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Effects of Weather Variations on Species Composition and Production in California's Grasslands

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As the drought of this past year has highlighted, vegetation composition and production in California's grasslands are strongly driven by fluctuations in weather patterns (Heady et al. 1992, Bartolome et al. 2007, Keeler-Wolf et al. 2007). Our grasslands experience high variability in weather across space and time. Average rainfall across California grassland sites varies from 4.7 to 79 inches per year (Bartolome et al. 2007), with the highest precipitation on the North Coast and lower precipitation as one moves inland and to the south. Even at a given site, annual precipitation can vary as much as 20–40 inches from its long-term mean (Pitt and Heady 1978, Reever Morghan et al. 2007), with high variation particularly associated with El Niño Southern Oscillation and drought periods (Reever Morghan et al. 2007).

This high spatial and temporal variability in rainfall makes management of California's grasslands particularly challenging, with management success stories from one site not always being relevant to other sites or even to the same site in another year. While there are always exceptions to the rule, generalities have emerged over the years about the impacts of rainfall patterns on California's grasslands. This article summarizes those general trends.

Figure 1. East Bay hills in late March 2014, highlighting vegetation patterns that can be typical of drought conditions: low biomass of annual grasses along with high prevalence of forbs and bare spaces. *Photo by author*

The timing of rainfall is generally more important than the total rainfall within a season.

While lower rainfall years tend to produce lower plant diversity (Bartolome et al. 1980), total rainfall does not reliably predict plant production and community composition; the timing of rainfall is far more

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CNGA Board Election for 2015

Election time for the 2015 Board of Directors is here, and this year we are doing things differently. In an effort to save paper and mailing costs, we will conduct an **online election**. Voting will be open from December 1 to December 19. When the polls open for this year's election, go to **www.cnga.org**, sign in as a member, and click on Election 2015.

On December 1, an email will be sent to all members with 1) directions to create your account if you have not done so already, and 2) access to election information and ballot.

If you have any questions or concerns please email admin@cnga.org or call 530.297.0500.

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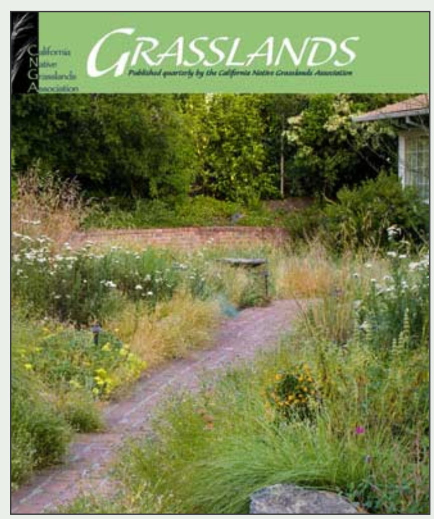

Weather Variations *continued*

important than the annual total (Pitt and Heady 1978, George et al. 2001, Reever Morghan et al. 2007). This is because most rainfall occurs during the winter, when temperature and daylight, not moisture, are limiting plant growth. Thus, additional rain during the winter has little impact on vegetation composition and growth (reviewed in Eviner in press). However, rainfall amounts in the fall and spring can have strong effects on plant growth and community structure. Plant production can vary as much as five-fold across years at a given site. Fluctuating dominance of grasses vs. forbs vs. legumes has been frequently observed across years in California's grasslands and has been attributed to variations in weather conditions (Pitt and Heady 1978, Keeler-Wolf et al. 2007). Some generalized findings include the following (reviewed in Eviner in press):

1. Plant production tends to be highest in years with high and steady rainfall during November–February, especially when temperatures are high during this period (Pitt and Heady 1978, George et al. 2001). However, this generalization does not always hold; even in long-term data sets, the timing and total amount of precipitation do not always correlate with production (Pitt 1975, Duncan and Woodmansee 1975), and different sites respond uniquely to the timing of rainfall. Sites in northern California's Coastal Range and foothills have their highest plant production when the fall and winter are warm and wet. In contrast, a drier southern California site has its highest plant production in years with higher spring precipitation (George et al. 2001).

