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# Climate Variability and Plant Response at the Santa Rita Experimental Range, Arizona

**Abstract:** Climatic variability is reflected in differential establishment, persistence, and spread of plant species. Although studies have investigated these relationships for some species and functional groups, few have attempted to characterize the specific sequences of climatic conditions at various temporal scales (subseasonal, seasonal, and interannual) associated with proliferation of particular species. Research has primarily focused on the climate conditions concurrent with or occurring just prior to a vegetation response. However, the cumulative effect of antecedent conditions taking place for several consecutive seasons may have a greater influence on plant growth.

In this study, we tested whether the changes in overall cover of plant species can be explained by antecedent climate conditions. Temperature, precipitation, and Palmer Drought Severity Index (PDSI) values at various lags were correlated with cover. PDSI had the strongest correlations for several drought-intolerant species at lags up to six seasons prior to the sampling date. Precipitation, surprisingly, did not correlate with species cover as strongly as PDSI. This is attributed to PDSI capturing soil moisture conditions, which are important to plant growth, better than raw precipitation measurements. Temperature correlations were weak and possessed little explanatory power as predictors of species cover.

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## Introduction

Climatic variability is reflected in differential establishment, persistence, and spread of plant species. Although studies have investigated these relationships for some species and functional groups (Ibarra and others 1995; Martin and others 1995; Neilson 2003; Neilson and Wullstein 1983), few have attempted to characterize the specific sequences of climatic conditions at various temporal scales (subseasonal, seasonal, and interannual) associated with proliferation of particular species. Research has primarily focused on the climate conditions concurrent with or occurring just prior to a vegetation response. However, the cumulative effect of antecedent conditions taking place for several consecutive seasons may have a greater influence on plant growth.

Our objective in this study was to test whether the changes in percent cover of individual plant species can be explained by climatic conditions at different time scales. We investigated this relationship for native perennial grasses using long-term monitoring data from the Santa Rita Experimental Range (SRER) located in southeastern Arizona, U.S.A.

## Methods

Plant cover data for 11 perennial grass species were obtained from the Santa Rita Experimental Range Digital Database. The species included in the analysis were sprucetop grama (*Bouteloua chondrosioides* [H.B.K.] Benth.), sideoats grama

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(*Bouteloua curtipendula* [Michx.] Torr.), black grama (*Bouteloua eripoda* Torr.), slender grama (*Bouteloua filiformis* [Fourn.] Griffiths), hairy grama (*Bouteloua hirsuta* Lag.), Rothrock grama (*Bouteloua rothrockii* Vasey), Arizona cottontop (*Digitaria californica* [Benth.] Henr.), tanglehead (*Heteropogon contortus* [L.] Beauv.), curly mesquite (*Hilaria belangeri* [Steud.] Nash), bush muhly (*Muhlenbergia porteri* Scribn.), and plains bristlegrass (*Setaria macrostachya* H.B.K.). Cover measurements, taken on all transects all sampling years, were aggregated by species for each sampling year and normalized by dividing the total by the number of observations. Pastures on the SRER have been grazed for many decades using various rotations. However, data for this study were not stratified by grazing rotation because differences in grass density and grazing rotations were detected for only one species in this study, *Muhlenbergia porteri* (Angell and McClaran 2001; Martin and Severson 1988).

We primarily focused on the SRER plant cover data for this study because the period of record (47 years) is much greater than that for density measurements (28 years). Data from 1953 to 1984 were analyzed in this study. Changes in both personnel carrying out the field work and season of the work (from autumn to spring) reduced the comparability of data collected throughout the entire period of record, 1953 to 2000. Many species demonstrate marked increases or decreases in cover between the period 1953 to 1984 and the period 1991 to 2000. There are several candidate explanations for this significant change in cover measurements. In 1991, the sampling was taken over by a different group of individuals than had performed the previous sampling. It is possible that observer bias played a role in the differing measurements. Additionally, samples taken during the 1953 to 1984 period were recorded in late summer or autumn while the 1990s data were collected in winter. A number of the grass species in this study exhibit low C:N ratios, leading to their quick breakdown following the growing period. This would cause some species to be under-represented when sampled in winter, and others to be over-represented when not sampled during the growing season. Finally, the introduced nonnative perennial bunchgrass *Eragrostis lehmanniana* heavily invaded the SRER between 1984 and 1990. The presence of *E. lehmanniana* may be influencing the cover of other native grasses. Confounding of both observer and season suggest that the data collected during the 1991 to 2000 period should be analyzed separately from the 1953 to 1984 data.

