California Native Grasslands Association

GRASSLANDS

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Grasslands Submission Guidelines

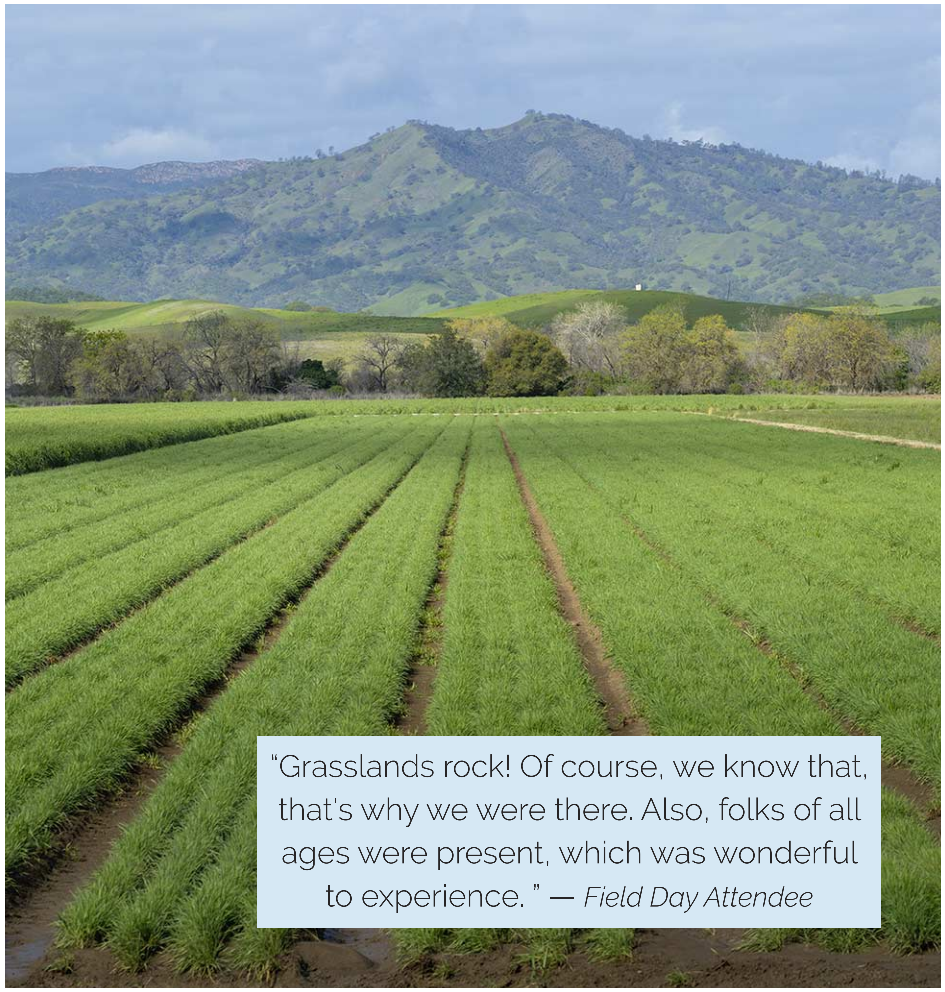
All submissions are reviewed by the *Grasslands* Editorial Committee for suitability for publication. Written submissions include peer-reviewed research reports and non-refereed articles, such as progress reports, observations, field notes, interviews, book reviews, and opinions.

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. Photo submissions should be at least 300 dpi resolution and include a caption and credited photographer's name.

Send all submissions, as email attachments, to the Editor at **grasslands@cnga.org**

Submission deadlines:

Spring 2024: 15 Feb 2024
Summer 2024: 15 May 2024
Fall 2024: 15 Aug 2024
Winter 2025 15 Nov 2024



A field of native grass soaks up the recent rains at Hedgerow Farms on Field Day. *Photo: Jock Hamilton.* *(See article on page 9.)*

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.

Grasslands Journal

Whitney Brim-DeForest, *Editor*
Michelle Halbur, *Editorial Committee Chair*

*For membership and other organization information, contact CNGA Administrator via **admin@cnga.org**.*

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In this issue

Morning welcome and introductions at CNGA's 15th Annual Field Day at Hedgerow Farms. Left to right: Hedgerow Farms Restoration Ecologist and CNGA Director Julia Michaels, CNGA President and Putah Creek Riparian Reserve Manager JP Marié, and Hedgerow Farms Farm Manager Jeff Quiter. *Photo: Jock Hamilton.*

From the President's Keyboard

Dear Members, Sponsors, Supporters, and Friends,

I am writing this note a little later than usual and want to apologize for the lateness of this combined Fall/Winter edition of *Grasslands* due to technical difficulties.

