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Association

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Mission Statement

The mission of the California Native Grasslands Association is to promote, preserve, and restore the diversity of California's native grasses and grassland ecosystems through education, advocacy, research, and stewardship.

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From the President's Keyboard

CNGA Workshop Responds to Drought *by Jon O'Brien, President*

I got almost half an inch of rain in my gauge in Sacramento during the last week of September. A good start for what we hope will be a wet winter!

We devoted the spring issue of *Grasslands* to the drought and the many implications for land management and water use, and in the "President's Keyboard," I discussed ways to conserve water by reducing irrigation and planting low-water-use plants. In response to the drought, CNGA organized a workshop titled "Convert Your Water-Hungry Lawn to a Drought-Tolerant Landscape" that took place on September 18 at UC Davis. It focused on reducing water use in the landscape and was intended for homeowners, landscape managers, designers, and maintenance staff. We received much positive feedback for this workshop, and it sold out at 120 attendees with over 30 people on the waiting list.

Many players contributed to the success of this workshop, and all deserve a huge thanks:

Presenters and Instructors: Chuck Ingels from UC Cooperative Extension, Ellen Zagary and Stacy Parker from UC Davis Arboretum, Andrew Fulks from UC Davis Putah Creek Riparian Reserve and Campus Naturalized Landscapes, Matt Forrest from UC Davis Grounds and Landscape Services, and Jodie Sheffield from Delta Bluegrass.

Keynote Speaker: John Greenlee (author, expert in grass ecology, and champion of sustainable design) gave an extremely informative address and brought many grass specimens for viewing.

Workshop Development: In about 7 weeks' time, CNGA Administrative Director Rebecca Green and CNGA Administrative Assistant Kristin Anicito took a basic workshop concept and transformed it into a first-class educational experience for a large audience.

Sponsors: Delta Bluegrass Company and Cornflower Farms helped sponsor the workshop and hosted tables at the event.

Major Funding: California Department of Water Resources (DWR) provided major funding for this workshop. CNGA hopes to continue working with DWR in developing and executing lawn conversion workshops around the state.

2015: A Big Year for Workshops!

Look for these and other great workshops:

CNGA Field Day at Hedgerow Farms

Introduction to Grass Taxonomy and Identification

Pesticide Safety Training and Herbicide Use in Grassland Restoration Projects

Hands-on Restoration and Revegetation

Conservation Photography

Using Technology in the Field

California's New Front Yard: Creating a Low-Water Landscape

Dates and locations to be determined. CNGA will notify members by Grass-blast emails. You can also keep an eye on our website **www.CNGA.org** for more information.

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

by Valerie Eviner[1], Associate Professor, Department of Plant Sciences, UC Davis

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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[1]Valerie Eviner is Associate Professor of Ecosystem Management and Restoration. Her research focuses on how plant species, environmental conditions, and management practices interact to determine plant community composition, ecosystem function, and the resilience of these in response to shifting environmental conditions.

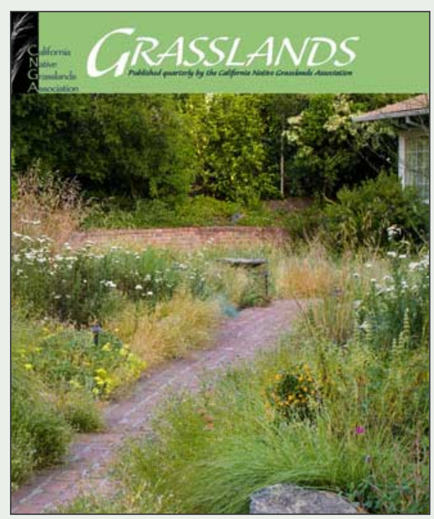
CNGA Board Election for 2015

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.

In this issue



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.

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.

