



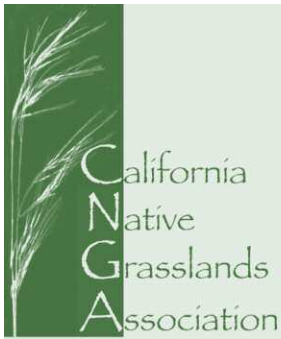
California
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Mission Statement

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.

P.O. Box 72405, Davis, CA 95617

www.cnga.org

530.902.6009 admin@cnga.org

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From the President's Keyboard

A Time of Transition

by J.P. Marié, President

Dear friends of CNGA,

Fall is a very busy time of the year for restoration practitioners, so we have decided to postpone the celebration of our 25th anniversary until next year. Fall is also time of change, which has me thinking about the transition from our hot, dry summer to a cooler season that will hopefully lead into a long, wet winter to offset our ongoing drought.

As I have observed in my area of Yolo County, the drought has led to noticeable changes in the life cycles of both native and nonnative plants. With the drought, plants have a shorter life cycle that starts slightly sooner in the year. Nonnative annual species are certainly following this pattern, with what seems to be record speed of life cycles for some species like foxtail barley, ripgut brome, medusahead, and barbed goatgrass. Many noxious broadleaf weeds are now growing all year long, like Russian thistle. Yellow starthistle, although still germinating about the same time in the winter, has been flowering late into October. Some native forbs have been thriving, like lupine, whose growth is stimulated by heat. While many of the nonnative species found in California's grasslands seem to be adapting to the ongoing drought, it remains to be seen if our native species will have a similar response.

I have also been thinking a lot about bigger-picture changes we have all been observing due to global climate change. Due to both the drought and the increasing effects of global change, California landscapes are changing rapidly, and we need to keep this in mind when planning and implementing conservation and restoration projects. I encourage you to keep an open mind and educate yourself on all these topics that impact what we do and how we do it when it comes to grassland conservation, restoration, and management. I wish you all the best of luck with your fall and winter projects, whether out in the field or around your house.

Lastly, in the spirit of change, I would like to welcome our new *Grasslands* editor, Kristina Wolf. Kristina will take over from the previous editor, Andrew Rayburn, starting in 2017.



Here are some of the workshops we have in the works:

Winter 2016 and Spring 2017 * Pasture Walks Let's look at the land together, see how grasslands work, and discuss management implications.

Late April 2017 * 10th Annual CNGA Field Day at Hedgerow Farms Join us for a day of expert talks, field tours, networking, and beautiful scenery in Winters CA.

Spring 2017 * Identification and Appreciation of the Native and Naturalized Grasses of California Grasses are fun and challenging to identify. Learn basic skills of identifying grasses and about California's grassland ecology in this 1-day classroom and field workshop.

Late Winter or Early Spring 2017 * Planned Grazing Workshop Managing land is extremely complex. Learn how to create the best possible grazing plan for the coming year, address all the variables needing attention, and go home with a sound grazing plan.

Early Spring 2017 * Monitoring Grassland Health and Soil Carbon Workshop Ranchers and land managers usually have either little time, money, or expertise to evaluate and document the effects of their management in grasslands. Attendees will learn simple, powerful, and inexpensive methods to monitor and document changes in grassland ecosystem processes.

Exact dates and locations for workshops are yet to be determined. CNGA will notify members of final details by Grass-blast emails. You can also look for updates on our website: www.cnga.org.

CNGA BOARD ELECTION FOR 2017

Election time for the 2017 Board of Directors is almost here!

We will again conduct an online election. Voting will be open from December 1 to December 20. When the polls open for this year's election, go to www.cnga.org, sign in as a member, and click on Election 2017.

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 530.902.6009.

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:

Winter 2017 — Nov 15, 2016 * **Spring 2017** — Feb 15, 2017 * **Summer 2017** — May 15, 2017 * **Fall 2017** — Aug 15, 2017



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Figure 1. Mattole Restoration Council planting native grass plugs. Photo: Hugh McGee, MRC

Restoring Native Coastal Prairies on California's Lost Coast

by Cassie Pinnell¹ and Hugh McGee²

Northern California's Lost Coast is a remote area located along the far western tip of Humboldt and Mendocino Counties, accessible only by winding and pothole-ridden mountain roads. These roads ensure that few people travel to the Lost Coast's Mattole River watershed and the King Range National Conservation Area (KRNCA), but those who do are rewarded with lush forests, beautiful waterways, and coastal prairies dotting the ridgelines overlooking the Pacific Coast (see cover photograph). Though these coastal prairies are picturesque, they are quickly disappearing. The Mattole River watershed has lost roughly 40–50% of grasslands over the last 50 years (Mattole Restoration Council, unpublished data). This loss is mainly due to encroachment of native and non-native vegetation. Of the grasslands that remain, many have been converted to non-native annual grasses (NNAG).