Your Board of Directors is also considering publishing a future issue dedicated to artists to include a larger community. Current thoughts are to ask our readership to submit drawings, poems, photos, etc. It's a work in progress and I am excited to see the results of this group effort.

I am pleased to report that we now have a full board of directors and wish to thank you for re-electing all of our former board members and electing our new board members: Ernesto Chavez-Velasco, Brian Peterson, Scott Dunbar, and Brooke Wainwright. I am looking forward to another productive year full of events and advocacy.

Here are some upcoming events you don't want to miss:

- Field Day at Hedgerow Farms is in planning and is scheduled for Friday, April 5th. Spaces are limited so don't forget to register early!
- It is my great pleasure to announce that, after a long hiatus, the CNGA symposium will return in early 2025 (most likely in February) at the Hopland Research Extension Center.
- Also, don't forget to join us for the ongoing virtual presentations by our GRASS scholars.
- Lastly, keep an eye out for low-key (half-day) guided site visits throughout the year.

Thanks to some generous donations, CNGA is doing well, but we need more funding to fulfill our mission. Please think about CNGA during giving times. We accept checks, stock donations, and more. As a 501(c)(3) nonprofit organization, all your donations are tax-deductible.

On behalf of CNGA, I wish you a happy, healthy, and successful year.

JP Marié, Board President

California Native Grasslands Association

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MEET A GRASSLAND RESEARCHER **Michelle Halbur**

Halbur is the Ecology Research Manager at Pepperwood Preserve, where she conducts research to assess how adaptive land stewardship practices impact upland terrestrial ecosystems in a changing climate.

What is your study system?

My research is focused on Pepperwood, a 3,200-acre nature reserve and climate-ecosystem sentinel site research station in the inner coastal Mayacamas Mountain Range, Sonoma County. The reserve is home to many different Mediterranean-climate vegetation communities including 900 acres of grasslands that are actively stewarded through cattle grazing, prescribed fire, weed control, and native grass plug plantings. Given our proximity to both coastal and inland climates, the reserve hosts a diverse suite of plant species. We also have small patches of serpentine outcrops that boast high native forb diversity and put on a vibrant wildflower show in good water years or following fire. Combine the bright forb displays with the spanning vistas of oak-covered hills and Mt. St. Helena in the background, and you have the perfect setting for an inspirational experience!

What are your primary research goals?

Starting in 2011 we have been monitoring long-term transects throughout our reserve to track how our grasslands are responding to our stewardship activities and climate change. We have 32 permanent transects in total with six paired transects that have been excluded from cattle grazing since 2016. After the start of our project, we experienced two major droughts and two wildfires in October 2017 and 2019, setting us up to ask questions about how natural disturbances — and their interactions — are impacting grassland communities in a managed system. We use our annual monitoring data internally to fine-tune our conservation grazing and prescription burning in response to fine fuel accumulation rates and the needs of the ecosystem. We also use the data to calibrate our observations in the field, monitor for new plant invaders (and in some cases successfully remove them!), and document community changes over time — all so we can support or enhance our native grassland biodiversity. In addition to our long-term monitoring program, we are monitoring stewardship activities such as invasive plant control, fuel break recovery, and prescribed burn impacts to assess whether we have achieved our management objectives and to track ecosystem response to our stewardship.

Who is your audience?

The work we do is mostly shared with land managers, landowners, and members of the public, primarily through on-site workshops and tours, presentations and webinars, and in-field volunteer workdays where we highlight the importance of our native grassland communities while collecting native seed, propagating in the greenhouse, or working up a sweat doing plug plantings.

Who has inspired you, including your mentors?

The long meandering pathway I took through my educational and professional development has resulted in many fabulous friends, colleagues, and mentors. But particularly noteworthy is my dear

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friend and field botany instructor, Steve Barnhart, who gave me my first scientific deep dive into the green world. My Master's advisor, Nancy Emery, openly listened to my questions about vernal pool ecology and supported my explorations with clarity and enthusiasm. In more recent years, I have been inspired by the work of Valerie Eviner, with her engaging and collaborative approach to conducting applied research on California's grasslands. And the tireless dedication of Pepperwood's Preserve Manager, Michael Gillogly, to enhance grassland health is astounding. Decades of his diligent work and tender care for our grasslands is showing itself through the abundant native diversity throughout the reserve, as well as Pepperwood's commitment to restore native grasslands as one of four primary organizational initiatives, which Michael crafted and advocated for. It takes a lot of time and effort to turn action into results and so the countless number of volunteers that have donated their free time to help us in this effort, all while smiling and enjoying the work, will forever be an inspiration for me.