2. High precipitation, with warm temperatures in the fall, tends to favor annual grasses. Annual grasses (e.g., wild oats [*Avena* sp.], bromes [*Bromus* sp.]) have adapted to germinate rapidly once their seeds have been exposed to 1.5 cm of rain within a week, leaving little-to-no seeds of the annual grasses in the seedbank. In these warm, moist conditions, annual grasses grow rapidly and crowd out other seedlings, so that plants that germinate even a few days later are unlikely to survive the competitive conditions (Chiariello 1989, Young and Evans 1989, Bartolome et al. 2007). If precipitation continues throughout the fall, annual grasses dominate the vegetation throughout the growing season.

3. Fall rains followed by a prolonged fall or early-winter drought tend to favor forbs and legumes. A significant germinating rain event, followed by prolonged lack of precipitation in the fall, can lead to mortality of the grass seedlings. When rains begin again, very few annual grass seeds remain in the seedbank, and thus the grassland community is composed of plants that can survive the fall drought (e.g., filaree [*Erodium* sp.]), or plants that germinate from the remaining seedbank, mostly forbs and legumes (e.g., poppies [*Eschscholzia* sp.], lupines [*Lupinus* sp.]) (Fig.1). The forbs and legumes in the seedbank have evolved so that seeds remain dormant until they encounter low competitive conditions (Young and Evans 1989, Bartolome et al. 2007, Keeler-Wolf et al. 2007). This is often why species like filaree, poppies, and lupines are common in disturbed areas such as newly eroded slopes, recently burned areas, or gopher mounds.

4. Prolonged mid-winter drought tends to favor forbs, clovers, and perennial grasses. While December and January are typically assumed to be part of California's rainy season, they experience an average of 19 consecutive days without rain (since 1950, the range has been from 8 to 53 days without rain) (Reever Morghan et al. 2007

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Definitions:

Forbs are broad-leafed herbaceous flowering plants that are not grasses or grass-like. In California's grasslands, these include most wildflowers as well as common exotic species such as filaree.

Legumes are a special type of forb that associates with bacteria to fix nitrogen from the atmosphere. In California's grasslands, these include species such as lupines and clovers.

Resilience is the capacity of a species or system to recover after disturbance.

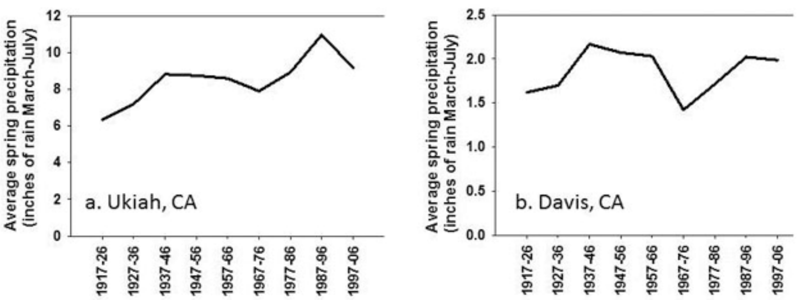

Figure 2. Changes in average spring precipitation (March–July) based on CIMIS weather station data accessed in July 2010. Note the different precipitation scales on the two graphs. **a. Ukiah, California**, has seen an average increase in spring precipitation of 2.3 inches since 1936, a 33% increase. **b. Davis, California**, has seen an average increase in spring precipitation of 0.26 inches, a 15% increase. This site had an average decrease in precipitation from 1966–1985. Excluding those two decades, spring precipitation has increased by 26% (0.4 inches).

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updated with California Irrigation Management Information System (CIMIS) weather station data, accessed August 2014)). When mid-winter droughts follow a relatively wet fall, this tends to favor species with high root investment, such as a number of forbs as well as perennial grasses. Winter and early spring droughts also tend to favor clovers (Corbin et al. 2007).