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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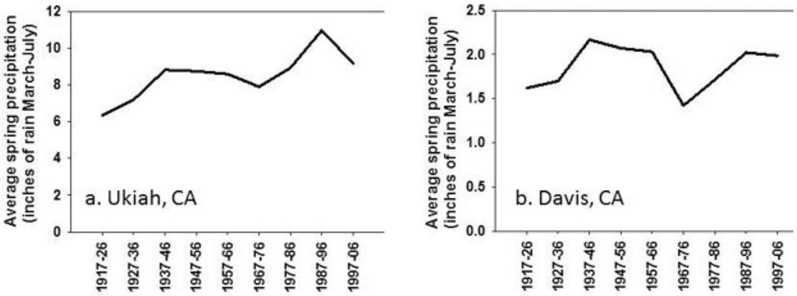

Figure 2. Changes in average spring precipitation (March–July) based on CIMIS weather station data accessed in July 2010. Note the different precipitation scales on the two graphs. **a. Ukiah, California**, has seen an average increase in spring precipitation of 2.3 inches since 1936, a 33% increase. **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).

Weather Variations *continued*

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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Left: Workshop participants tour the UC Davis Arboretum. *Right:* John Greenlee delivers keynote address. *Photos: Melissa Cruz*

NOTES FROM THE FIELD:

CNGA Workshop on Water Conservation in the Landscape

by Andrew Fulks, Assistant Director, UC Davis Arboretum and Public Garden

CNGA held the workshop "California's New Front Yard: Creating a Low-Water Landscape" at the Mondavi Center on the UC Davis Campus on September 18, 2014. The California Department of Water Resources (DWR) funded the workshop to provide information, resources, and inspiration for lowering water use in the landscape. The workshop was split into two sections: a morning classroom session and an afternoon walking tour. The workshop had 130 participants and 30 people on the waiting list, which shows the demand for water conservation information during the current drought.

CNGA Vice-President Andrew Fulks served as the master of ceremonies, giving an introductory talk that showed some successful and not-so-successful residential and municipal lawn conversions. Speakers from the UC Davis Arboretum and Public Garden covered lawn removal techniques, native and drought-tolerant plant selection, as well as irrigation alternatives, design, and conversion from overhead spray to drip irrigation. Noted landscape designer and horticulturalist John Greenlee was the keynote speaker, delivering a challenge to all attendees to think beyond traditional landscape design and integrate design with natural processes to create the new American meadow.

Workshop participants take a walking tour at UC Davis Mondavi Center to learn about lawn alternatives. *Photo: Melissa Cruz*

For the afternoon walking tour, attendees visited no-mow lawn alternatives at the Mondavi Institute, which showcases a turf space that is occasionally used and has 30–40% less water demand. A visit to the Law School landscape gave participants an idea of possibilities for a garden that uses a simple palette of native plants to create broad swaths of bunch grasses and valley oaks. This design uses less water and requires less maintenance than traditional turf. At the Mary Wattis Brown California Native Plant Garden, the tour showcased a more complex design, with over 1,400 native grasses, forbs, shrubs, and trees. The scale of this garden is more intimate and suitable as an example for homeowners with smaller yards. It is a great example of variety in the garden and a haven for wildlife. For the final stop of the tour, participants visited the California Central Valley Native Plant Garden. This garden features broad swaths of native grasses arranged in formal rows, which allows visitors to identify various native grasses easily because they are planted together in large groups.

We wish to give a huge thank you to DWR for underwriting the workshop, to our keynote speaker John Greenlee, and to workshop sponsors Delta Bluegrass and Cornflower Farms. Their support made the workshop memorable and educational as we work together to improve our environment and save water.

CNGA is working to hold this workshop in other parts of the state, so watch for announcements via email and on our website!

Weather Variations *continued*

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Constraints on Direct Seeding of Coastal Prairie Species: Lessons Learned for Restoration

by Karen D. Holl[1], Grey F. Hayes[2], Coral Brunet[3], Elizabeth A. Howard[4], Lewis K. Reed[5], Mickie Tang[6], and Michael C. Vasey[7]