Five climate variables were used in the lagged correlation analysis. Four of the variables, including daily total precipitation (PPT), minimum temperature (TMIN), maximum temperature (TMAX), and mean temperature (TMEAN), were measured at the Santa Rita Experimental Range through the cooperative observer program of the National Weather Service on a daily basis. These data were obtained from the National Climatic Data Center (NCDC). The fifth variable, the Palmer Drought Severity Index (PDSI), was obtained for climate division #7, representing five counties in southeastern Arizona, from NCDC. The PDSI values were calculated from temperature and precipitation measurements from across southeastern Arizona and represent an area-wide indication of soil moisture conditions.

Daily data (PPT, TMEAN, TMIN, TMAX) and monthly data (PDSI) were combined into seasonal averages for the period from 1950 to 1984. Seasons were defined as winter (DJFM), spring (AMJ), summer (JAS), and autumn (ON). These definitions differ from the convention of even 3-month seasons, but are more appropriate for the unique seasonality of precipitation and temperature in southern Arizona. Precipitation is bimodal with 30 percent falling in DJFM and 50 percent falling during the monsoon season of JAS (WRCC 2003). The adjusted definitions are more sensitive to these seasonal variations in precipitation.

For each season in the study period, precipitation amounts were summed and all other variables averaged. This resulted in four seasonal values for each year for the period from 1950 to 1984. The time series of seasonal climate variables was matched to the time series of species cover measurements sampled at various years between 1950 and 1984. Each climate variable was then lagged one to 12 seasons from each sampling date, creating a lagged climate sequence for each species cover amount and each variable. Paired observations were correlated to produce Pearson's *r* values for each species and climate variable at all seasonal lags.

## Results

The cover of 11 perennial grass species was tested for correlation with the five climatic variables. Of the 11 grass species, six grass species exhibited significantly positive ($p < 0.05$) correlations with precipitation at one or more seasons (table 1). These species included *B. eripoda*, *B. filiformis*, *B. rothrockii*, *H. contortus*, *M. porteri*, and *S. macrostachya*. Four demonstrated significantly positive ($p < 0.05$) correlations with PDSI at one or more seasons (table 2). These grasses were *B. eripoda*, *D. californica*, *H. contortus*, and *S. macrostachya*. Four species exhibited significantly positive ($p < 0.05$) correlations with TMIN at one or more seasons (table 3). These grasses were *B. eripoda*, *B. rothrockii*, *H. contortus*, and *S. macrostachya*. Results for TMAX and TMEAN were similar to those for TMIN.

## Discussion

The Palmer Drought Severity Index accounts for antecedent precipitation, moisture supply, and moisture demand (Palmer 1965). By incorporating accumulated moisture deficiencies or surpluses, it is a better measure of plant-available water. Strong positive relationships between grass cover and PDSI were found for several species in this study. Several species showed significantly positive relationships with PDSI. These species, which include *Bouteloua eripoda*, *D. californica*, *H. contortus*, and *S. macrostachya*, are all drought-susceptible perennial bunchgrasses (Burgess 1995; Herbel and others 1972; Matthews and others 1999). No significant relationships were detected between PDSI at any lag and cover of the perennial bunchgrasses *B. curtipendula*, *B. filiformis*, *B. rothrockii*, *B. chondrosioides*, *B. hirsuta*, *H. belangeri*, and *M. porteri*. These grasses are all considered to be drought tolerant (Judd 1962; Matthews and others 1999; Ruyle and Young 1997; Stubbendieck and

**Table 1**—Pearson's r correlation coefficients between grasses and precipitation at the Santa Rita Experimental Range, Arizona.