5. The effects of spring rains vary depending on plant community composition. Effects of late spring rains are variable, depending largely on which species are already established and able to respond to the later rains. The range of responses includes: increased perennials, increased non-natives, increased abundance and diversity of forbs, and increased diversity of grasses (reviewed in Eviner in press). Most of the annual grasses that dominate California's grasslands (e.g., wild oats, bromes) are hard-wired to senesce by early summer, even in the presence of ample moisture (Chiariello 1989). Similar patterns are seen in early flowering forbs (e.g., filaree, lupine, poppies). So while production can increase due to early spring rains (e.g., March, early April), there is little shift in vegetation composition in communities dominated by species that senesce in early- to mid-spring (Pitt and Heady 1978), and there is no impact of late-season rains on production (Pitt and Heady 1978, Reever Morghan et al. 2007). However, when communities contain late-season species that can remain active into the summer (e.g., native late-season forbs such as tarweeds [*Centromadia* sp.], perennial grasses or exotics such as yellow starthistle [*Centaurea solstitialis*], medusahead [*Elymus caput-medusae*], and goatgrass [*Aegilops triuncialis*]), spring rains can greatly increase the prevalence of these later season species and enhance total plant production (Chiariello 1989). In fact, the spread of late-season noxious weeds, such as goatgrass, medusahead, and yellow starthistle, may be due to increases in late-season rains. Compared with the time period of 1917–1936, since 1937 northern California has experienced a 15–33% increase in spring rainfall (March–July) (Fig. 2).

How do these generalizations relate to site-to-site variation in response to this past season's drought? The generalizations presented above are broad patterns, and one must keep in mind that the moisture available to plants is not only due to rainfall, but also due to soil (its ability to infiltrate and then store water), aspect (with drier conditions on south-facing slopes, which are more exposed to direct sunlight), topography (whether on a slope that drains vs. in a valley that collects water), and management (e.g., mulching, grazing, fire, mowing, all of which can affect the amount of water in the soil). Also, there can be strong local variations in precipitation events. Thus, while the generalizations discussed above can be a helpful first step in predicting how vegetation will respond to variable weather, it is common to see site-by-site variations (Jackson and Bartolome 2002). For example, in this past year, the following three vegetation patterns were common across various sites in northern California:

- Annual grasses germinate in the fall, survive in stunted form through the winter, and grow rapidly in response to February rains (thus little change in species composition compared with other years).
- Annual grasses germinate early in the fall, most die in the drought, and they are replaced by high cover of forbs and legumes after the rains in February.
- Little germination of any vegetation in the fall. Established perennial grasses persist through the drought, but annual grasses germinate and flourish with February–March rains.

How is weather expected to change California's grasslands in the future?

Understanding how the climate of California's grasslands is changing now and is expected to change in the future will be critical for guiding vegetation management goals. Are there certain types of native plants that are more suitable for withstanding new climate conditions? Are there certain exotic plants that will become more prevalent and harder to control due to changing climatic conditions favoring them?

For this century, models predict temperature rises of 3–5°F if we can greatly curb greenhouse gas emissions and 7–10°F if emissions remain high (Dukes and Shaw 2007, Cayan et al. 2008). Warming will be more intense inland than on the coast (Pierce et al. 2013). Summer temperatures will become markedly hotter. By the year 2060, a modestly cool July will be the same temperature as our hottest July temperatures to date. Mean temperatures in the winter will also increase, but the coolest days will be as cool or cooler than they are now (Pierce et al. 2013). Warming in the winter is expected to increase production and accelerate flowering and senescence of many species (Dukes and Shaw 2007), but cooler days may make plants more susceptible to frost kill. Total annual precipitation will only change slightly, but there will be significant shifts in the timing of that precipitation. For example, in northern California, winters

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will be 1–10% wetter, but times of peak plant growth will be drier, with spring precipitation decreasing 11–18% and fall precipitation decreasing 3–8% (Pierce et al. 2013). Southern California is also likely to have drier springs and falls, but unlike northern California, its winters will also be drier (1–5%) and its summers will be wetter (46–59%) due to monsoons (Pierce et al. 2013). While projections of precipitation changes are mixed (Dukes and Shaw 2007), all precipitation predictions agree that there will be increased variability in precipitation across years, with increased frequency of El Niño events and a projected 1.5–2.5-fold increase in drought frequency (Dukes and Shaw 2007, Reever Morghan et al. 2007). In addition, extreme rain events are likely to increase in frequency and magnitude, with a 10–50% increase in large three-day rain events by 2060 (Pierce et al. 2013).

