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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

Dear CNGA Members,

With record-setting rainfall and snowfall, all lakes, reservoirs, and streams are full and most of California is finally out of the recent drought. However, it does not mean we should not keep working on our individual and collective efforts to convert water-hungry landscapes, like low-used turf areas, into native plant landscapes to save water and enhance the urban environment. Across the state, due to heavy rainfall, erosion has degraded the land in many areas. I urge everyone to use this opportunity to work towards revegetating those bare, damaged areas using native grasses to prevent future erosion issues while enhancing wildlife habitat. Some agencies like Caltrans have done this over the years in the Sierra Nevada and elsewhere and it looks fantastic while fulfilling erosion and sedimentation control efforts.

I am looking forward to another exciting year with our 10th Annual Field Day at Hedgerow and several great workshops on grass identification, grazing, restoration practices, and more.

Also, do not forget the Big Day of Giving coming on May 4th! We need your support to keep moving forward with our advocacy, outreach, and educational work.

Lastly, we want to hear from you! If you have any comments, feedback, journal contributions, or workshops you would like to see us lead, drop us a note! Follow us on Facebook @CANativegrassland and Twitter @CAGrasslands.

Looking forward to seeing many of you at the Hedgerow Farms Field Day on April 21st.

JP Marié, President

Big Day of Giving: Support California's Grasslands on May 4th

CNGA is joining hundreds of other local nonprofits on the Big Day of Giving — an opportunity for you to give to the organizations that make up this place you call "home."

With only 1% remaining, California's native grasslands are among the most endangered ecosystems in the U.S. There is only one organization that works solely toward conserving California's valuable native grasslands: CNGA.

Please consider making a donation to support CNGA and its programs on May 4th — anytime from midnight to midnight! For more information, go to **www.cnga.org** or search for California Native Grasslands Association at **www.bigdayofgiving.org**. You can also go to our page directly at: **www.bigdayofgiving.org/californianativegrasslandsassociation**.

Not around on May 4th? Schedule a pre-donation beginning April 14th!



Upcoming Workshops from CNGA

CNGA's 10th Annual CNGA Field Day at Hedgerow Farms

Essential Elements: Lessons from a Decade of Field Days

Friday, April 21, 2017, 8:45am–4:30pm * Hedgerow Farms, 21905 County Road 88, Winters

We are celebrating our 10th year of field days at Hedgerow Farms by bringing back some of our favorite experts from previous years to share pearls of grasslands wisdom as well as show us where grassland restoration is headed. Join us for this unique opportunity to network and gain practical, hands-on learning about California's spectacular native grasslands. The driving tour will be a new route in the Farm's back restoration area where we will see native plantings on ponds, canals, hillsides, and in a riparian zone. We will also be touring the demonstration garden which includes single species plots and a milkweed propagation trial.

\$75/CNGA members | \$90/Non-members | \$45/Students with ID

CNGA Grass Identification Workshop at Bodega Bay

Saturday, May 13, 2017 **SOLD OUT!**

CNGA Technology Workshop

Apps and Snaps: Smartphone, Camera, and Online Technology for Grassland Plant Mapping, Tracking, and Identification

Saturday July 15, 2017, 9am–4pm * Trudeau Conference Center, Redwood Regional Park, 11500 Skyline Blvd, Oakland, CA 94619

With the proliferation in technology comes an increased ability to collect, share, and manage data. This workshop will focus on using iNaturalist and Calflora apps, as well as tips for taking photos to aid in later identification or photomonitoring. Technology-based tools for plant ID will also be covered. We will spend the morning in the classroom, then use our gadgets in the field after lunch, returning to the classroom to go over data upload and editing. Some experience or comfort with technology is preferred but not essential; we will focus on basic, broadly useful tools but this is not meant to be an introductory course.

Registration to open soon.

Register online at

www.cnga.org

or contact Diana Jeffery

at **admin@cnga.org** or

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Look for more workshops and updates on our website:

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Grasslands Submission Guidelines

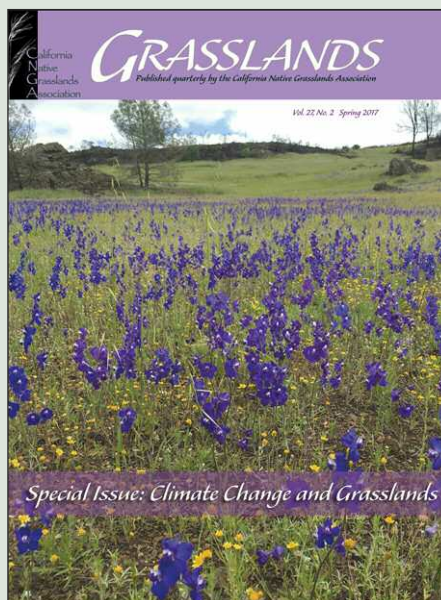
Send written submissions, as email attachments, to grasslands@cnga.org. All submissions are reviewed by the *Grasslands* Editorial Committee for suitability for publication. Contact the Editor, Kristina Wolf, for formatting specifications: grasslands@cnga.org.