Unlike NNAG, native perennial grasses are deep-rooted and long-lived. Some species of native grass in the Mattole, such as purple needlegrass (*Stipa pulchra*), are bunchgrasses that typically can live for 200 years — and maybe many hundreds more (Stromberg and Kephart 2014). The root systems of these long-lived grasses range in depth from 6 to 20 feet, compared to 6 to 12 inches of

shallow-rooted NNAG. The deep roots of native perennial bunch grasses stabilize steep hill slopes and create subsurface soil ecosystems where a diversity of soil microbes, insects, and mycorrhizae flourish. Large amounts of root biomass found in native perennial grasslands generally increase water infiltration which helps sustain soil moisture (Curtis et al. 2015). This allows plants to stay green longer, providing long-term forage for wildlife throughout the hot dry Mattole summer. Individual bunchgrasses also act as structures that provide shade and micro-climates for grassland flora and fauna. Because native grasslands have evolved with fire, and hold water in the soil and plants longer, native grasslands are fire-adapted and more resistant than NNAG systems. Intact native grasslands reduce the intensity and risk of wildfire to both human and wildlife communities.

In order to best plan and implement high priority restoration projects, the Mattole Restoration Council (MRC) and the Bureau of Land Management (BLM) have spent the last decade trying to gain a better understanding of these Lost Coast grasslands. Through surveying the area and mapping out native grass populations, many remnant populations of native grasses have been observed, including big squirreltail (*Elymus multisetus*), blue fescue (*Festuca idahoensis*), blue wildrye (*E. glaucus*), California brome (*Bromus carinatus*), California fescue (*F. californica*),

Mattole Restoration Council. ¹Executive Director. ²Native Ecosystem Restoration Program Director

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Restoring Native Coastal Prairies

continued

California melicgrass (*Melica californica*), California oatgrass (*Danthonia californica*), Junegrass (*Koeleria macrantha*), leafy reedgrass (*Calamagrostis foliosa*), Lemmon's needlegrass (*Stipa lemmonii*), nodding oatgrass (*Trisetum canescens*), purple needlegrass, and tufted hairgrass (*Deschampsia cespitosa*). These observations lend support to reports that northern California coastal prairies have fared better than many other grassland systems, and still maintain a high diversity of native grass species and intact floral assemblages (Heady et al. 1988, Stromberg et al. 2002, Hayes and Hall 2003).

Perched on the edge of the Pacific just south of Cape Mendocino, the publicly-owned Prosper Prairie is approximately 850 acres of flat and gently rolling tables, floating above steep cliffs draining directly to the Pacific. Early records indicate that this area was once wide open grasslands, with scrub and trees limited to the steep drainages. This composition remained fairly unchanged from our earliest visual records (1861 US Coast Survey maps) through aerial images in the 1940s. Up through the 1940s, Prosper Prairie was intentionally burned as often as every 3–5 years to maintain the open prairie, first by the native Mattole and then by ranchers. Burning began to decline in the 1940s, and all burning was officially halted after the property was purchased by the BLM in the 1970s. Since then, a wave of vegetation has been observed encroaching into the grasslands, starting with scattered coyote brush (*Baccharis pilularis*) and progressing to dense, impenetrable Douglas-fir (*Pseudotsuga menziesii*) forests. CalFire's estimate of the current fire return interval for the area is now approximately 25 years, with most fires starting from backpackers along the Lost Coast trail or by lightning strikes.

Prosper Prairie now supports pockets of high woody fuel loads, which coupled with strong coastal winds, presents a wildfire threat to the bordering Mattole watershed and King Range. As is, intentional burning cannot be reapplied to the landscape without first addressing the existing fuel loads. Additionally, this brush and tree encroachment has been quickly reducing coastal prairie habitats and associated functions. To address these concerns, the BLM invested 13 years of community coordination and planning efforts to produce the Prosper Ridge Prairie Plan, which aims to restore coastal prairie conditions and improve fire management by removing the encroaching vegetation, replanting native grasses, and re-introducing intentional burning to maintain grassland conditions.

Recently, the BLM has partnered with neighboring landowners, the Humboldt Blacktail Chapter of the Mule Deer Foundation, and the MRC to restore the coastal prairie conditions of Prosper Prairie. The Prosper Ridge Prairie Restoration Project includes mechanical removal of coyote brush and Douglas-fir on approximately 800 acres, prescribed burning of grasslands, and native grass revegetation through seeding and plug planting. The combination of these techniques is intended to not only restore



Figure 2. Students volunteering at the MRC native plant nursery.
Photo: Monica Scholey, MRC

the structure of the grasslands, but also the associated ecological processes and functions. Additionally, restoring these grasslands will also provide a firebreak to protect the Mattole watershed and KRNCA from catastrophic wildfires that start along the Lost Coast Trail.