| Species | n | JAS (p) | AMJ (p) | DJFM (p) | ON (p) | JAS-1 (p) | AMJ-1 (p) | DJFM-1 (p) | ON-1 (p) |
|---|---|---|---|---|---|---|---|---|---|
| *Bouteloua chondrosioides* | 12 | –0.156 (0.628) | 0.229 (0.474) | –0.056 (0.863) | –0.399 (0.199) | –0.106 (0.742) | –0.341 (0.278) | –0.123 (0.703) | 0.389 (0.211) |
| *Bouteloua curtipendula* | 14 | –0.021 (0.944) | –0.234 (0.420) | –0.039 (0.893) | 0.053 (0.857) | –0.147 (0.616) | 0.311 (0.279) | 0.340 (0.235) | 0.303 (0.293) |
| *Bouteloua eripoda* | 16 | 0.250 (0.351) | 0.354 (0.179) | –0.151 (0.577) | 0.702[b] (0.002) | 0.555[a] (0.026) | –0.247 (0.357) | 0.439 (0.089) | –0.187 (0.488) |
| *Bouteloua filiformis* | 16 | –0.159 (0.557) | –0.004 (0.987) | –0.049 (0.856) | –0.194 (0.472) | –0.286 (0.283) | –0.190 (0.482) | 0.001 (0.997) | 0.338 (0.200) |
| *Bouteloua hirsuta* | 16 | –0.027 (0.921) | –0.298 (0.262) | 0.072 (0.792) | –0.235 (0.381) | 0.404 (0.121) | –0.258 (0.335) | 0.068 (0.803) | –0.136 (0.614) |
| *Bouteloua rothrockii* | 16 | 0.287 (0.281) | 0.241 (0.369) | 0.027 (0.921) | 0.484 (0.058) | 0.528[a] (0.035) | –0.369 (0.160) | 0.230 (0.392) | –0.063 (0.815) |
| *Digitaria californica* | 16 | 0.074 (0.786) | 0.394 (0.131) | –0.070 (0.795) | 0.336 (0.204) | 0.187 (0.488) | –0.156 (0.563) | 0.416 (0.109) | –0.372 (0.156) |
| *Heteropogon contortus* | 16 | 0.364 (0.166) | 0.535[a] (0.033) | –0.128 (0.637) | 0.698[b] (0.003) | 0.429 (0.098) | –0.078 (0.774) | 0.517[a] (0.040) | –0.319 (0.229) |
| *Hilaria belangeri* | 16 | –0.368 (0.161) | –0.073 (0.787) | –0.065 (0.811) | 0.151 (0.578) | –0.156 (0.565) | –0.068 (0.801) | 0.096 (0.724) | 0.479 (0.061) |
| *Muhlenbergia porteri* | 16 | 0.108 (0.690) | 0.503[a] (0.047) | –0.119 (0.660) | 0.129 (0.634) | –0.144 (0.594) | –0.063 (0.818) | –0.034 (0.900) | –0.347 (0.187) |
| *Setaria macrostachya* | 16 | 0.286 (0.282) | 0.465 (0.069) | –0.088 (0.746) | 0.610[a] (0.012) | 0.337 (0.202) | –0.177 (0.513) | 0.592[a] (0.016) | –0.375 (0.152) |

[a] Correlation significant at $p < 0.05$.
[b] Correlation significant at $p < 0.01$.

**Table 2**—Pearson's r correlation coefficients between grasses and Palmer Drought Severity Index at the Santa Rita Experimental Range, Arizona.

| Species | n | JAS (p) | AMJ (p) | DJFM (p) | ON (p) | JAS-1 (p) | AMJ-1 (p) | DJFM-1 (p) | ON-1 (p) |
|---|---|---|---|---|---|---|---|---|---|
| *Bouteloua chondrosioides* | 12 | –0.306 (0.333) | –0.364 (0.245) | –0.555 (0.061) | –0.430 (0.163) | –0.415 (0.180) | –0.342 (0.276) | –0.540 (0.070) | –0.506 (0.094) |
| *Bouteloua curtipendula* | 14 | –0.091 (0.756) | –0.053 (0.857) | –0.150 (0.609) | –0.208 (0.476) | –0.181 (0.535) | 0.188 (0.519) | –0.040 (0.892) | –0.193 (0.509) |
| *Bouteloua eripoda* | 16 | 0.503[a] (0.047) | 0.474 (0.064) | 0.667[b] (0.005) | 0.752[b] (0.001) | 0.787[b] (0.000) | 0.644[b] (0.007) | 0.668[b] (0.005) | 0.252 (0.346) |
| *Bouteloua filiformis* | 16 | –0.351 (0.183) | –0.305 (0.251) | –0.395 (0.130) | –0.338 (0.201) | –0.224 (0.405) | 0.022 (0.935) | –0.037 (0.893) | –0.160 (0.555) |
| *Bouteloua hirsuta* | 16 | –0.120 (0.657) | –0.209 (0.438) | –0.195 (0.469) | –0.167 (0.536) | 0.000 (0.999) | –0.307 (0.247) | –0.462 (0.072) | –0.552[a] (0.027) |
| *Bouteloua rothrockii* | 16 | 0.397 (0.128) | 0.452 (0.079) | 0.494 (0.052) | 0.475 (0.063) | 0.493 (0.052) | 0.291 (0.275) | 0.301 (0.257) | –0.035 (0.899) |
| *Digitaria californica* | 16 | 0.436 (0.091) | 0.522[a] (0.038) | 0.472 (0.065) | 0.486 (0.056) | 0.296 (0.266) | 0.226 (0.400) | 0.093 (0.733) | –0.237 (0.377) |
| *Heteropogon contortus* | 16 | 0.642[b] (0.007) | 0.621[b] (0.010) | 0.706[b] (0.002) | 0.783[b] (0.000) | 0.680[b] (0.004) | 0.585[a] (0.017) | 0.501[a] (0.048) | 0.049 (0.857) |
| *Hilaria belangeri* | 16 | –0.408 (0.116) | –0.267 (0.317) | –0.263 (0.325) | –0.194 (0.471) | –0.053 (0.847) | 0.251 (0.348) | 0.239 (0.373) | 0.102 (0.706) |
| *Muhlenbergia porteri* | 16 | 0.276 (0.300) | 0.312 (0.239) | 0.219 (0.415) | 0.306 (0.248) | –0.043 (0.874) | –0.036 (0.896) | –0.063 (0.818) | –0.136 (0.617) |
| *Setaria macrostachya* | 16 | 0.555[a] (0.026) | 0.563[a] (0.023) | 0.599[a] (0.014) | 0.681[b] (0.004) | 0.537[a] (0.032) | 0.446 (0.083) | 0.328 (0.214) | –0.166 (0.539) |