Written submissions include peer-reviewed research reports and non-refereed articles, such as progress reports, observations, field notes, interviews, book reviews, and opinions.

Also considered for publication are high-resolution color photographs. For each issue, the Editorial Committee votes on photos that will be featured on our full-color covers. Send photo submissions (at least 300 dpi resolution), as email attachments, to Kristina Wolf at grasslands@cnga.org. Include a caption and credited photographer's name.

Submission deadlines for articles:

Summer 2017 — May 15, 2017 * **Fall 2017** — Aug 15, 2017 * **Winter 2018** — Nov 15, 2017 * **Spring 2018** — Feb 15, 2018



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SPECIES SPOTLIGHT:

Douglas' Meadowfoam (*Limnanthes douglasii*)

by Andrea Williams, CNGA Vice-President, photos courtesy the author

Douglas' meadowfoam is a spring-blooming annual wildflower comprised of at least five subspecies. The "classic," most widespread subspecies (*L. douglasii* ssp. *douglasii*) has yellow-centered, white-tipped flowers, giving rise to another common name "poached egg plant." Other subspecies include yellow-flowered *L. douglasii* ssp. *sulphurea*, and three white-flowered subspecies parsed by their petal vein and anther colors. Meadowfoams can be told from similarly yellow-centered, white-tipped tidytops (*Layia* sp.) by their highly dissected leaves and five heart-shaped petals.

While some subspecies are considered rare, the main subspecies of Douglas' meadowfoam is not uncommon. Found from south of the San Francisco Bay Area north to southern Oregon, it prefers wet meadows and tolerates grazing and clay soils. Douglas' meadowfoam can also be found in cultivation, where its tolerance of heavy soils and unattractiveness to slugs and snails (not to mention its profusion of showy flowers and ferny foliage) make it a star performer. Meadowfoam also attracts a variety of beneficial insects, including hoverflies and other pollinators, giving one even more reasons to add it to a garden's palette.

In 2016, as part of an effort to measure the health of Mt. Tamalpais in Marin, I compiled a list of species that had been extirpated (gone locally extinct) from the mountain. I was surprised at the number of species that had gone "missing" based on their having been previously collected but not seen within the past 50 years

(http://www.norcalbotanists.org/files/NCB_2017Poster_35_Williams.pdf). Another surprise was the number of grassland species on that list, especially those dependent on wet meadows—including Douglas' meadowfoam. Still a common sight just a few miles north and west, the species appears to be gone from previously collected locales on Mt. Tamalpais, in Mill Valley, and north of San Rafael. It may also be extirpated from the East Bay, although *L. douglasii* ssp. *rosea* is still present.



The quiet disappearance of a spectacular wildflower from several sites in the Bay Area is a matter of concern and cause for some speculation: is it a change in land use patterns—a lack of grazing and fire and a profusion of people—or is it a changing climate, or a response to invasive species; or perhaps more than one cause? Given that the species still occurs more coastally, and in ungrazed areas, Douglas' meadowfoam may be an example of a "climate refugee," although in this case populations are disappearing inland and remaining north and west in cooler spots. Climate projections vary in the predicted amount of rainfall, but both temperatures and variability are likely to increase (<http://climate.calcommons.org/crn/mmw>), resulting in plants "experiencing" more drought stress regardless of how much rain comes. So whatever future comes, it appears to be less hospitable to Douglas' meadowfoam.



California's Drier Future: *What Will it Mean for Grasslands?*

by Susan Harrison¹

Increased frequency and severity of drought are among the more predictable facets of California's climatic future. This prognosis arises from bioclimatic models that incorporate influences of temperature, precipitation, and seasonality on biologically relevant measures of water availability, such as the Palmer Drought Severity Index. In essence, these models say that rising temperatures will increase environmental water demand so much that soils will become drier in the growing season, and runoff into rivers and streams will diminish, under virtually any reasonable scenario for future precipitation (Cook et al. 2015, Thorne et al. 2015). Beyond this broad temperature-driven generalization, of course, there lies much uncertainty about the future amount, timing, and reliability of rainfall, with "increased variability" being one of the few fairly confident predictions. Nonetheless, it is reasonable to focus on drier average conditions and more extreme drought events when considering the future of Californian ecosystems.

Since the late 1990s, my lab and I have studied grassland diversity in a suite of 80 sites scattered about the remote and heterogeneous landscapes of the 2850-ha McLaughlin UC Natural Reserve (nrs.ucdavis.edu/mcl). Each site consists of five 1-m² quadrats spaced 10 m apart, within which we annually record visual cover by species. The original purpose was to compare the effects of livestock grazing on species diversity in the native-rich grasslands on serpentine soils and the more exotic-dominated grasslands on sedimentary soils at the site (Harrison 1999). But when nearly half the sites burned in a 1999 wildfire, the study was expanded to include fire effects on grassland diversity (Harrison et al. 2003). Then the study was extended to 10 years to determine whether dry years favor a special set of grassland species or just a nested subset of those

present in wetter years (Elmendorf and Harrison 2009). My students and I also used the growing dataset to examine other questions, including whether or not diversity is 'regulated' such that low-diversity years tend to be followed by increases in diversity and vice versa (Elmendorf and Harrison 2011); whether remote sites are best for restoration (Moore et al. 2011); and how serpentine and nonserpentine grasslands respond differently to yearly rainfall patterns (Fernandez-Going et al. 2012). We became reluctant to stop maintaining this increasingly valuable dataset.