In 2011, several acres of encroaching Douglas-fir and coyote brush were removed using mastication. Though this did remove Douglas-fir, it also left a bed of fuels that were counterproductive to the project's goals of improved fire security. Additionally, coyote brush removal was not successful as this species continued to spread through vigorous root sprouts and prolific seeds. The mastication method was abandoned, and in 2014, the BLM contracted the MRC to use heavy equipment to pull the encroaching vegetation at a time when the coyote brush was not in the flower stage. Coyote brush and Douglas-fir have since been removed on 150 acres, using a CAT 312C and other small- to medium-sized excavators. Removal is conducted when soil moisture levels are ideal for root removal, generally April through May. The vegetation is then piled with a loader into giant stacks that will be burned by the BLM.

After vegetation is removed, the exposed soil is replanted with native grass seed or plugs (Fig. 1), and covered with mulch. Grass seed was hand-collected from nearby wild populations in the KRNCA by MRC staff and volunteers. To date, over 150 lbs of native grass seeds have been collected for Prosper Prairie. Some seeds were set aside for broadcast seeding (mainly *E. glaucus* and *B. carinatus*), which was conducted on over 8 acres. In addition, approximately 25,000 seeds were planted in the native plant nursery (Fig. 2), where they were grown for seven months until the plugs were large enough to be planted across the site. The remaining seeds were planted into our two native grass farms, totaling 1.75 acres, which are currently being cultivated to meet future seed demands (Fig. 3).

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Restoring Native Coastal Prairies

continued

Overall, we estimate that the cost of vegetation removal for the Prosper Prairie site has been approximately \$1,000 to \$2,500 per acre (including heavy equipment, staff, management, and administration). In addition, 10 acres of direct re-vegetation has totaled approximately \$37,500 (seed collection, cultivation, and planting). It should be noted that these costs have been offset greatly by volunteer efforts. Thus far, we have observed no resprouting of Douglas-fir across the site, and less than 20% resprouting of coyote brush. We have not yet collected data on revegetation success, but preliminary observations suggest that a large amount of non-native perennial velvet grass (*Holcus lanatus*) has established in treatment sites. We look forward to assessing native grass response to these treatments, especially once prescribed burning is reinstated on the site.

Future phases for this project include vegetation removal on 500 additional acres, revegetation of 20 additional acres, and reinstating prescribed fire at 3-5 year intervals. In these future phases we hope to apply many lessons learned, including: 1) improve pre- and post-revegetation monitoring (currently limited by funding); 2) improve community outreach for locals and neighboring landowners; 3) improve timing for seeding and vegetation removal (soil moisture dependant); 4) reduce revegetation costs by using a drill seeder; 5) use a CAT 312C to remove large Douglas-fir trees; and 6) stack vegetation piles high versus long for better burning.

For more information about our native grassland program or native plant materials, please feel free to contact us at 707.629.3514 or visit our website at www.mattole.org/programs/restoration/.



Figure 3. MRC native grass production farm. Photo: Hugh McGee, MRC

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Figure 1. UC Davis researcher Craig Schriefer collects vegetation samples from a restored grassland in Yolo County. Photo: Andrew Rayburn

Seedbanks in Restored and Degraded Annual California Grasslands: Implications for Management

by Andrew Rayburn, Independent Consultant and CNGA Board Member¹

Introduction

Soil seedbanks represent the suite of plant species that could germinate and recruit into the above-ground plant community, given suitable conditions. Seedbank composition reflects the historic and present composition of the plant community, climate, plant interactions, seed dispersal and transport, granivory (“seed-eating”) by wildlife, seed survival in the soil, and other factors. The degree of species similarity between seedbanks and above-ground vegetation varies widely, especially in grasslands (Gibson 2009). Substantial differences between seedbanks and vegetation could indicate patchy species distributions, high rates of species turnover, or significant shifts in community composition as a result of natural processes and/or management.

Seedbank analysis has many applications for land management including habitat restoration, rare plant conservation, and invasive species control. Seedbanks hold evidence of past conditions, informing selection of target species or habitats for treatment or restoration (Matzek and Hill 2012). Seedbank analysis can also be used to assess the effectiveness of invasive species control efforts by

checking if viable seeds still persist in the soil after treatment (Matzek and Hill 2012).