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

Pepperwood's programs, and the research I am involved in, directly support all four of these actions. We have an extensive education program that connects people of all ages and backgrounds to the reserve, its natural resources including grasslands, and the importance of caretaking the land that supports us. Our management methods and research results are integrated into on-site workshops, hikes, and classes in a way that reaches many audiences and ages. We advocate the importance of native grasslands by putting it front and center with our Restoring Native Ecology Initiative committed to grassland restoration and stewardship specifically. This initiative integrates our grassland-based research, stewardship activities, and collaborative partnerships so that we may all learn from our work and carry the torch into the community to support regional change.

Why do you love grasslands?

Those who know grasslands know how mysterious and often unpredictable — or surprisingly, predictable — they can be, which keeps curious folks like me entertained for decades. I humbly appreciate that grasslands don't fit well within our mapping schemes, or tendency to categorize and delineate spatial boundaries. But I also recognize that this poses a challenge when advocating for their importance and conservation priority. I often wonder how we can adequately capture their complex dynamics, diversity, and mobility. Or how we can characterize their potential, which is often sequestered as seedbank waiting for generations to emerge from their time capsule following environmental triggers like fire. How can we demonstrate these important and intricate characteristics in a way for all to understand and value? These challenges intrigue me enough that I continue revisiting the same plots year after year after year so I can better understand the language of the land and interpret the message into a story.

SOILS CORNER Soil Textures and the Soil Texture Triangle

by Soil Scientist, CNGA director

The Soils Corner, a new ongoing column, will cover topics related to soils and soil properties and their role in plant growth and establishment, starting with today's topic: Soil Textures and the Soil Texture Triangle.

Soil texture plays an essential role in vegetation expression, germination, and establishment — as well as how plants respond to climate and disturbances. Each unique native grassland across the state of California has different soil properties that are key to its survival. Soil textures are one of the most critical characteristics.

Soil texture is defined as the relative percent of sand, silt, and clay-sized materials in the soil. The primary difference between sand, silt, and clay is particle size. Sand particles range from 0.05 to 2.0 mm, silt particles range from 0.002 to 0.05 mm, and clay particles are less than 0.002 mm (Figure 1.)

Sand will also be loose, gritty to the touch, and visible to the naked eye. Sand particles are usually many different shapes (angular, round, flat, elongated, etc.), which create a soil matrix with more pore spaces between particles that allow for greater amounts of water infiltration into the soil profile, evaporation, evapotranspiration, and biological activity. Silt particles are smooth, dust-like particles that are easily transported by wind, water, and ice. When dry, the particles feel almost like wheat flour and when wet, they feel slippery and smooth. Soils high in silt will be very fertile, but easily displaced and impacted by natural and human disturbances. Clay particles are very small, fine-grained particles that consist of microscopic particles of chemical compositions from rocks. Clay particles are usually flatter particles that are often sticky when wet, readily bond to other textural particles, and can hold a significant amount of water when compared to the other particles. Clay soils will expand when wet and shrink down when not holding onto water, and depending on the source of clay particles, they can vary in how much they are bonded and sticky. Therefore, depending on the mixture of sand, silt, and clay particles, the soil texture will vary in its ability to provide a proper growth medium for vegetation. While understanding soil texture and the texture triangle is useful, focusing on the soil textures within the top 8–10 inches will be most helpful for most grasslands and will provide critical information for management decision-making.

The USDA classifies soil types according to a soil texture triangle chart that names various combinations of clay, sand, and silt. The Soil Triangle is a commonly used visual representation of the possible soil type combinations based on soil particle size (Figure 2).

The numbers along each side of the triangle are arranged symmetrically around the perimeter. On the left the numbers correspond to the percentage of clay, and on the right the numbers correspond to the percentage of silt. At the bottom of the triangle chart are the percentages of sand. To classify a soil sample, you find the intersection of the three lines that correspond to the three proportions you have determined through either field or lab testing. Using the chart, all of the percentages will add up to 100%. For example, to classify a soil sample that is 30% clay, 15% silt, and 55% sand, you will first, locate 30% on the clay axis, and draw a line horizontally from left to right. Next, locate 15% on the silt axis, and draw a line