Introduction

California coastal prairies have been adversely affected by agriculture, development, and changing disturbance regimes, and they are the focus of extensive restoration efforts given the high number of species of concern they host (Stromberg et al. 2001, Ford and Hayes 2007). Grassland restoration throughout California generally involves reducing exotic cover and reintroducing native species, given that many native grasses and forbs are absent from both the seed bank and standing vegetation community and dispersal is limited (Seabloom et al. 2003, DiVittorio et al. 2007, Stromberg et al. 2007). One frequently suggested and implemented strategy for reintroducing native propagules is seeding, as the associated costs are often less than planting seedlings (Moore et al. 2011). Some past studies in both interior and coastal California grasslands have suggested that seeded grasses can establish (Buisson et al. 2008) and outcompete exotics over a period of a few years (Kephart 2001, Seabloom et al. 2003, Stromberg et al. 2007). A much larger number of studies, however, suggests that establishment from seed is highly unpredictable (Dyer et al. 1996, Hamilton et al. 1999, Orrock et al. 2008, Hayes and Holl 2011, Seabloom 2011), which the authors attribute to variable rainfall, competition with exotic species, and seed predation.

Here, we summarize results from three studies in the vicinity of Santa Cruz, California, that tested seeding of native grass and forb species into weed-dominated coastal prairies combined with different management regimes designed to reduce exotic grass and forb cover. Our results show low rates of establishment for most species seeded into existing weedy coastal prairie, which suggests that this approach has limited utility for coastal prairie restoration. All study sites were located in coastal terrace prairies within 2 km of the ocean that were dominated by exotic grasses and forbs. Seeds were collected locally when possible or obtained from commercial suppliers of seed from the closest available source population. Seeding rates varied across studies based on seed availability, viability (percent pure live seed or germination), and size (fewer seeds of larger-seeded species), and all fell in the middle to high end of the range of seeding rates typically used for California grasslands (Stromberg et al. 2007).

Case Study 1

We seeded a number of grass and forb species as part of a study designed to test the effect of mowing on the balance between native and exotic vegetation (Hayes and Holl 2011). The study was conducted at three sites: UC Santa Cruz (UCSC) campus (36° 59' 5.5" N, 122° 3' 0.9" W), Swanton Pacific Ranch (37° 4' 13.4" N; 122° 15' 0.0" W), and land owned by the Elkhorn Slough Foundation (36° 52' 4.3" N, 121° 44' 23.8" W). All sites had sandy loam soils >1 m deep and slopes of <10°. All sites were likely lightly surface tilled (<5 cm) in the early 1900s and grazed periodically between the 1950s and the start of the study. The sites were dominated by exotic grasses (primarily *Brachypodium distachyon, Bromus* spp., *Festuca myuros,* and *Festuca perenne*) and exotic forbs (largely *Erodium* spp., *Geranium dissectum, Plantago lanceolata,* and *Trifolium* spp.). See Hayes and Holl (2011) for a detailed description of site conditions and species composition.

We manually broadcasted seeds in nine 3 × 3 m plots at Swanton and UCSC without removing the existing vegetation cover or taking any additional management actions (e.g., raking in seeds or providing supplemental watering). In fall 2003, we seeded 500 seeds m^{-2} of each of five species: *Danthonia californica* and *Stipa pulchra* (native perennial grasses), *Castilleja exserta* spp. *exserta* and *Gilia capitata* (native annual forbs), and *Sisyrinchium bellum* (native perennial forb). In fall 2004, we reseeded the same species, as well as *Calandrinia ciliata, Eschscholzia californica,* and *Lupinus nanus* (native forbs), at a density of 500 seeds m^{-2} per species. Since most species seeded in 2003 and 2004 had very low or no establishment, we tried again to enhance species richness in these plots by seeding five annual and one perennial (*Achillea millefolium*) forb species in fall 2009 and 2010 at one to three sites (Table 1); some species were not seeded at all sites due to the presence of existing populations of the species or limited seed. We recorded the number and cover of seedlings beginning the spring following seeding through spring 2012 for all species. We also conducted greenhouse germination tests for seeds used in 2009 and 2010 to assess viability.

We recorded no establishment of seedlings in the first growing season following the 2003 seeding, during which annual rainfall was

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Table 1. Seeding and germination rates in the greenhouse and field for forb seedlings in fall 2009 and 2010 in Case Study 1. All species are annuals except *A. millefolium*. Values are means ± 1 SE. Seedling density in the field is reported for the growing season after seeding (either spring 2010 or 2011) and spring 2012.