[a] Correlation significant at $p < 0.05$.
[b] Correlation significant at $p < 0.01$.

**Table 3**—Pearson's r correlation coefficients between grasses and minimum temperature at the Santa Rita Experimental Range, Arizona.

| Species | n | JAS (p) | AMJ (p) | DJFM (p) | ON (p) | JAS-1 (p) | AMJ-1 (p) | DJFM-1 (p) | ON-1 (p) |
|---|---|---|---|---|---|---|---|---|---|
| *Bouteloua chondrosioides* | 12 | 0.184 (0.567) | –0.285 (0.369) | 0.155 (0.631) | 0.180 (0.575) | 0.413 (0.182) | 0.208 (0.516) | 0.029 (0.928) | –0.134 (0.677) |
| *Bouteloua curtipendula* | 14 | 0.131 (0.656) | –0.236 (0.416) | –0.004 (0.990) | 0.284 (0.326) | 0.393 (0.164) | 0.059 (0.842) | –0.136 (0.644) | 0.099 (0.735) |
| *Bouteloua eripoda* | 16 | –0.553[a] (0.026) | 0.149 (0.582) | –0.109 (0.687) | –0.389 (0.136) | –0.558[a] (0.025) | –0.534[a] (0.033) | –0.530[a] (0.035) | –0.287 (0.281) |
| *Bouteloua filiformis* | 16 | 0.327 (0.216) | 0.330 (0.213) | 0.484 (0.058) | 0.279 (0.296) | 0.465 (0.069) | 0.032 (0.907) | 0.014 (0.958) | 0.256 (0.339) |
| *Bouteloua hirsute* | 16 | –0.083 (0.760) | 0.169 (0.530) | –0.022 (0.935) | 0.249 (0.352) | –0.196 (0.467) | –0.038 (0.890) | 0.092 (0.734) | 0.389 (0.136) |
| *Bouteloua rothrockii* | 16 | –0.635[b] (0.008) | –0.333 (0.207) | –0.527[a] (0.036) | –0.631[b] (0.009) | –0.680[b] (0.004) | –0.857[b] (0.000) | –0.702[b] (0.002) | –0.523[a] (0.038) |
| *Digitaria californica* | 16 | –0.174 (0.519) | 0.308 (0.246) | 0.026[a] (0.924) | –0.346 (0.190) | –0.289 (0.277) | –0.303 (0.255) | –0.202 (0.453) | –0.406 (0.118) |
| *Heteropogon contortus* | 16 | –0.527 (0.036) | –0.037[a] (0.891) | –0.176 (0.513) | –0.569 (0.021) | –0.549 (0.027) | –0.644 (0.007) | –0.473 (0.064) | –0.431 (0.096) |
| *Hilaria belangeri* | 16 | 0.419 (0.106) | 0.007[b] (0.979) | 0.341 (0.196) | 0.130 (0.631) | 0.282 (0.290) | 0.093 (0.733) | –0.227 (0.398) | 0.189 (0.482) |
| *Muhlenbergia porteri* | 16 | –0.084 (0.757) | 0.138 (0.609) | –0.058 (0.830) | –0.479 (0.060) | –0.059 (0.829) | –0.010[a] (0.970) | 0.157 (0.560) | –0.523 (0.038) |
| *Setaria macrostachya* | 16 | –0.358 (0.173) | 0.098 (0.719) | –0.094 (0.728) | –0.525 (0.037) | –0.491 (0.054) | –0.572 (0.021) | –0.339 (0.199) | –0.366 (0.163) |