In 2014 we were amazed to discover a long-term trend of diversity decline, on which we published a paper two years ago (Figure 1; Harrison et al. 2015); this trend continues today. Over the 15- (and now 17-) year period, there were declines in species richness and abundance at the 5-m² scale (one plot), as well as species richness at the landscape (i.e., all plots) scale, on both serpentine and nonserpentine soils. Native annual forbs showed the strongest diversity declines, but no functional group (native/exotic, annual/perennial, grass/forb) showed a significant increase in either diversity or cover. Diversity declines occurred on sites that burned in 1999 and those that did not burn, and on sites that were grazed by cattle until 2000 and those that were ungrazed since the early 1980s. The study area is remote from any atmospheric N deposition, and is too arid to be undergoing succession to woody vegetation. In other words, we could rule out all of the usual non-climatic explanations for diversity loss, including land-use change, disturbance, succession, pollution, and their effects on exotic species invasion.

Instead, our analyses led us to focus on climate, and specifically on drier conditions in winter (Dec–Mar; Figure 2). When we examined

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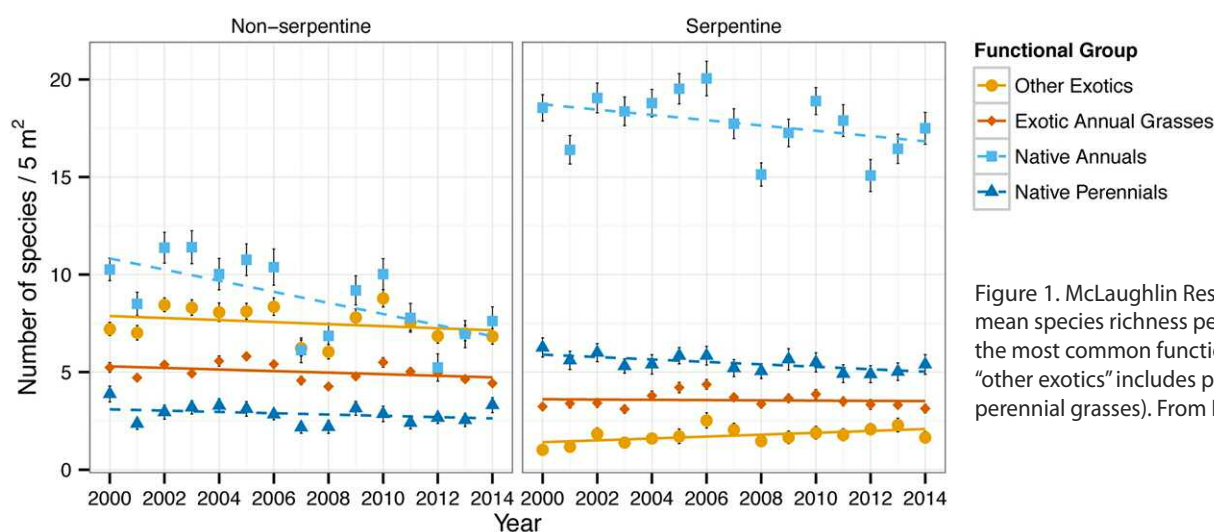


Figure 1. McLaughlin Reserve 80-site study; mean species richness per 5 m², 2000–2014, for the most common functional groups (note that "other exotics" includes perennial forbs and perennial grasses). From Harrison et al. (2015).

¹Susan Harrison is a Professor in the Dept. of Environmental Science and Policy at UC Davis. Research in the Harrison lab seeks to understand the processes that shape and maintain plant species diversity at the landscape scale, where small-scale forces such as competition and facilitation interact with large-scale forces such as niche evolution and dispersal. Much of their recent work focuses on the impacts of climatic drying on grassland community diversity.

California's Drier Future *continued*

the minimum, maximum, and means of temperature, in addition to rainfall, humidity, and cloud cover for each of the four seasons, we found just three significant trends over the 15-year period: 1) lower rainfall and 2) cloud cover in winter, and 3) lower humidity in winter and spring. These trends toward greater winter dryness were statistically linked to declining grassland species diversity, and also to another related trend: The selective loss of native annual forb species with a trait indicating low drought tolerance (specific leaf area, or leaf area divided by dry mass). These trends were just as strong in 2000–2008 as 2009–2016, so they are not just the result of the 2013–2014 drought. Drought-intolerant species “blink out” a little more often and “blink back in” a little less often over the years than do hardier species. We concluded that increasingly sunny, rainless conditions in midwinter (when annuals are present as tiny seedlings) have been preventing germination, causing seedlings to die, or both (Harrison et al. 2015).