Species	Year Seeded	No. of sites	Seeds m^{-2}	Greenhouse germination (%)	Seedlings m^{-2} in spring following seeding	% yield	Seedlings m^{-2} in spring 2012
Achillea millefolium	2009	2	65	66.0 ± 4.9	0	0	0
Clarkia davyi	2010	3	700	26.8 ± 8.4	1.7 ± 0.7	0.1	0.6 ± 0.3
Deinandra corymbosa	2009	1	245	33.3 ± 0.6	0	0	0
	2010	1	60	11.0 ± 6.4	0	0	0
Madia sativa	2009	1	75	30.5 ± 0.7	1.8 ± 1.2	2.4	1 seedling*
Navarretia squarrosa	2009	2	500	81.8 ± 8.4	0.3 ± 0.3	<0.1	1 seedling*
Trifolium willdenovii	2009	3	200	no data	0	0	0
	2010	3	500	49.2 ± 8.1	0	0	0
TOTAL	2009		585				
	2010		1260				

*Only 1 seedling was observed in all the quadrats surveyed.

Direct Seeding *continued*

close to average (Hayes and Holl 2011). Two species (*Stipa pulchra* and *Sisyrinchium bellum*) had higher cover in seeded vs. non-seeded plots at one or both of the sites 2–4 years following the 2004 seeding, during which rainfall was above average (Hayes and Holl 2011). Two species (*Eschscholzia californica* and *Gilia capitata*) had higher establishment in seeded plots in the first growing season, but not thereafter. The remaining four species showed little (<4 seedlings total at all sites) or no establishment in seeded plots. There was no difference in exotic species composition in seeded vs. unseeded plots, and inter-annual variation in vegetation composition is described in detail in Hayes and Holl (2011). In 2012 (7.5 years after seeding), both *Stipa pulchra* and *Sisyrinchium bellum* cover remained higher in seeded vs. unseeded plots (*Stipa*—seeded: 11.4 ± 2.5%, unseeded: 1.9 ± 2.5, F = 11.0, p = 0.0022; *Sisyrinchium*—seeded: 2.2 ± 0.7%, unseeded: 0.0 ± 0.0, F = 7.4, p = 0.0107, Fig. 1), which shows that these two species were able to establish successfully from seed.

Of the six species seeded in 2009 and 2010, only half established in the field experiments (Table 1) and only one (*Madia sativa*) had a yield rate (number of seedlings per number of seeds) of >0.1%. Viability was not likely to be the limiting factor in this case, as 11–82% of the seeds germinated in the greenhouse (Table 1). Rainfall was below average in fall 2009, whereas rainfall was well above average throughout the 2010–2011 growing season.

Figure 1. UCSC experimental plots from Case Study 1. Note *Stipa pulchra*, one of the few species that established from seed. *Photo: Lewis Reed*

Case Study 2

In a second study, we either used controlled burns (conducted in late September 2007 using a burn box) to reduce above-ground vegetation or scraped off the top 5 cm of soil to reduce competition by removing vegetation and the exotic annual forb and grass seed bank (Buisson et al. 2006), as well as to create optimal habitat for recruitment of the endangered Ohlone tiger beetle (*Cicindela ohlone*). Each treatment was replicated in two blocks of ten 2 × 2 m plots in two different areas of coastal prairie with sandy loam soils on the UCSC campus (n = 40 per treatment). Vegetation prior to treatments and in control plots consisted of a dense cover (~90%) of exotic grasses (primarily *Avena barbata, Briza maxima, Bromus hordaceous,* and *Festuca myuros*) and forbs (mostly *Medicago polymorpha, Plantago lanceolata,* and *Erodium botrys*). Native perennial grasses and forbs made up ~10% of the cover and consisted of species such as *Danthonia californica, Ranunculus californicus, Stipa pulchra, Chlorogalum pomeridianum, Eschscholzia californica,* and *Sisyrinchium bellum*. The plots were seeded at a rate of 1,150 seeds m^{-2} with seven native annual forbs in fall 2007 (Table 2) to try to enhance the diversity of this guild, and no supplemental water was provided. We monitored establishment of seeded species for the two subsequent growing seasons (spring 2008 and 2009). Seed viability was not tested in the greenhouse, so it is possible that low viability may have affected establishment.