In terms of restoration, seedbank analysis can inform the selection of active versus passive restoration methods. For example, seedbanks are also reservoirs of biodiversity, helping to maintain communities of desirable native species and conserving genetic diversity. Native species in seedbanks of degraded sites may suggest that passive restoration could be sufficient to achieve restoration goals. Rare or otherwise unique native species, the presence of which might preclude the use of herbicide or other site preparation methods, can also be identified. Conversely, an absence of native species in seedbanks of a degraded site might suggest a more active restoration approach that could include intensive site preparation (e.g., to control invasive species) and planting of seeds, plugs, and/or container stock. In addition, including seedbank and seedbank-vegetation analysis in monitoring protocols provides another means to assess restoration trajectories — too few viable seeds of planted species in seedbanks may suggest that further seeding or planting may be required to achieve long-term success.

Little is known about seedbanks and seedbank-vegetation relationships in California grasslands, especially in the context of increasingly popular restoration efforts that seek to improve

¹Andrew Rayburn is the editor of *Grasslands* and an independent ecological consultant whose work focuses on habitat restoration, invasive species control, and conservation planning.

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Seedbanks in Restored and Degraded Annual Grasslands *continued*

degraded habitat and enhance ecosystem services such as infiltration, forage production, and carbon sequestration. The extent to which restoration leads to planted native species actually dispersing viable seeds into seedbanks has rarely been measured. Yet, this must occur in order for the majority of restoration projects to be successful over time. More information is needed, especially since grassland researchers and land managers have observed that many native grass species planted during restoration tend to “drop out” of the community over time. This loss of species diversity can potentially reduce both the value of the restored habitat for native species and the provision of ecosystem services.

In a study that will be published in the December issue of *Ecological Restoration*, my co-authors and I examined relationships between seedbanks and above-ground vegetation in restored and unrestored, degraded annual grasslands in the Sacramento Valley (Rayburn et al. 2016). We sought to address several questions with substantial management implications. In unrestored, degraded annual grasslands dominated by nonnative species, have remnant native grasses persisted by “hiding out” in the seedbank? In restored grasslands, what happens to the native grass species planted during restoration? Are they present in the above-ground plant community and/or the seedbank, or have they dropped out of the community completely? Lastly, how can the answers to these questions inform grassland management?

Methods

As part of a broader study, we collected seedbank and vegetation data in paired restored and unrestored grasslands at five sites that ranged in time since restoration (4–12 years) and post-restoration management (e.g., grazing, fire, mowing, herbicide, or some combination). Lists of species seeded during restoration efforts were determined through historical records and interviews with



Figure 2. Researchers monitor seedling emergence in a greenhouse on the UC Davis campus. Photo: Aubrianne Zamora

landowners and native seed providers. Native forbs were not included in any of the seed mixes, so this study focused on native grasses.

At the peak of the 2012 growing season, we sampled vegetation in five plots at each site to assess botanical composition (Fig. 1). In fall 2012, prior to the onset of rain that would initiate seed germination, we collected three seedbank samples from each plot that were combined together, spread across sterilized soil in trays, and germinated in a greenhouse at the University of California Davis from January–July 2013. Seedlings were identified and tallied as they emerged (Fig. 2). Seedlings that were challenging to identify were transferred into pots and grown to maturity so that flower and seed

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Seedbanks in Restored and Degraded Annual Grasslands *continued*

characteristics could be used for identification. Analyses focused on seedbank composition (species richness, diversity, and native species seeded during restoration), within-field seedbank similarity, and seedbank–vegetation similarity.

Results

Across all sites, 65 species were detected in seedbank samples, while 78 species were detected in the standing vegetation. Common invasive species such as medusahead (*Elymus caput-medusae*), barbed goatgrass (*Aegilops triuncialis*), and yellow starthistle (*Centaurea solstitialis*) were found in both seedbank and vegetation samples in all fields and sites. In general, nonnative and invasive species were dominant in most restored and unrestored fields.

Seedbank species richness and diversity tended to be higher in restored fields at some sites, although patterns were not consistent. Seedbank similarity was generally low within fields, as was the similarity between seedbanks and above-ground vegetation. These results suggest a patchy species distribution and resulting seed dispersal, as well as a high rate of species turnover that may be dependent on broader-scale factors such as soil moisture differences in wet and dry years.

In restored fields, the number of planted native grass species found in seedbanks and/or standing vegetation varied widely. When planted grasses were detected in both seedbanks and vegetation, relative abundance was always higher in the vegetation. Purple needlegrass (*Stipa pulchra*) was planted at all five study sites, and was found in both seedbanks and vegetation at all sites. Blue wildrye (*Elymus glaucus*) was found in seedbanks and vegetation on two of the four sites where it was planted. Slender wheatgrass (*E. trachycaulus*) and creeping wildrye (*E. triticoides*) were planted at one and two sites respectively, and were found in the seedbank and vegetation at one site each. Big squirreltail (*E. multisetus*) was found in the vegetation at the only site on which it was planted, but not in

the seedbank. The persistence of these species was likely driven in part by their known competitive ability relative to the widespread nonnative species, in addition to presumably higher seeding rates since these species often make up the bulk of seed mixes.