Our current work focuses on understanding exactly how grassland diversity is linked to dry winter conditions, and in turn, how resilient we can expect diversity to be if wetter winter conditions return — as they seem to be doing this year. Have some native annual forb species been lost permanently from many sites over the past 15 years, or will they rebound readily from a dormant seedbank? At the same time, graduate student Marina LaForgia is taking a deeper look at how wetter or drier winters affect the competitive balance of native forbs and exotic annual grasses. We have set up 40 experimental plots on diverse soils that receive weekly watering from Dec–Mar to ensure

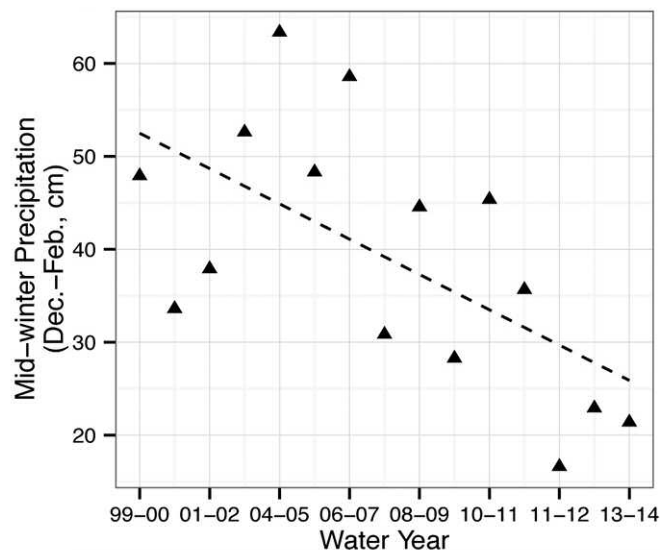


Figure 2. McLaughlin Reserve 80-site study; total winter (Dec-Feb) precipitation, 2000–2014. From Harrison et al. (2015).

the long-term average amount of rainfall is equaled or exceeded, as well as 40 unwatered control plots. We have also set up 10 plots that are covered by rain-out shelters from Dec–Mar and 10 unsheltered control (business as usual — no experimental manipulations) plots. Within these treatments, we have added seeds of various forb species, marked their seedlings with toothpicks, and removed (or not) their grass competitors. Early experimental results from 2015–2016 suggest that winter drought inhibits germination, elevates seedling mortality, and reduces the growth and final sizes of mature plants

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California's Drier Future *continued*

But we still don't know yet whether diversity can recover fully on its own when the climate is right, or whether seed supplementation will be required. We believe that in 2019, with 20 years of observational data and a five-year experiment, we will have a solid answer.

We are eager to see whether similar trends in climate and grassland diversity are affecting other sites in California, and UCSC graduate student Josie Lesage is gathering data to answer this question. We are also interested in exploring the implications of our results for grassland restoration, and specifically for whether it's time to consider a switch to more drought-tolerant forb species. Another area for future work is the ecosystem consequences of drought-driven grassland diversity loss; our experimental setup should allow us to disentangle how drought itself, versus drought plus diversity loss, affect such outcomes as soil microbial composition and nutrient cycling.

Amid the general grimness of rapid climate-induced changes in Californian ecosystems, my collaborators and I have also identified a few small optimistic notes. One is that the extreme, "500-year" drought of 2012–2014 seems to have had only one "extreme" effect on the plant communities we study: namely, a sharp if likely temporary decline in the cover of exotic annual grasses (Copeland et al. 2016). In spring 2014, after two full years of the drought, we resampled hundreds of sites from our previous studies across California and southern Oregon. We asked which plant community attributes showed changes that were both consistent across multiple studies, and extreme in the sense of exceeding the magnitude of pre-drought responses to varying water availability. Not only did exotic annual grasses show such an extreme response in their abundance above ground, but they also diminished steeply in the seedbank (Marina LaForgia, unpublished data). We conjecture that prolonged, severe droughts could possibly have some indirect benefits for native species if they drastically reduce the competitive effect of exotic grasses.

Finally, grasslands and other plant communities on serpentine and other highly infertile soils appear to be relatively insensitive to climatic variation, including both increases and decreases in water availability (reviewed in Damschen et al. 2012, Harrison et al. 2014). This surprising conclusion is good news because infertile soils often support an abundance of native, endemic, and rare species, with California's serpentine grasslands certainly being no exception (Harrison and Viers 2007). In a five-year watering and fertilization experiment, this 'climate-resistance' of serpentine grassland communities appeared to have two complementary causes (Eskelinen and Harrison 2013, 2015; also see Fernandez-Goig and Harrison 2013). One is that nutrients and water can limit plant growth in a synergistic fashion, such that watering has little effect on biomass on an infertile soil unless nutrients are also added. The other is that plant species confined to infertile soils often have slow-growing, stress-tolerant life history strategies, and must be replaced by other species — such as fast-growing exotics — before biomass can increase in response to watering and fertilization. Serpentine grasslands may remain relatively secure refuges for our native flora as long as they are not bombarded simultaneously by added nutrients and resource-demanding exotic species.

Your insights and observations on California grasslands, climate, and native annual forbs would be much appreciated! Please send them to sparrison@ucdavis.edu.