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Table 2. Seeding rate and annual forb seedling density in scraped plots for the first growing season following seeding for Case Study 2. Values are means ± 1 SE.

Species	Seeds m^{-2}	Seedlings m^{-2}	% yield
Castilleja densiflora	113	0.0 ± 0.0	0.0
Clarkia rubicunda	465	1.9 ± 0.6	0.4
Lasthenia californica	276	1.2 ± 0.4	0.4
Layia platyglossa	41	0.7 ± 0.2	1.7
Lepidium nitidum	32	0.5 ± 0.2	1.4
Lupinus nanus	15	0.4 ± 0.2	2.5
Triphysaria eriantha	212	0.4 ± 0.1	0.2
TOTAL	1154	5.0 ± 1.2	0.4

One individual of *Lasthenia californica* was the only seedling from seeded species observed in burned plots in the first growing season when annual rainfall was close to average, and no seeded individuals were observed in burned plots in the second growing season. Only a few individuals of six of the seven species were observed in scraped plots in the first growing season (Table 2), despite the fact that scraping substantially reduced exotic cover and increased bare ground in scraped plots (46.5 ± 2.4%), as compared with burn (9.4 ± 0.9%). By the second growing season, there were only a few individuals of *Layia platyglossa, Lasthenia californica,* and *Lupinus nanus* in some scraped plots, at which time approximately half of these plots were still ~25% bare of vegetation.

Case Study 3

The third study was conducted in a weedy, moist, formerly coastal prairie site that had been used for several decades for agriculture and then had been abandoned for over 20 years at the UC Younger Lagoon Reserve located in Santa Cruz, California (+36° 57' 00.75", -122° 03' 47.80"). At the time of the study site initiation, it was covered by nearly 100% exotic species, dominated by exotic grasses (primarily *Festuca perenne* and *Bromus diandrus*) and exotic forbs (such as *Raphanus sativus, Medicago polymorpha,* and *Helminthotheca echioides*). In summer 2011, plots were mowed to reduce the cover of standing thatch and fenced to minimize herbivory from rabbits. During October 2011 following the first rain and emergence of annual weeds, the site was treated with a broad-spectrum herbicide (2.5% glyphosate). Immediately prior to seeding in November 2011, any exotic regrowth was treated with herbicide and then the thatch was raked off the plots. In five 10 × 10 m plots, we seeded each of eight coastal prairie grasses and forbs (Table 3) into a single, 10-m long row consisting of two hand-cut furrows. Seeds were hand-buried to a depth of 7–10 mm to simulate drill seeding and manually tamped to improve seed–soil contact. Given the small size of the plots, a regular drill seeder was not used. Due to unusually dry conditions, the plots received supplementary water in December to help ensure germination and survival of germinated seedlings. We planted the same species as plugs in rows in five additional 10 × 10 m plots in January 2012. In April–May 2012 and 2013, each seeded row was surveyed for planted seedlings, and plant survival was recorded in planted plots. We also conducted greenhouse germination studies to assess seed viability.

In the greenhouse, most species had germination rates >50%; however, *Symphyotrichum chilense* and *Juncus patens* had very low germination (Table 3). Two forb species, *Trifolium willdenovii* and *S. chilense*, were not observed in the field during the first year. For the remaining three forb species (*Achillea millefolium, Clarkia davyi,* and *Grindelia stricta*), percent yield (seedlings/live seed planted ×100) was 1–2% in Year 1 (Table 3), but no individuals of the two perennial species survived until the second year. In the field, the grasses and one rush species planted could not be distinguished from the large number of exotic grass seedlings (Fig. 2) and, therefore, were not quantified; but even by the second year we did not record identifiable individuals of those species, and the sites retained a dense cover of the exotic grasses and forbs present prior to the initiation of the experiment. As a comparison, 72% of planted plugs survived in Year 1 and 40% in Year 2, ranging in survival from 64% for *Hordeum brachyantherum* to 13% for *S. chilense* in Year 2 (Tang 2013).

