How are plant communities in the Sonoran Desert responding to increasing temperatures and changing precipitation patterns?

Sonoran Desert plant communities are responding to climate change through widespread species-specific declines—particularly in grasses, shrubs, and trees sensitive to warming temperatures and reduced precipitation—while cacti are increasing, with precipitation variability and drought emerging as more influential drivers of community-level dynamics than temperature trends alone.

Abstract

Evidence from two long-term studies indicates that Sonoran Desert plant communities are responding to increasing temperatures and changing precipitation patterns through species-specific changes that vary by community type and topographic position. Documented responses include declines in perennial grasses with reduced precipitation , decreases in key woody species such as *Cercidium microphyllum* and *Fouquieria splendens* on hillslopes and south- and west-facing slopes with increasing mean annual temperature , and reductions in *Larrea tridentata* and *Krameria grayi* with decreased cool season precipitation and increased aridity . Conversely, cacti have increased in mesquite savanna communities . Over 80% of tested species showed climate sensitivity, with sensitivity related to local dominance rather than growth form or longevity .

At the community level, decadal-scale climate variation explains substantial variance in species richness (26%), relative density (45%), and total plant cover (55%) , though directional temperature change over the past century had less influence on community dynamics than precipitation variability and drought . Dominant species appear to buffer climate impacts through demographic processes but are particularly vulnerable to drought . Both studies project continued reductions in vegetation cover and species richness under increased drought conditions , with potential breakdown in demographic buffering of dominant species potentially altering facilitative and competitive community processes .

Paper search

We performed a semantic search using the query "How are plant communities in the Sonoran Desert responding to increasing temperatures and changing precipitation patterns?" across over 138 million academic papers from the Elicit search engine, which includes all of Semantic Scholar and OpenAlex.

We retrieved the 50 papers most relevant to the query.

Screening

We screened in sources that met these criteria:

- **Geographic Focus**: Was this study conducted within the Sonoran Desert ecoregion or its recognized boundaries?
- **Plant Community Subject**: Does this study examine plant communities, populations, or individual plant species as primary subjects?
- **Climate Variables**: Does this study include temperature and/or precipitation as measured variables or factors?
- **Empirical Data**: Does this study present original empirical data (field observations, experiments, or monitoring) rather than relying solely on theoretical models without field validation?
- **Publication Quality**: Is this study published in a peer-reviewed journal, conference proceeding, institutional report, or is it a systematic review/meta-analysis?

- **Natural Plant Systems**: Does this study focus on natural plant systems rather than cultivated plants, agricultural systems, or horticultural applications?
- **Methodological Detail**: Does this study provide adequate description of methods to allow assessment of data quality and reproducibility?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Data extraction

We asked a large language model to extract each data column below from each paper. We gave the model the extraction instructions shown below for each column.

- **Study Context**:

  Extract key study details including:

- Geographic location within Sonoran Desert (specific sites/regions)
- Study duration and time period covered
- Number and type of study sites/plots
- Vegetation community types studied (e.g., mesquite savanna, Arizona Upland, shrublands)

- **Climate Variables**:

  Extract all climate variables studied and their observed changes including:

- Temperature metrics (mean annual, seasonal, extremes)
- Precipitation metrics (annual, seasonal, cool/warm season)
- Drought indices or aridity measures
- Direction and magnitude of climate trends over study period
- Extreme events or anomalies analyzed (droughts, freezes, heat waves)

- **Community Response Metrics**:

  Extract all plant community-level responses measured including:

- Species richness/diversity changes
- Total vegetation cover changes
- Community composition shifts
- Functional group changes (trees, shrubs, grasses, cacti, etc.)
- Quantitative results with direction and magnitude where provided

- **Species-Level Responses**:

  Extract specific species responses including:

- Species names and their response direction (increase/decrease/no change)
- Magnitude of population changes where quantified
- Species grouped by growth form, longevity, or functional traits
- Climate sensitivity patterns by species characteristics
- Habitat-specific responses (slope aspect, elevation, microhabitat)

- **Climate Thresholds**:

  Extract information about climate thresholds or tipping points including:

- Specific temperature or precipitation thresholds identified
- Non-linear responses to climate variables
- Critical climate combinations or interactions
- Evidence of directional vs. fluctuating responses

- **Response Mechanisms**:

  Extract explanations for observed responses including:

- Physiological or ecological mechanisms proposed
- Competitive vs. facilitative interactions
- Demographic processes (recruitment, mortality, buffering)
- Habitat suitability changes
- Interactions between climate factors and species traits

- **Temporal Patterns**:

  Extract information about timing of responses including:

- Lag times between climate events and vegetation response
- Decadal vs. annual scale patterns
- Historical baselines and departure from baseline conditions
- Seasonal timing of climate impacts
- Evidence of directional vs. cyclical changes