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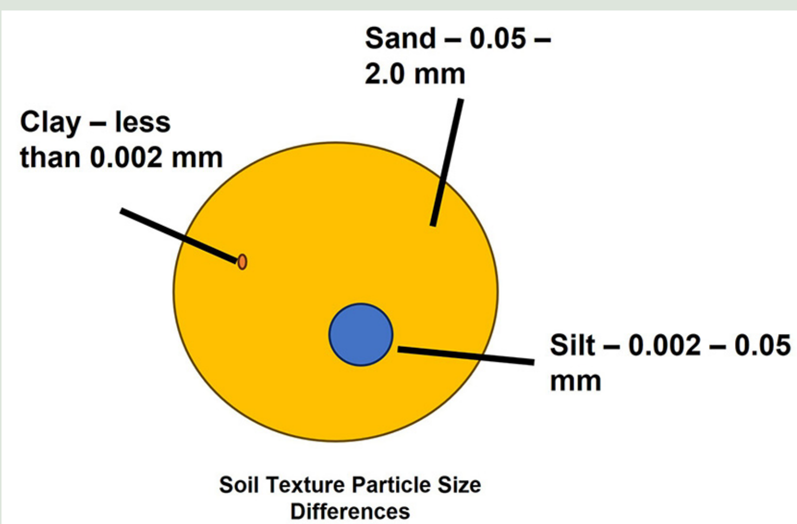

Figure 1. Soil texture particle size differences.

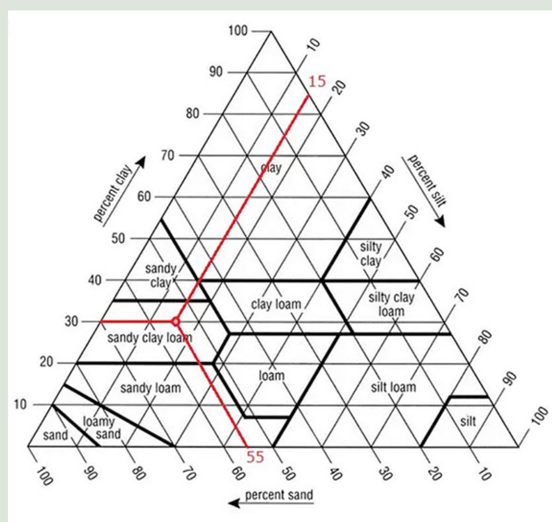

Figure 2. Texture Triangle example.

going down diagonally to the left. Finally, locate 55% on the sand axis, and draw a line going up diagonally to the left. The intersection is in a region called Sandy Clay Loam. The USDA also provides an interactive worksheet to calculate soil texture on the triangle. Visit **https://www.nrcs.usda.gov/resources/education-and-teaching-materials/soil-texture-calculator** and enter the information according to the instructions.

Many times, vegetation for land management is most impacted by the top eight inches of soil, called the surface horizon. Surface textures will matter most critically for seedlings and establishment success, and potentially for invasive pest management. Therefore field soil samples within the top eight inches may be necessary to properly prescribe land management decisions. Textures will affect pore spaces, bulk densities, etc. which will matter for water infiltration, root penetration, water availability, and nutrient availability for germination and establishment requirements.

For example, a loamy sand (70 to 90% sand particles) surface horizon will not have much soil structure (particles are loose and do not hold together well, if at all), and will have rapid infiltration rates that limit plant-available water in summer. Evapotranspiration rates will be high — especially in the hotter climates (losing water from the profile back into the atmosphere easily) because they are unable to hold onto the water; and because the source materials for sand are low in chemicals needed for plant growth, they will be low fertility and have very low organic matter and microbial communities. This type of surface soil will impact plant germination and establishment, which requires specific soil water availability long enough to support the germination and establishment process. Soil temperatures in a surface horizon that are loose, coarse textures will be higher and less mediated, being more in line with the air temperatures that may not be consistent enough for many species. Indian ricegrass is a good example of a species that does well in sandy soils — however, in order to succeed, it requires seeding at a deeper depth than many other grass species in order to provide more consistent soil temperatures for germination and establishment (Young et. al, 1994). In comparison, silty clay loams have good water-holding capacity due to the reduced pore sizes from the smaller, more similarly shaped, particles in the horizon to retain water and limit evapotranspiration. They will also provide greater plant-available nutrients and organic matter source material based on the rock types that source silt and clay particles, and slower infiltration rates keeping available water longer into the growing season. More water availability in the surface horizon opens the site for many species that have more specific growing requirements and may provide an environment unsuitable for a plant species that prefers drier soils for growth and more pore spaces for root establishment.