Figure 2. Recently germinated *Clarkia davyi* seedling underneath dense exotic grass cover at Younger Lagoon Reserve (Case Study 3). *Photo: Lewis Reed*

Discussion and Conclusions

The results of the three case studies presented, as well as Buisson et al. (2006), show extremely low establishment rates in coastal prairie from seed with yields of 1–2% at best in the first year and numbers

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Table 3. Seeding and germination rates in the greenhouse and the first year in the field for Case Study 3.* Values are means ± 1 SE. Note that units of germination in the field are per meter of drill-seeded row.

Species	Growth form	Seeds m^{-2}	Greenhouse germination (%)	Mean ± seedlings m^{-1}	SE % yield
Clarkia davyi	Annual forb	135	50 ± 4.5	3.0 ± 1.1	2.1
Trifolium willdenovii	Annual forb	90	36 ± 4.9	0	0
Symphyotrichum chilense	Perennial forb	180	10 ± 0.4	0	0
Achillea millefolium	Perennial forb	180	76 ± 4.7	2.6 ± 0.7	1.4
Grindelia stricta	Perennial forb	135	85 ± 2.4	1.7 ± 0.6	1.2
Bromus carinatus	Perennial grass	135	61 ± 3.7	no data	
Hordeum brachyantherum	Perennial grass	135	65 ± 2.7	no data	
Stipa pulchra	Perennial grass	135	46 ± 3.8	no data	
Juncus patens	Perennial sedge	180	<2	no data	
TOTAL		1305			

*It was impossible to reliably identify recently germinated native grass and rush seedlings in the field from the huge number of recently germinated exotic grass seedlings; no native grass and rush seedlings were observed in larger size classes.

Direct Seeding *continued*

declining in subsequent years. Of the many species we seeded, only *Stipa pulchra* and *Sisyrinchium bellum* established populations (and only at one site) that were observed in any abundance after the first 2 years. We reiterate, however, that we were unable to reliably identify native grass seedlings in the third Case Study, and some seed may have germinated after the second year of Case Studies 2 and 3. There are several reasons for such low yield rates: highly variable rainfall typical of California, which often results in seedling desiccation (Hamilton et al. 1999, DeFalco et al. 2012); competition with abundant exotic grasses, the seeds of which often outnumber and germinate before natives (DiVittorio et al. 2007, Abraham et al. 2009, Wainwright et al. 2012); and high levels of herbivory (Orrock et al. 2008, Maze 2009, DeFalco et al. 2012). These factors also present challenges to restoring coastal prairies by planting seedlings, but outplanting larger seedlings overcomes losses due to seed predation, failed germination, and mortality of recently germinated seedlings, which are typically quite high (Clark et al. 2007, James et al. 2011).

We note that results of direct seed-sowing may be more favorable when seeds are 1) drill seeded into recently abandoned agricultural lands where weeds have been controlled for many years, thereby reducing the exotic seed bank and competition, and/or 2) extensive exotic control measures are undertaken after seeding (Lulow 2008, Nyamai et al. 2011, Watsonville Wetland Watch 2013). Typically, efforts to improve seed–soil contact, such as drill seeding, tamping, or using a heavy roller, improve establishment from seed (Rotundo and Aguiar 2005, Desimone 2011, DeFalco et al. 2012). The low establishment from our simulated drill seeding likely resulted from a low rainfall year combined with high cover of exotic grasses (particularly *Festuca perennis*), although it is important to note that we found low establishment from seed in years that annual rainfall spanned from below to well above the average.

One important consideration is the relative cost of seeding vs. other revegetation methods. Typically, seeding is much less expensive than planting seedlings, due to nursery propagation and outplanting costs for seedlings (Moore et al. 2011). Relative costs, however, vary greatly depending on 1) whether seed is purchased from a seed supplier with propagation fields or locally hand collected, 2) germination rates, and 3) labor costs, particularly if volunteer labor is available for small restoration planting efforts. For example, in our third Case Study, the contract for collecting and processing seed was double that for producing plugs for a similar area of land, and the project had substantial volunteer labor support to reduce the cost of planting plugs. Moreover, plug planting resulted in much higher cover of native grasses and forbs than did seeding (Tang 2013).