Other native grasses, including California brome (*Bromus carinatus*), small fescue (*Festuca microstachys*), meadow barley (*Hordeum brachyantherum*), California melicgrass (*Melica californica*), one-sided blue grass (*Poa secunda*), nodding needlegrass (*Stipa cernua*), and foothill needlegrass (*S. lepida*) were not found in seedbanks or vegetation at any of the sites on which they were planted. These species may have been planted at lower rates, and some (e.g. one-sided blue grass) are known to be less competitive relative to nonnative species.

Notably, no native grasses were detected in any seedbank samples from unrestored fields, and only *E. triticoides* and *E. multisetus* were ever detected (once each) in the vegetation in unrestored fields. This strongly suggests that passive restoration (e.g., removing exotic species and altering management) will not be sufficient for native grass recovery and that active planting will be required to restore native grasses.

A lack of available data precluded formal analysis of site age and management as explanatory factors, however these factors likely also influenced native grass persistence. For example, the oldest site (planted in 2000) had only one native grass (*S. pulchra*) in the seedbank or standing vegetation. The most recent site (planted in 2008) had three species (*S. pulchra*, *E. glaucus*, and *E. trachycaulus*) in both the seedbank and standing vegetation. Results were mixed, however, for the other three sites. Management before and after restoration varied widely between sites, and included prescribed fire, grazing, mowing, and herbicide application.

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Seedbanks in Restored and Degraded Annual Grasslands *continued*

Conclusion

In Central Valley grasslands, most native grasses reproduce primarily by seed with the notable exception of *E. triticoides*, which spreads readily from rhizomes in addition to seed. If native grasses planted during restoration are to persist on restored sites through time, viable seeds of these species must be present in the seedbank to allow for germination and establishment of new recruits. In this study, we found no native grasses in seedbanks of the five unrestored, degraded annual grassland sites even though they were essentially adjacent to restored fields. This is compelling evidence that active restoration will be required to reestablish native grasses in the Central Valley.

In restored sites, we found that some perennial native grass species (*S. pulchra*, *E. glaucus*, *E. trachycaulus*, and *E. triticoides*) persisted since planting in both seedbanks and standing vegetation, although many did not. Our findings echo previous observations that there are challenges in retaining native grassland species on restoration sites in subsequent years after planting. If restoration success is predicated on a high-diversity grassland, additional site preparation (e.g., several seasons of nonnative species control) coupled with active post-restoration management (e.g., controlled burning, flash grazing, invasive species control) and monitoring of seedbanks and vegetation to inform adaptive management may be required to prevent the loss of native species from the community.

Seedbank analysis is a useful and underutilized tool for informing restoration methods, assessing site trajectories, and guiding adaptive management. Seedbank sampling methods are inexpensive, relatively straightforward, and well-documented in the literature (Matzek and Hill 2012; Rayburn et al. 2016). Monitoring protocols for vegetation, such as randomly-placed quadrats or transects, can also be used for choosing locations for seedbank samples. One constraint is the need for a greenhouse or some other location for germinating samples. A partnership with a research institution or local nursery could be the most efficient solution, especially if interns or students were able to assist with the project.



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Breeding Systems and Hybridization Potential of Native Grassland Species *by Sylvia Delfino*¹

Introduction

Ecological restoration in California is still a young field both in terms of theory and practical application. The definition of ecological restoration is “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” as defined by the Society for Ecological Restoration. Implementation methods and strategies are still being tested and ecologists strive to rehabilitate California’s ecosystems using materials that do not adversely alter the genetic structure of a site’s existing or historical plant populations. Materials for projects in California often come from native seed producers within the state. Producers strive to provide materials that are genetically true to a species and to the geographic distribution in which it was collected (i.e., ecotype). Producers take precautions to reduce the chances of hybridization between species and cross-pollination between ecotypes, while also maximizing genetic diversity of seeds during the harvest and cleaning processes (e.g., making sure to harvest both early- and late-setting seeds for a particular species).

This review focused on two questions: First, what are the breeding systems of the species grown in large-scale production? Second, with which other species and/or genera does the species hybridize? The information presented here is a combination of observational data gathered at two well-known California native seed production farms which have grown various species in large-scale production for more than 20 years, and information from existing literature on the breeding mechanisms of California native species and their propensity for hybridization. Additional data were provided by faculty in the Department of Plant Sciences at the University of California Davis.

