the movement of wildlife (migrations) across park lands. It can also be leveraged to answer many more questions, such as:

- Where are the most- and least-sensitive vegetation types in the park, and when might they experience chronic conditions that force change?
- Are forests likely to experience drought stress or transition sooner than shrublands?
- Which soil types most effectively buffer drought stress, and where do they occur in the park?
- After disturbances, such as wildfire or extreme drought, are climate conditions likely to support historical vegetation types?
- Are animal species of concern dependent on climate-sensitive vegetation types?

Vegetation provides valuable ecological services and adds to park viewsheds in immeasurable ways. But plants are sensitive to weather and climate—and when those conditions change, they respond. This report provides a foundation for understanding where, when, what, and why change may occur. Park managers can use that information to manage park resources through continuous change.

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*Information in this article was summarized from **Landscape phenology, vegetation condition, and relations with climate at Capitol Reef National Park, 2000–2019**, by D. Thoma (2023).*

Other cited material includes:

*Gangopadhyay, S., C.A. Woodhouse, G.J. McCabe, C.C. Routson, and D.M. Meko. 2022. Tree rings reveal unmatched 2nd century drought in the Colorado River Basin. Geophysical Research Letters, June 9. **https://doi.org/10.1029/2022GL098781**.*

*Kannenberg, S.A., A.W. Driscoll, D. Malesky, and W.R.L. Anderegg. 2021. Rapid and surprising dieback of Utah juniper in the southwestern USA due to acute drought stress. Forest Ecology and Management 480 (January 15):118639. **https://doi.org/10.1016/j.foreco.2020.118639**.*

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