As described above, the effects of shifts in precipitation on California grasslands will largely depend on the timing of rainfall. It is likely that late-season El Niño rains will favor late-season invasive species such as goatgrass, medusa head, and yellow starthistle, but these species will likely decrease overall due to most springs being drier. While species composition within grasslands is likely to change, the larger change may be in the persistence of grasslands. Warmer and drier conditions are expected to increase shrubland areas at the expense of grasslands, resulting in a 14–58% decrease in forage production by the late twenty-first century (CCCC 2009). However, other climate scenarios predict an increase in the extent of grasslands at the expense of woody vegetation, as increased temperatures and increased frequency of droughts significantly enhance the frequency, intensity, and extent of fires, which woody species cannot tolerate (Dukes and Shaw 2007).

Implications for management

While variation in precipitation across sites and years presents a management challenge, it may also present some management opportunities. What is presented here is a current "best guess" based on the information reviewed above and preliminary results from ongoing studies.

1. Once native perennial grasses are established, they are likely to persist through high variations in rainfall across years. Monitoring of restoration projects and experiments have shown that while well-established perennial grasses may be "hidden" amidst exotic annuals for many years, they persist and can be particularly visible during drought years. In years with high late-spring rainfall, most perennial grasses can grow later into the summer. Their growth can also increase in the autumn after a late rainfall year, as they begin to grow before the first fall rains (relying on deep soil moisture reserves that remain through the hot, dry summers). The resilience of native perennial grasses is good news for restoration, but the big challenge is understanding how to best establish native grasses under such variable conditions.

2. Native perennial grasses may limit increases of late-season invaders (e.g., goatgrass, medusa head) in years with late-season rains. While goatgrass and medusa head are likely to outcompete young native grasses, established perennials can suppress some of the increase of these noxious weeds in response to late-season rains (V. Eviner, K. Rice, and C. Malmstrom in preparation). Years with dry springs will generally lead to poor seed production by the noxious late-season weeds and will be a good time to focus efforts on eradication of these invasives.

3. Forbs and legumes can be critical for maintaining vegetation cover and production during years that are detrimental to annual grasses. As reviewed above, the strategy of many forbs and legumes is to remain dormant in the seed bank until they are relatively free of competition from grasses. This makes them critical for maintaining grassland production and cover (and thus erosion control, water infiltration, etc.) when grasses do not establish in the following scenarios:

- Disturbed sites (e.g., road cuts, eroded areas, burned sites)
- The year following a spring with failed seed production by grasses (e.g., due to fires, grazing, mowing, etc.)
- Years when the annual grass populations die due to extended drought in the fall and early winter

Because forbs and legumes have evolved to remain dormant as seeds until competitive pressures are low, it is biologically improbable to have consistently high forb and legume cover across years, unless grasses are frequently removed by intense livestock grazing, mowing, or burning (D'Antonio et al. 2006). Undisturbed sites with consistently high forb and legume cover often are associated with soil conditions that restrict grasses (e.g., serpentine soils, vernal pools) (Kruckeberg 2006). When restoring native forbs in California's grasslands, it is important to gauge restoration success by the occasional prevalence of these species and to expect little-to-no cover in other years.

Improving management recommendations

It is important to remember that these are working hypotheses. Even if further research supports these generalizations, we expect strong site differences in the effects of a given management practice. Sites will also likely differ in which management practice is most effective for a given vegetation goal. This site dependence will always be strong due to California's diverse soils, topography, microclimates, vegetation, and land management techniques.

To improve our understanding of how to restore natives and control exotics across sites and years, it is critical to synthesize across hundreds to thousands of case studies. A team of UC Davis researchers is developing a management database to do precisely this. For more information, see the Winter 2013 *Grasslands* issue, or contact Valerie Eviner: veviner@ucdavis.edu. We are actively seeking collaboration with managers and scientists who are willing to contribute case studies or research studies.

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