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Figure 1. Exposed, compacted pond edges at low water stage. Photo credit: Vic Claassen

Soil Characteristics Influence Drought Tolerance of Perennial Plants During Mediterranean Summers or Projected Climate Changes *by Vic Claassen¹, photos courtesy the author*

Plant-soil interactions in California's Mediterranean climate

For rangeland plants growing in California's Mediterranean climate, summer drought generates an extended period of moisture stress. Climate change studies project that soil moisture availability for plant growth in California will become even more variable in the future, including more intense rainfall, longer intervals between rains, and greater heat loading from warmer soils and air temperatures (Durack et al. 2012, Tollefson 2016). Intense storms that historically occurred at about 20-year return intervals may start to occur at 10-year intervals (Hall 2016). If more of the annual moisture is received in fewer events throughout the year, the duration between storms is prolonged. In general, California can be expected to have "wetter wets and drier dries" (Chou et al. 2013).

As storms become more intense and shorter in duration, soil infiltration becomes a more critical factor for rainfall capture. Soils supporting perennial plants provide an example of the characteristics needed in that they support continued growth through the summer. Surface infiltration rates were shown to be greater under perennial grass stands compared to adjacent annual grass stands in central and northern California (Curtis et al. 2015). Perennials have greater rooting depths and longer periods of active root growth and greater carbon inputs to soil than annual grasses, extending subsoil structure and porosity (Holmes and Rice 1996, Koteen et al. 2001). Historical conversion of landscapes from perennial to mostly annual species

can be expected to reduce water infiltration and a range of other ecosystem services. Regeneration of some of these soil characteristics was the goal of treatments in the habitat regeneration project described below.

Project site description

The Bear Creek Ranch Unit in the Coast Range of western Colusa County was purchased by the Bureau of Land Management as a wildlife area in 1999. Grazing and oak harvesting had converted hundreds of acres of oak woodland into an open annual grass sward with frequent evidence of increased runoff and surface erosion. As part of continuing work to improve the area for elk and deer habitat, the California Department of Fish and Wildlife sponsored a project to regenerate perennial grasses and shrubs around the compacted, bare edges of existing stock ponds to regenerate browse for elk and deer and provide protective cover for deer fawning.

One of the factors that makes reestablishment of perennial species around stock ponds difficult is that the pond 'edge' migrates great distances laterally across the basin as summer progresses and pond levels drop (Figure 1). Soils near the water's edge are moist, soft, and scantily vegetated. Hoof impact and wallows of visiting animals readily mold and compact these soils. As the waterline recedes, these areas dry to a hard, dense mass that makes deep rooting difficult. With impaired rooting to deeper horizons, large areas of the basin within the fluctuating water levels become colonized by fast-growing, shallow-rooted annual weeds that complete their lifecycle before the surface horizons dry and harden each summer.

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¹Vic Claassen is a soil scientist at UC Davis specializing in soil fertility in wildlands systems, revegetation of drastically disturbed soils with native species, endomycorrhizae, and soil organic matter.

Soil Characteristics *continued*

Nearby soils under perennials provide a reference example of the beneficial characteristics needed to support plant growth through the dry summer. These soils develop soil aggregates that are visible as bread crumb-sized structures when gently broken down by hand. These aggregates, formed by physical disintegration of plant litter by soil invertebrates and microbial decomposition of a nutrient-rich organic duff, maintain open pore spaces for rainfall infiltration. In contrast, soils on compacted dirt roads or trails, excessively tilled fields, or areas of concentrated animal impact appear as fine, powdery dusts that wet up into a mushy mass and then dry to a dense material that reduces infiltration and rooting in subsequent seasons.

Roots are also deeper in reference soils compared to those populated by weedy annuals growing around pond edges. Longer duration of active plant growth and deeper root placement keeps organic materials flowing into these soils and keeps them open and infiltrative. Roots of yellow star thistle (*Centaurea solstitialis* L.) and medusahead (*Elymus caput-medusae* L.) may extend to moderate depths but they don't root as deeply or extensively, or contribute as much organic material from the roots as perennial grasses or summer-active shrubs.

Soil treatment

To regenerate soil infiltration on these dense substrates, compaction was broken up using a single 27-in deep parabolic ripper shank on a 100-hp orchard crawler tractor (Figure 2). Tillage occurred in late summer when soils were dry and would shatter and crack rather than smear and compact. Preliminary trials showed that a single pass fractured the soil extensively but it also created large individual clods with large empty spaces (1–5 cm; 0.5– to 2-in wide) between them. These cracks greatly accelerated drying during the summer. To mitigate this effect, duplicate ripper passes were made, parallel to the first pass but offset laterally by about a foot. The second pass shattered large clods and partially closed large void spaces. Multiple passes were made and the final pass was left open. Loose clods around the slot were graded into a wide, shallow furrow that was partially filled with the organic amendments described below.