Synthesis of Existing Data

Pollination occurs in two ways: either through closed flowers pollinating themselves (cleistogamous flowers) or by open flowers releasing and receiving pollen for pollination (chasmogamous flowers), and both flower types can be found on the same plant. Despite barriers to self-compatibility in flowering plants, it is thought that self-pollination occurs as a method of ensuring the next generation. Perennial species tend to be self-incompatible while annual species have many more instances of self-pollination (Baumann et al. 2000; see online Appendix 1 for list of references). Self-pollination through cleistogamous flowers is the most common method in grass species while forb species often self-pollinate through chasmogamous flowers. In general, we found that previous assumptions that California native species primarily cross-pollinate are in some cases incorrect, and that levels of self-pollination vary across species depending on environmental conditions. Surprisingly, some of the species that are primarily self-pollinators do not lose

genetic diversity when self-pollination occurs, nor do they display reduced reproductive fitness. In fact, several of the species that predominantly self-pollinate have high levels of genetic diversity within as well as between the populations sampled. The highlights of our review are presented below by genus, with additional information provided in online Appendix 2.

Native grasses

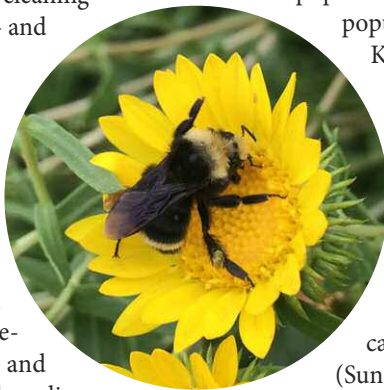
Elymus spp.

Many *Elymus* species are highly self-pollinating, such as *E. glaucus* and *E. trachycaulus*. As a result, the levels of homozygosity (having identical pairs of alleles for a given gene) within a population are high, as are levels of inter-population genetic diversity (Jensen et al. 1990). This causes stark differences in the genes and their physical expression between populations. In *E. glaucus* gene flow between populations is limited, leading to genetically distinct populations within a close geographic range (Rice and Knapp 1996). Pollen and seed dispersal is limited in *E. glaucus* due to the reduced size of dispersal structures on the pollen and seed. Correspondingly, ecotypes in the wild as well as in production remain distinct. Though cross-pollination is rare, *E. glaucus* can form hybrids with *E. elymoides*, *E. stebbinsii*, *E. trachycaulus*, and *Hordeum brachyantherum* ssp. *brachyantherum* (Baldwin et al. 2012). Hybridization can also occur between *E. trachycaulus* and *H. jubatum* (Sun 2006, Baldwin et al. 2012). *Elymus triticoides* does not display the same characteristics as many of the species in the *Elymus* genus. *Elymus triticoides* is found to be a highly self-sterile, obligate cross-pollinating species. Though it must cross-pollinate to set fertile seed, it does not set seed every year. The primary mechanism of reproduction for *E. triticoides* is by vegetative rhizome, only setting and dispersing seed when under stress to ensure survival of the next generation (Jensen et al. 1990, Hedgerow Farms staff 2016). Hybridization can occur between *E. condensatus* and *E. mollis*.

Bromus carinatus

There are multiple levels of complexity to the systematics of the genus *Bromus*. At one point it was thought to have as few as four species, and up to as many as fourteen belonging to the sect *Ceratochola* under the genus *Bromus* where *B. carinatus* is found (Stebbins and Tobgy 1944, Barkworth et al. 2006). *Bromus carinatus* can have both cleistogamous and self-compatible chasmogamous flowers on the same panicle. It is unclear as to what triggers cleistogamy and chasmogamy in the *B. carinatus* complex, however environmental conditions are thought to play a role (Knowles 1943, Harden et al. 1945). This leads us to believe *B. carinatus* self-

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¹Project Coordinator/Sales Assistant, Hedgerow Farms, Inc.

Breeding Systems *continued*

pollinates under stressful environmental conditions. In addition, this species forms distinct “races” due to rapid rates of self-pollination and genetic inputs through sporadic cross-pollination. Hybrid vigor between races is high, but drops off after a few generations of selfing. If enough new gene flow occurs, the races can become separate populations with their own distinct genetic identity without losing the hybrid vigor and reverting back to the base population. Over 100 races were found when the populations surrounding the city of Berkeley were sampled (Stebbins and Tobgy 1944, Harden et al. 1945). Taxonomists have found it difficult to differentiate between variations in the *B. carinatus* complex due to a lack of clear genetic and geographic distinction (Barkworth et al. 2006). In studies done at UC Berkeley and UC Davis it was found that *B. carinatus* can form hybrids with *B. mollis*, however the hybrid vigor of the first generation was found to be poor, with reduced survival and seed set (Knowles 1943).