- **Future Projections**:

  Extract any projections or predictions including:

- Forecasted community changes under future climate scenarios
- Vulnerable species or community types identified
- Projected thresholds or tipping points
- Implications for ecosystem services or conservation
- Uncertainty ranges where provided

Results

Characteristics of Included Studies

Study	Full Text Retrieved?	Study Duration	Study Sites/Plots	Vegetation Communities	Primary Focus
S. Munson et al., 2012	No	References 20th century changes	39 large plots across four protected sites	Mesquite savanna, Arizona Upland, shrublands	Cross-site analysis of species responses to climate variability

Study	Full Text Retrieved?	Study Duration	Study Sites/Plots	Vegetation Communities	Primary Focus
Charlotte Brown et al., 2023	No	106 years	Not specified	Not specified	Decadal-scale climate impacts on community dynamics

Both studies examined Sonoran Desert plant communities but differed substantially in temporal scope and analytical approach. The Munson et al. study employed a cross-site comparative design across multiple vegetation community types , while Brown et al. utilized an exceptionally long 106-year dataset from a single community to examine decadal-scale dynamics and climate sensitivity of 39 species .

Climate Variables and Observed Changes

Climate Variable	Munson et al. (2012)	Brown et al. (2023)
Temperature trends	Increasing mean annual temperature (MAT)	Directional change in temperature over the last century had little impact
Precipitation trends	Decrease in annual precipitation; decrease in cool season precipitation	Non-linear shifts in precipitation anomalies
Aridity/drought	Increased aridity	Increased drought frequency
Extreme events	Not analyzed	Drought; frequency of freeze events; wetter periods with frequent freeze events
Temporal scale of analysis	Past climate variability	Decadal-scale climate variation

The two studies reveal contrasting perspectives on the relative importance of temperature versus precipitation. Munson et al. documented hotter and drier conditions driving vegetation change , while Brown et al. found that directional temperature change over the century had little influence on community dynamics, with precipitation and drought being more influential .

Community-Level Responses

Response Metric	Munson et al. (2012)	Brown et al. (2023)
Species richness	Not reported	Decadal-scale climate explains up to 26% of variance; reductions with increased drought and freeze events
Total vegetation cover	Not reported	Decadal-scale climate explains up to 55% of variance; reductions with increased drought and freeze events
Species relative density	Not reported	Decadal-scale climate explains up to 45% of variance

Response Metric	Munson et al. (2012)	Brown et al. (2023)
Community composition	Shifts in functional group dominance across community types	Directional shifts over 106 years, but climate had little influence on directional change

Brown et al. provided quantitative measures of climate-driven variance, demonstrating that decadal-scale climate variation substantially explains community metrics, with total plant cover being most responsive (55% variance explained) followed by species relative density (45%) and species richness (26%) . Critically, increased drought frequency and wetter periods with frequent freeze events led to larger reductions in these metrics .

Species-Level Responses

Species	Response Direction	Climate Driver	Habitat Specificity	Source
Perennial grasses	Decrease	Decrease in annual precipitation	Mesquite savanna	Munson et al.
Cacti	Increase	Not specified	Mesquite savanna	Munson et al.
Prosopis velutina	Decrease (reversal of expansion)	Increasing MAT	Mesquite savanna	Munson et al.
Cercidium microphyllum	Decrease	Increasing MAT	Hillslopes in Arizona Upland	Munson et al.
Fouquieria splendens	Decrease	Increasing MAT	South- and west-facing slopes	Munson et al.
Larrea tridentata	Decrease	Decrease in cool season precipitation	Xeric shrublands	Munson et al.
Krameria grayi	Decrease	Increased aridity	Xeric shrublands	Munson et al.
Ambrosia deltoidea	Decrease	Drought and freeze events	Not specified	Brown et al.
Encelia farinosa	Decrease	Drought and freeze events	Not specified	Brown et al.

Munson et al. identified distinct responses across vegetation community types. In mesquite savanna communities, perennial grasses declined while cacti increased , and there was a reversal of 20th-century *Prosopis velutina* expansion in response to increasing MAT . In Arizona Upland communities, the dominant leguminous tree *Cercidium microphyllum* declined on hillslopes, and *Fouquieria splendens* decreased especially on south- and west-facing slopes , demonstrating topographic mediation of climate responses. In the most xeric shrublands, codominant *Larrea tridentata* and its hemiparasite *Krameria grayi* decreased with reduced cool season precipitation and increased aridity .

Brown et al. found that over 80% of the 39 tested species were sensitive to climate, with sensitivity related to local dominance rather than longevity, geographic range, or growth form . Dominant species exhibited demographic buffering—they were more sensitive to drought but better able to capitalize on hot and wet conditions than subdominant species .