A modest fertility amendment was made using slowly available nutrients to facilitate regeneration of perennial plant biomass. The amendment used was the 1- to 3-in woody material screened out during production of yard-trimming compost known as 'compost overs', or 'coarse compost'. The coarse woody fragments of this amendment help maintain rapid infiltration of the tillage treatment by filling the ripping slot with a vertical band of woody organic fragments. The composted overs were loaded into the furrow at a rate of 0.6 m³/100 m (7 cu ft/100 ft of ripper slot) using a side-discharge compost spreader.

A concurrent goal was to offset fossil carbon introduced into the atmosphere from vehicle trips to the field site. This was accomplished by loading stabilized carbon that had been removed from the atmosphere a year previously through agricultural production at a walnut orchard. Waste walnut shell was partially burned for



Figure 2. Ripper shank and orchard crawler tractor used to decompact pond edge slopes.

cogeneration of power and biochar (Dixon Ridge Farms, Winters CA). Biochar was loaded at a rate 80 kg/100 m (50 lb/100 ft) of ripper slot. The biochar-stabilized carbon will remain in the soil for centuries (Lehmann and Joseph 2009), compared to only decades of time for coarse woody material and only a few months for herbaceous materials. The two organic amendments placed in the furrow were incorporated into the open ripper slot and covered in a shallow berm approximately 20 cm (8 in) high. The shallow berm acted to pond overland flow and increase infiltration into the ripper slots and fractured soil.

Plot location

The ripper slots and berms were installed in long contour bands within the pond basin at approximately 60 to 70 cm (24 to 27 in) below the highest water level (Figure 3). This level of the pond basin is flooded in most winters but plants are typically exposed and growing for a month or so before fawning season in late April and May.

Plantings

Plants were selected that recovered and grew after seasonal flooding that sometimes lasts for several months, but that also were able to

continued next page



Figure 3. Parallel sets of multiple ripper passes for each berm.

Soil Characteristics *continued*

root well and survive hot and dry upland conditions on only subsoil moisture. Selected species were creeping wild rye (*Elymus triticoides* Buckley), mulefat (*Baccharis salicifolia*, (Ruiz Lopez & Pav.) Pers.) and red, arroyo, and sandbar willow (*Salix laevigata* Bebb, *S. lasiolepis* Benth., *S. exigua* Nutt.). Creeping wildrye was propagated using seeds collected from local stands and excavated root balls that were teased apart by hand and then grown out. Woody plants were propagated from cuttings initially rooted in water and transferred to 2x10-in cardboard sleeves filled with a mix of yard trimmings compost and one third volume of site-collected soil. Sleeves were placed in slotted plastic trays and allowed to become moisture-stressed periodically to condition and harden the roots. Previous year's work indicated that mulefat and willow species could be planted directly in flooded pond sites as thin whips, but they tended to root more extensively along the stem when flooded rather than in the bottom sediments. With little root anchoring in the soil, young plants were pulled out of the soil when shoots were browsed by elk and deer. For this reason the second-year cuttings were rooted in sleeves rather than direct-planted in the pond. The woody plant cuttings were tall enough so that the tops would remain exposed above pond water throughout the winter.

Installation and early establishment.

Tillage was completed in dry conditions by the end of August 2016, but project scheduling required that plants be installed several months before the fall rains started. To accomplish this out-of-season planting and take advantage of the deep soil preparation, the berm and ripper slots were flood-irrigated a single time with pumped pond water until the soil profile was fully wetted immediately after planting. After planting, plots were fenced and herbivory was discouraged with bloodmeal- or egg solids-based repellents that emitted sulfurous odors.

In spite of extended hot temperatures (over a week with daily maximum temperatures of 100 to 105°F), mulefat and creeping wildrye plants continued to grow and showed no signs of wilting. Within a week they set new shoots. No additional water was applied through the next several months of late summer weather. None of these plants wilted or died and survival was 100% until the onset of fall rains in the third week of October. Plants browsed by heavy pressure from deer and elk herbivory resprouted within a week.

Willows showed less extensive rooting and were less drought resistant during this late summer planting. Many stems showed sun scald and browning. Survival, as judged by stem and leaf condition, was perhaps 50 to 70% by late fall. But in previous year's plantings, dormant buds resprouted from the cuttings just below the soil surface even when the above ground shoot was completely desiccated, so survival may be higher than indicated by shoot condition. Future treatments with willow will emphasize larger or more extensive root development before out-planting and timing of installation for more moderate weather. In addition, the soil moisture release curve of the propagation material is being re-designed to retain more moisture during drier conditions than conventional organic-based mixes that tend to dry quickly. Although tillage effects

immediately change the soil's physical characteristics, the longer-lasting changes in infiltration will have to be measured the following summer after a winter cycle of submergence, plant growth and soil drying.

Conclusions

While these soil treatments are intensive, each soil treatment is targeted at a specific limiting site condition. Treatment components can be tailored to a wide range of unique site conditions of degraded eroded, mined, or construction-impacted sites, or for those anticipated under altered climate regimes. By regenerating soil functions such as infiltration and rooting depth, revegetation can be successful even in severely degraded environments. An understanding of how soils support plant growth under harsh conditions is also useful for identifying soils and landforms where climate change impacts may be observed more quickly or that may create harsher growth conditions. Conversely, soils or landforms can be identified that have favorable capacity to support desired plants under increased climatic stresses and that can be managed to retain desired habitats.