In summary, our results from multiple studies demonstrate that sowing seeds into weed-dominated coastal prairies, where exotic plant competition is high and rainfall is unpredictable, is likely to have a low success rate. Further research on the prospective value of direct seeding in coastal prairies should focus on pre-planting site preparation and post-planting weed control, which ameliorates exotic plant competition and methods for overcoming drought stress during initial years of establishment.

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GETTING TO KNOW GRASSLAND RESEARCHERS: Meghan Skaer Thomason[1]

by Sheri Spiegal, CNGA Board Member

Land managers, producers, restoration practitioners, and scientists are working together to preserve and restore grasslands across California. Scientists are seeking to provide information that can support the achievement of conservation goals, and communication with people on the ground is critical to keeping their research relevant and useful. In this new feature of *Grasslands*, "Getting to Know Grassland Researchers," we will introduce the people who work toward grassland conservation using a scientific approach. Our first researcher in this feature is CNGA board member and UC Davis doctoral candidate Meghan J. Skaer Thomason.

Figure 1: Meghan Skaer Thomason in her natural habitat—on hands and knees in a grassland. Here, she works on understanding how a decrease in rainfall might alter the success of invasive, non-native species in grasslands with the use of "rain shelters." *Photo: Hopland Research and Extension Center, Mendocino County*

What is your study system? What are your primary research goals?

I work primarily in annual grasslands that are invaded by non-native species, and I am trying to gain a better understanding of what makes the non-native invasives so successful currently and in the future as the climate changes. I am especially interested in two more-recent invaders, barbed goatgrass (*Aegilops triuncialis*) and medusahead *(Elymus caput-medusae* or *Taeniatherum caput-medusae*). These two species have increased in abundance and range in California over the last 50–75 years, and they tend to spread in dense patches rather than mix in with other plants. This is particularly surprising because usually plants of the same species do not grow densely near each other. If you and your neighbor were using the same fork and knife to eat off the same dinner plate, would you be happy? Probably not. Plants are the same way. When their neighbors use the same strategy to acquire the same resources at the same time, the level of competition is very high. So, the driving question in my doctoral research is: Why do these new invasive grasses want to be so close together (i.e., eating off the same dinner plate)? Early results from my research suggest that they actually benefit from this strategy. I am still working on the "how" of this question.

Who is your audience?

Land managers, conservationists, restoration practitioners, and ranchers can all benefit from my research about the interactions between native and non-native, invasive plants in grasslands.

Who has inspired you, including your mentors?

One of my first inspiring mentors was my high school biology teacher, Roger "Rog" McGeehee, who had a contagious enthusiasm for plants. I also had some excellent mentors when I interned with the "Rare Plant Team" at Point Reyes National Seashore, including Michelle Coppoletta and Shelly Benson, who gave me a lot of encouragement.

How does your research promote CNGA's mission "to promote, preserve, and restore the diversity of California's native grasses and grassland ecosystems through education, advocacy, research, and stewardship"?

Through my research, I hope to provide a better understanding of the ecology of non-native, invasive plants and therefore help develop better control strategies, which will lead to better management of grassland ecosystems.

Why do you love grasslands?

My parents played a major role in developing my love of grasslands. My earliest memories are of hiking and picnicking in the meadows of Mt. Tamalpais in Marin County. From a distance, I love the way grasses blow in the wind, with the appearance of crushed velvet. Up close, I love how many individual plants can be found in such small spaces and how they each contribute to the greater whole.

[1]Meghan J. Skaer Thomason, M.S., is a Ph.D. candidate in the Graduate Group in Ecology, Department of Plant Sciences, UC Davis. Her academic adviser is Dr. Kevin Rice. She has been involved in grasslands research for 11 years.

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Front cover: Meadow garden with California native grasses and perennials. *Photo: Saxon Holt*

Back cover: Participants at the CNGA Water Conservation and Lawn Conversion workshop tour the UC Davis Arboretum and Native Grass Gardens. *Photo: Melissa Cruz*