Climate Thresholds and Non-Linear Responses

Threshold/Non-linearity	Evidence	Source
Temperature threshold for *Prosopis* expansion reversal	Expansion experienced in 20th century reversed with increasing MAT	Munson et al.
Non-linear precipitation responses	Non-linear shifts in precipitation anomalies	Brown et al.
Climate interaction effects	Drought × freeze event frequency × above-average summer precipitation interactions	Brown et al.

Both studies identified non-linear climate-vegetation relationships. Munson et al. documented the reversal of *Prosopis velutina* expansion, suggesting a temperature threshold beyond which this species' dynamics fundamentally change . Brown et al. emphasized that climate had little influence on directional community change primarily due to non-linear shifts in precipitation anomalies , and identified critical climate combinations including the interaction between drought frequency, freeze events, and above-average summer precipitation .

Response Mechanisms

Mechanism	Description	Source
Demographic buffering	Dominant species better able to buffer climate variability through demographic processes	Brown et al.
Competitive dynamics	Reversal of *Prosopis velutina* expansion suggests shifting competitive outcomes under warming	Munson et al.
Habitat suitability changes	Changes in plant species abundance and composition due to hotter and drier conditions	Munson et al.
Facilitation breakdown	Potential changes in facilitative and competitive processes due to breakdown in demographic buffering	Brown et al.

The studies propose complementary mechanisms. Munson et al. implicated shifts in habitat suitability and competitive interactions as drivers of observed changes . Brown et al. identified demographic buffering as a key mechanism whereby dominant species maintain populations under climate stress but may be vulnerable to buffering breakdown under increased drought . This breakdown could fundamentally alter community dynamics through changes in facilitative and competitive processes .

Future Projections

Both studies identified vulnerable species and projected continued community changes. Munson et al. identified perennial grasses, *Cercidium microphyllum* , *Fouquieria splendens* , *Larrea tridentata* , and *Krameria grayi* as vulnerable to projected climate conditions , with findings critical for forecasting future shifts in plant community composition, structure, and productivity .

Brown et al. projected that with increased drought frequency, reductions in total vegetation cover and species richness may occur through loss of dominant species , potentially through breakdown in demographic buffering capacity that could fundamentally change community dynamics via altered facilitative and competitive processes .

Synthesis

The apparent contradiction between studies—Munson et al. emphasizing temperature-driven changes versus Brown et al. finding temperature changes had little impact —can be reconciled through several considerations.

Temporal scale differences : Munson et al. analyzed spatial variation in responses across community types to identify climate sensitivity patterns , while Brown et al. examined 106 years of temporal dynamics at decadal resolution . The decadal-scale analysis revealed that climate explains substantial variance in community metrics (26-55%) , but directional temperature change over the century had less influence than precipitation variability .

Community type context : Munson et al.'s findings of temperature-driven species declines occurred in specific community contexts—Arizona Upland and mesquite savanna—and were often topographically mediated (e.g., south- and west-facing slopes) . Brown et al.'s single-community focus may not capture this cross-community heterogeneity in temperature sensitivity .

Mechanistic reconciliation : Both studies agree that precipitation and drought are primary drivers of community dynamics. Munson et al. documented declines in perennial grasses, *Larrea tridentata* , and *Krameria grayi* with reduced precipitation and increased aridity . Brown et al. found drought frequency among the most influential climate factors, with decadal-scale precipitation anomalies driving substantial variance in community metrics . Temperature effects may operate primarily through interactive effects with precipitation rather than independently.

Species dominance as a moderator : Brown et al.'s finding that dominant species exhibit demographic buffering but are more drought-sensitive helps explain why overall community change may appear buffered against temperature trends while individual species show clear responses. The 80% climate sensitivity of tested species indicates widespread individual responses, even when aggregate community metrics show resilience.

In summary, Sonoran Desert plant communities are responding to climate change through species-specific declines driven by warming temperatures and altered precipitation patterns, with effects mediated by community type, topographic position, and species dominance status. Precipitation variability and drought appear more influential than temperature trends alone for community-level dynamics, though temperature effects are evident for specific species in specific habitats. Future projections of increased drought suggest continued reductions in vegetation cover and species richness, potentially accelerated by breakdown of demographic buffering in dominant species.

References

Charlotte Brown, Susana Rodríguez Buriticá, Deborah E Goldberg, Frank Reichenbacher, D. Venable, Robert H. Webb, and Benjamin T. Wilder. “One Hundred and Six Years of Change in a Sonoran Desert Plant Community: Impact of Climate Anomalies and Trends in Species Sensitivities.” *Ecology*, 2023.

S. Munson, R. Webb, J. Belnap, J. Andrew Hubbard, D. Swann, and S. Rutman. "Forecasting Climate Change Impacts to Plant Community Composition in the Sonoran Desert Region," 2012.