Festuca microstachys

This species is commonly used as a nurse crop in restoration projects. Its annual growth habit and ready reseeding make it ideal for quick vegetative cover. *Festuca microstachys* is a highly selfing species almost exclusively through cleistogamous flowers, with less than one in 1,000 fertilizations caused by cross-pollination (Kannenberg and Allard 1967, Adams and Allard 1982). In populations displaying inbreeding depression, it is typical to see levels of heterozygosity halved with each generation of inbreeding. Despite frequent instances of self-pollination, the most extreme level of inbreeding, *F. microstachys* displays high levels of both inter- and intra-population genetic diversity. Genetic diversity in normal populations is displayed by equal levels of homozygosity and heterozygosity (multiple alleles per gene). *Festuca microstachys* displays high genetic diversity through homozygosity at many different locations on the chromosome, rather than normal levels of heterozygosity. This results in many different genotypic differences within one population, despite high levels of homozygosity. The cause of this variation is thought to be infrequent instances of cross-pollination, thereby introducing new genetic material into a population (Adams and Allard 1982).

Hordeum spp.

Hordeum brachyantherum is a self-pollinating species that has few instances of cross-pollination. *Hordeum brachyantherum* ssp. *californicum* also displays high levels of self-pollination. Both displayed sporadic instances of heterozygosity suggesting the occasional occurrence of cross-pollination (Johansen and Bothmer 1994, Ottosson et al. 2002). *Hordeum depressum* is a self-pollinating species primarily through cleistogamous flowers on the panicle (Johansen and Bothmer 1994). Intergeneric hybridization can occur between *H. brachyantherum* and *E. glaucus* in rare instances of cross-pollination (Baldwin et al. 2012).

Stipa spp.

Stipa pulchra has been found to both self- and cross-pollinate, as seen in contradicting accounts of its breeding mechanism (Campbell et al.



Harvesting *Lasthenia glabrata* with a swather. Photo: John Anderson, Hedgerow Farms

1983, Larson et al. 2001, Bartolome et al. 2007, Dyer et al. 2016). This leads me to believe this species of needlegrass reverts to self-pollination in unfavorable environmental conditions. It can form hybrids with *S. lepida* and possibly *S. cernua*, but it is unclear if the hybrids are sterile or fertile. *Stipa lepida* and *S. cernua* both predominantly cross-pollinate and hybridize with each other as well as *S. pulchra*. Propagules resulting from those hybridizations are sterile (Love 1954, Younger and Mckell 1972, Dyer and Rice 1997).

Native forbs

California native forbs are typically pollinated by the insects that visit during bloom periods. Many species such as *Achillea millefolium*, *Grindelia camporum*, *Phacelia* spp., *Clarkia* spp., and *Lupinus* spp. support the highly diverse populations of native insects and invertebrates within California ecosystems (Eviner 2016). The majority of California native forb species are cross-pollinators. Some, such as the *Lupinus* genus, self- and cross-pollinate to ensure seed set when conditions are unfavorable (Huang 2010). Self-pollination can occur in species of forbs with many branching growth habits resulting in many flowers open at the same time on the same plant, as in *Clarkia* spp. (Wedberg et al. 1968). In these species, insects that visit multiple flowers on the same plant precipitate self-pollination, however barriers to self-compatibility may prevent the success of self-pollinated progeny.

Lupinus spp.

The *Lupinus* genus is a historically difficult genus to determine the number of species belonging to it. Species within the genus are closely related, making the genetic distinction between species often uncertain. The genus has been broken into clades that roughly fit geographic distribution. Similar to the behavior of annual and perennial native grasses, it has been found that most of the perennial species of *Lupinus* are predominantly cross-pollinating and are self-incompatible, and the annual species are self-compatible and utilize both methods of pollination (Ainouche and Bayer 1999). Though *L. bicolor* has a high rate of self-pollination, hybridization has been observed between *L. bicolor* and *L. nanus* in production as well as between farm and wild populations (Karoly 1994). *Lupinus*

Breeding Systems *continued*

microcarpus var. *microcarpus* and *L. microcarpus* var. *densiflorus* are very closely related and thought to be able to form fertile hybrids (Drummond 2008).

Asclepias spp.

Asclepias species were historically thought to have extremely low levels of hybridization due to extensive physiological, and mechanical barriers to cross-pollination. A study done by Hatfield and Kephart (2003) of hybridization between *A. fascicularis* and *A. speciosa* has found hybridization to be possible, though highly improbable. In rare instance of hybridization, the viability of seed that is set is drastically reduced. In most cases hybrid seed pods abort before they are fully developed. Observational data from large-scale production confirms this with no hybrids found after consecutive years of three species grown next to each other.