[a] Correlation significant at $p < 0.05$.
[b] Correlation significant at $p < 0.01$.

others 1985; Weaver and Albertson 1956). Therefore, PDSI can be a good indicator of cover for perennial grasses that are drought susceptible.

Water is the chief abiotic factor affecting the productivity and distribution of grasslands ecosystems (Sala and others 1988; Stephenson 1990). It is “very likely” that precipitation has increased over mid- and high latitude Northern Hemisphere continents by 0.5 to 1 percent per decade since 1900 (IPCC 2001). The ecological impacts of these changes have been documented in ecosystems ranging from tropical marine to polar terrestrial environments (Hughes 2000; Parmesan and Yohe 2003; Root and others 2003), affecting reproduction and species ranges of plants and animals alike. Little work has evaluated the effects of these changing precipitation patterns on the distribution, structure, or composition of plant communities, as a step in understanding future vegetation change. Such changes have implications for the seasonality and intensity of fires, the spread of nonnative species, and the sustainable management of rangelands.

Aggregating climatic data to the season removes extreme events that likely exert the greatest amount of influence on physiological processes such as reproduction and growth. This reduces the predictive power of directly measured climatic variables such as monthly average temperature and monthly total precipitation. Precipitation had a significantly positive correlation with cover of six species at six of the 12 different seasonal lags (table 1). These correlations did not seem to reflect any obvious relationships. We expected to find strong relationships between grass cover and the precipitation of the previous season. Although the grasses in this study are warm season grasses that are known to respond to summer precipitation, we did not find a strong relationship between grass cover and the precipitation of the previous season. We believe these relationships are lacking because precipitation is not necessarily representative of plant-available water. Precipitation is a measure of water reaching the earth, but depending on the amount and intensity of the precipitation event, plants may not be able to use all of the moisture. In addition, plant response to water is a function of the plant’s condition. Long periods of drought may stress plants to a point that they do not respond immediately to precipitation.

For three of the four grasses exhibiting significantly positive relationships with PDSI, we see consecutive relationships of seasonal PDSI up to winter of the previous year (six seasons prior). For both *B. eripoda* and *H. contortus*, the first season significantly correlated with cover was winter of the previous year (DJFM-1). The first season correlated with *S. macrostachya* was summer of the previous year (JAS-1). *Digitaria californica* was significantly correlated with PDSI in only one season, winter of the sampling year (DJFM). Two seasons prior also show a strong but insignificant relationship ($p < 0.10$) with PDSI.

The correlations between grass cover and PDSI were assumed to be independent, but PDSI values are dependent on those of preceding seasons due to the water balance accounting inherent in its calculation. Our results of several consecutive seasons significantly correlated with PDSI for these species may be due to this temporal autocorrelation. Nonetheless, successive seasons of high positive PDSI values (wet conditions) seem to favor greater cover values for these grasses.

A majority of the significant correlations between grass cover and TMIN, TMEAN, and TMAX were negative, that is, higher grass cover amounts were correlated with lower temperatures at various seasonal lags. This counter-intuitive finding is likely due to the inherent relationship between wet periods and cooler temperatures. PDSI captures this relationship due to the inclusion of temperature in the calculation of evapotranspiration. Lower temperatures result in lower rates of potential evapotranspiration and higher soil moisture.

## Conclusions

Plant-available water captured in the PDSI explains the greatest amount of variation in plant cover for perennial grasses at the Santa Rita Experimental Range. The strength of the PDSI’s explanatory power is that it accounts for antecedent precipitation, moisture supply, and moisture demand. By incorporating accumulated moisture deficiencies or surpluses, it is a better measure of plant-available water than precipitation. Grasses known to be drought-susceptible showed the strongest relationships with PDSI, while drought-resistant grasses demonstrated little or no relationships. A critical finding of this study is the utility of PDSI over precipitation in predicting cover changes for perennial grasses that are drought susceptible.

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