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Experimental Approaches to Addressing Climate Change Challenges in Prairie Restoration

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Abstract

Climate change is one of the greatest threats to the future of biodiversity on the planet. As the climate shifts, species that cannot move or adapt quickly enough are at risk of being left behind, or even losing their habitats entirely (Malcolm et al. 2002, Thuiller et al. 2005, Burrows et al. 2014). Conservationists and restoration practitioners are working to incorporate climate change projections into their long-term strategies. Here we explore some challenges that restoration practitioners encounter in the face of climate change and suggest possible research agendas to maximize our chances of success. We illustrate these with examples from our own research.

Climate change offers multiple interrelated challenges for restoration

There is no longer any doubt that the earth is warming at an unprecedented rate (Pachauri et al. 2014). The consequences of this shift include rising sea levels and latitudinal and altitudinal shifts in the distributions of species and the habitats they depend upon. This warming is also increasing evaporation from the ocean, resulting in overall increases in global precipitation (Trenberth 2011). Patterns of rainfall at the regional level are less certain, and this drives much of the difficulty in predicting the *effects* of climate change (Walther et al. 2002): Some regions are expected to experience increases in rainfall, while others will experience decreases. Rainfall is also likely to become more variable from year to year (Pachauri et al. 2014, Berg and Hall 2015) and an increasing likelihood that rainfall events will occur as fewer, more intense episodes, the latter of which is already being documented (and Soden 2008). Even in regions that will

experience increases or no change in total rainfall, drought stress also might be increased due to the warming temperatures (AghaKouchak et al. 2014).

The combined effects of climate change are also contributing to climate patterns that have no recent historical equivalents (i.e., “analog”), but instead incorporate previously unseen combinations of mean precipitation, rainfall patterns, and temperatures (Williams and Jackson 2007). Such “non-analog” climatic conditions complicate restoration efforts, as practitioners have no reliable reference communities upon which to make restoration decisions. In light of these novel combinations of climate variables, the relatively straightforward prediction of species’ and communities’ movement pole-ward and up in elevation may prove overly simplistic.

How can restoration respond to both predictable and novel changes?

One option is to continue creating restoration plans that seek to recreate local historical reference communities. This may appear short-sighted, but we are still not sure precisely how most organisms (especially plants) will respond to uncertain climate change projections, and their historic distributions may not be entirely defined by climate; for example, interactions with other species may be important (Suttle et al. 2007, Gilman et al. 2010, HilleRisLambers et al. 2013). Given this uncertainty, many feel that a default “do no harm” approach is one that continues to approximate historical reference communities. However, even current climates have already shifted from their historical means, and so local reference communities may already be ‘behind the curve’ (Bradley et al. 2009).

Another approach is to try to get ahead of the curve, and plant species or communities that we anticipate will be better suited to projected future climates (McLachlan et al. 2007, Thomas 2011). This strategy raises at least two possible concerns. First, it assumes that climate projections are accurate (which is more likely for temperature than for rainfall at this stage) at the scale for which the planting is being conducted, and that we understand which climate variables drive

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Figure 1. Dr. Kurt Vaughn and Dr. Stephen Fick seeding prairie restoration experimental plots at the Hopland Research and Extension Center.

Experimental Approaches *continued*

species and community responses (see Funk et al. 2008). Second, the practitioner must decide how far into the future to make their projection. Too far out, and the current plantings may fail, but not far enough, and they will become too quickly out of date (Broadhurst et al. 2008). This approach also doesn't provide any better understanding of the potential for local ecotypes (i.e., populations of plants that are adapted to local environments) to tolerate possible changes or whether existing populations have the capacity to adapt (Aitken and Whitlock 2013). Planning tools are available in some regions to help practitioners wishing to choose species or ecotypes based on future climate projections (e.g., www.seedlotselectiontool.org), but they are not currently in widespread use and more research is needed.

An additional strategy is to plant a wider mixture of species and ecotypes, matching a range of current conditions and future projections (Lesica and Allendorf 1999, Broadhurst et al. 2008). This can be thought of as "planting them all, and let nature sort them out". If approached thoughtfully, this could be designed to inform restoration strategies for an accelerated version of natural migration patterns (Sgrò et al. 2011). One question that arises is how different ecotypes will respond when planted in competition with each other or under variable environmental conditions. A recent experiment in California grasslands demonstrated that planting a variety of ecotypes did not increase the "home-field advantage" of local ecotypes, suggesting that a mixture of ecotypes may provide some room to sort themselves out over a number of years (Balachowski 2015). Another study found that ecotypes from southern California, which historically have experienced greater between-year variation in precipitation,

were better able to respond to different watering regimes relative to ecotypes from central and northern California (Pratt and Mooney 2013). Sorting out the importance of traits that confer an advantage competitively under one set of environmental conditions from those that confer tolerance and survival under another will be important for understanding the persistence of different ecotypes over years with variable weather.