Discussion

Due to the possibility of cross pollination and hybrids, it is important to understand the mode of distribution that native plant species use to disperse pollen and seed. Grasses are primarily wind pollinated. It has been found that pollen dispersal of wind-pollinated species can occur over at least 65–75 m (Rognli et al. 2000, Friedman and Barrett 2009). Larger populations release larger quantities of pollen and display increased rates of cross-pollination. When planning the placement of species in a large-scale production setting, producers must isolate cross-pollinating species by ecotype as well as potential hybridization. The following suggested Best Management Practices (BMPs) enable native seed producers to maintain the genetic identity of their species and ecotypes. Conservative recommendations for isolation of wind pollinated species have been between 100–300 m (Basey et al. 2016). Our BMP recommended distances between wind-pollinated species must exceed 75 m based on literature. Prevailing wind direction of the production site should be taken into consideration to ensure no gene flow between different ecotypes and species occur during production. Rotating crossing species and ecotypes to be grown in alternate years, and the use of barriers (self-pollinating and/or non-hybridizing species and hedgerows) are additional methods native seed producers can implement to ensure the maintenance of species' genetic identity in production.

California native forb species are primarily insect-pollinated. Because of the high level of agricultural production in California, the most common insect contributing to pollination in the state is the European honey bee (*Apis mellifera*) (AOSCA 2012). Studies done by the Association of Official Seed Certifying Agencies (AOSCA) found that pollen-mediated gene flow distributed by honey bees fell within the 0.6–16 km range. The average pollen foraging honey bee travels between 0.8–6.4 km from the hive. When there is a scarcity of pollen resources closer to the hive, pollen foraging bees will travel over significantly greater distances, at least 27 km round trip (Beekman and Ratnieks 2000, AOSCA 2012). Because agricultural land owners use the European honey bee so frequently, native seed producers should adhere to the regulations set for standard California agricultural crops despite endemic insect

species' pollination services. The UC Agricultural and Natural Resources California Crop Improvement Association recommended isolation distances for insect pollinated crops are 0.8–3.2 km. Integration of barriers, and alternating the years in which hybridizing species are grown are important steps when placing species in large-scale production due to the added complexity of insect movement and foraging. These are effective means of preventing cross pollination by insect movement.

In addition to hybridization concerns, producers are aware of the possibility of mechanical selection unintentionally applied to species in production (Dryer et al. 2016). The methods of harvest used in the production of California native species have been adapted from conventional crop methods to meet the need of native seed producers. Differences in height, flowering time, and rates of seed ripening all play a role in the methods and timing of harvest. Fields are closely monitored to determine the best timing and technique to use for harvest. To capture seed at every stage of ripeness and to account for height differences, several methods of harvesting are used including stripping, swathing, and combining. The use of multiple harvest techniques ensure growers are capturing as much of the seed as is practical to increase representation of the population's genetic composition. For species with delicate seed or complex seed structures, as in *Asclepias* spp., hand harvesting is done. Seed cleaning is another aspect of native seed production where growers must be aware of the possibility of reducing the genetic diversity of a population. Seed size, weight, moisture content, and viability all play a role in the seed cleaning process. Native seed growers attempt to separate out inert matter and non-viable seed from viable seed during the cleaning process while maintaining a healthy representation of the population's genetic composition (Basey et al. 2016). In this step of the process, conventional seed cleaning equipment has been adapted for cleaning native seed at both farms observed for this study. Each lot of seed is watched closely throughout the cleaning process to ensure as much viable seed as possible is collected. In addition, each species and ecotype is cleaned separately and the machines are thoroughly cleaned between each lot of seed.

Conclusion

As restoration and conservation of California's ecosystems becomes more important, ecologists depend on native seed producers to maintain the genetic identity of the species and ecotypes put into production. These large-scale production farms are one of the main sources of material for use in restoration and conservation efforts in California. By taking this information into consideration, as well as the suggested BMPs, native seed producers can further ensure the ecotypes and species they grow are not compromised. As a result, restoration and conservation efforts can continue with little fear of altering the genetic composition of already substantially altered systems.



Additional comments or examples are welcome and can be sent to sdelfino@hedgerowfarms.com

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Above: Western meadowlark.
Photo: Ryan DiGaudio

Right: CNGA Grass ID workshop.
Photo: CNGA Archives



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Front cover: Prosper Prairie, just south of Cape Mendocino along Northern California's Lost Cost region. Photo: Mattole Restoration Council

Back cover: Ridgeline grassland at the King Range National Conservation Area in the Mattole River watershed. Photo: Hugh McGee, Mattole Restoration Council