Research Approaches

Research can help pave the way to deciding which of these approaches are likely to be successful, and how best to carry them out. Traditional approaches to climate change research, as it relates to plant communities, include a) temperature and/or precipitation manipulations (e.g., Walker et al. 2006, Suttle et al. 2007, Young et al. 2015), and b) modeling the climatic tolerances of individual species or vegetation types (e.g., Araújo and Rahbek 2006, Hijmans and Graham 2006, Thorne et al. 2016, Hereford et al. 2017). Although each can be useful, both have limitations that may limit their broader effectiveness in practical use (Araujo and Peterson 2012, Schwartz 2012). Increasing the number of research studies using traditional experimental approaches such as planting common gardens (Miller et al. 2011), reciprocal transplants (Johnson et al. 2015), and competition gradients with seeding rates (Dyer and Rice 1997) would provide much needed information regarding the capacity of restoration as a tool to mitigate the impacts of climate change.

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Figures 2–4. Temporal priority prairie restoration experimental plots.

Experimental Approaches *continued*

Alternative approaches

We have been exploring an additional research strategy using natural variation in climate over locations and time to examine the longer-term consequences of climate for plant community development. Practitioners have long noted that restoration outcomes vary strongly from site to site and year to year, suggesting that they will indeed be strongly sensitive to climate change. However, linking this observation to experimental work on climate change and restoration has lagged.

Successional theory suggests that plant communities will converge on a particular stable state determined by long-term climate means (and soil conditions). More recently, assembly theory has suggested that variation in conditions at the time of establishment can produce different communities that are essentially stable (Young et al. 2001, MacDougall et al. 2008, Baeten et al. 2010). Differences in initial conditions driving long-term differences in community composition may include different arrival times of species, giving an advantage to species that arrive first (a “temporal priority”), and weather in the year of establishment. Variability in these conditions geographically, and over time, may alter relative success among species during establishment in ways that can structure longer-term communities.

We have been studying the power of temporal priority to drive differences in community structure in a series of experiments in California’s Central Valley grasslands (Figures 1–4). This factor can provide broad insights into how various initial conditions may affect community assembly and trajectories. The emerging themes from this research suggest that:

- ✱ Temporal priority can have profound effects on short-term community development (Porensky et al. 2012, Vaughn and Young 2015, Stuble et al. 2017a);
- ✱ Initial differences can extend to longer-term shifts in community trajectories (Werner et al. 2016);
- ✱ Temporal priority advantage may not be consistent across species and guilds (Lulow 2004, Werner et al. 2016, Young et al. 2017); and
- ✱ Small differences across sites and planting years can strongly influence the strength of temporal priority and community structure (Young et al. 2015, 2017, Stuble et al. 2017b).

As between-year differences in weather might promote the initial establishment of some species over others, they can also create priority advantages for certain species. We expect therefore that the patterns we see from the manipulated temporal priority of species would also play out as differences in restoration outcomes driven by weather patterns experienced in the year of establishment.

If climatic variation in the years of establishment can have long-term implications for community structure, might it also provide a window into how communities will respond to climate change? If so, then examining species or communities that establish in years more closely resembling projected future climates may tell us how they may respond to climate change. With California’s high between-year variation in weather, many species have persisted despite not successfully recruiting each year — but will there be a tipping point when those recruitment years become too few and far between? We now have evidence of just such effects in restorations of California grasslands from temporal priority experiments (Stuble et al. 2017a,b).

We have also shown that between-year differences in rainfall can have predictable effects on community structure, potentially allowing projections beyond current data sets (Stuble et al. 2017b). Thus, while our predictions held up in 3 of 4 years (in nine separate experiments), these projections faltered in an unusual weather year in which rain fell in a few heavy rain events (a weather pattern that, while currently unusual, is precisely the direction of some climate projections; see Cayan et al. 2008). On the one hand, this suggests that non-analog climates will pose a serious obstacle to our ability to project community responses to climate change. On the other hand, historically extreme weather patterns do occur occasionally, and perhaps these rare years can provide useful windows into an uncertain future (Stuble et al. 2017a). In this way, multi-year experiments can be used to predict which species or source populations are likely to thrive under various ranges of conditions. These types of results would allow restoration practitioners to manage not only for a single predicted future, but to select species or ecotypes likely to succeed under a range of potential future conditions.

Lastly, seeding or planting the same plant material across known differences in available soil moisture along topographic and soil gradients at the same time provides an opportunity to learn about the range of tolerance among species and ecotypes. Restoration studies

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Experimental Approaches *continued*

conducted in this manner have found significant differences both among species within plant groups and more general patterns across plant guilds (Lulow et al. 2007, Kimball et al. 2017).

Conclusion

The relationship between ecological restoration and climate change is still very much in flux. Both the nature of the climatic challenges and the possible responses to them are far from resolved. It is likely that only as multiple approaches are undertaken, and found to be variously effective within certain regions or climatic contexts, will any sort of consensus occur. Until then, we suspect that ecological restoration will need to continue to be light on its feet, trying new ideas and adjusting on the fly. Luckily, ecological restoration has a long history of doing precisely that.



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Experimental Approaches *continued*

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