In general, these different types of soil textures will respond differently to disturbance as well. During a rainstorm, sandy surface textures typically allow more rapid infiltration than clayey textures, but lose the water more rapidly, become very dry, and limit plant-available water late into the growing season. However, clayey surface soils can hold water late into the growing season but can become very muddy and sticky, easily displaced by foot or tire traffic; and then when dry, they can become hard and repel water, and their size and shape make them susceptible to wind and water erosion. Surface coarse fragments can also play a role by reducing infiltration capacity, but can also limit water loss due to evaporation. For example, a gravelly loam has a slower maximum infiltration rate than a non-gravelly loam, but the gravelly loam would typically experience a lower rate of evaporative water loss.

Having a foundational understanding of soil particles and soil textures provides key information for land management by understanding an essential property for plant establishment, growth, and maintenance, as well as how they may respond to disturbance and climate fluctuations. In the next Soils Corner, we will discuss more about understanding the different types of soil map units used for USDA soil mapping design — consociations, associations, and complexes — what do these mean about how you interpret these reports and use the data?

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Save the Date
CNGA's 16th Annual Field Day at Hedgerow Farms
Grasslands Where You Least Expect Them
April 5, 2024

"Very well done: excellent speakers, knowledgeable staff, super organization!!!" — *Field Day Attendee*

CNGA Directors and staff, left to right: Chad Aakre (Conservation Chair), Sarah Gaffney (Secretary), JP Marié (President), Julia Michaels (Director), Jodie Sheffield (Treasurer), Justin Luong (Director), and Diana Jeffery (Administrative Director).

CNGA's 15th Annual Field Day at Hedgerow Farms:

Community supporting grasslands, grasslands supporting community

by Jodie Sheffield, Sod & Seed Specialist, Delta Bluegrass Co., CNGA Treasurer, and Diana Jeffery, CNGA Administrative Director. All photos by Jock Hamilton, unless otherwise specified.

CNGA's 15th Annual Field Day at Hedgerow Farms on March 31, 2023, was an absolute delight for anyone passionate about conservation, restoration, and the beauty of our native grassland ecosystem heritage. The theme "Community Supporting Grasslands, Grasslands Supporting Community" was beautifully reflected in the presentations and activities, which focused on raising awareness about the importance of preserving grasslands and emphasizing how these ecosystems play a pivotal role in supporting the well-being of wildlife and the community. Participants were genuinely impressed by the thoughtful organization, engaging activities, and wealth of knowledge shared by experts and enthusiasts alike.

Nestled in the heart of California's countryside, Hedgerow Farms provided the perfect setting for a celebration of the state's diverse and vital native grasslands. From the moment participants stepped onto the grounds, they were greeted by vibrant green hills and verdant fields of colorful native grasses and forbs. The farm's commitment to preserving and promoting California's precious native grasslands and indigenous flora was evident in every aspect of the event.

Over 18 environmental and farm specialists spoke on various topics including the challenges faced by grassland ecosystems and the innovative strategies employed to conserve and restore them. After a welcome and overview of the day — presented by CNGA President JP Marié and Hedgerow Farms Restoration Ecologist/Designer Julia Michaels — the day kicked off with an inspiring presentation by Dr. Valerie Eviner (Professor, UC Davis Department of Plant Sciences), whose passion for native grasslands and their significance was both contagious and enlightening. She set the tone for the day, emphasizing the importance of preserving California's native grasslands as a crucial step toward mitigating climate change and fostering biodiversity.

Speakers on stage throughout the day included Rachael Long (Retired UC Cooperative Extension Farm Advisor), Justin Luong (Assistant Professor, Cal Poly Humboldt Forestry, Fire, and Rangeland Department), Jeanne Wirka (Ecologist, Center for Land-Based Learning), and Jessica Kay Cruz (Senior Pollinator Conservation Specialist, Xerces Society).

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Community supporting grasslands, grasslands supporting community

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“Great speakers and the tours were excellent!” — *Field Day Attendee*

From top: Soil Scientist Vic Claassen gives the dirt on soils. A walking tour group stops to learn about soils with Claassen after crossing one of the straw bale bridges provided by Hedgerow Farms staff as “mud protection.” *Photo by Diana Jeffery.* Julia Zuckerman, Delta Bluegrass Co., delights in hands-on participation at the California Hawking Club’s exhibit.

Everyone participated in ongoing hay rides, walking tours, seed barn tours, and exhibits. Each activity was carefully curated by the Field Day Team to educate and inspire. Vic Claassen (UC Davis Department of Land, Air & Water Resources), Sarah Gaffney (Restoration Science Manager, River Partners), and Tanya Meyer (Senior Program Manager, Yolo County RCD) gave instructive talks at key stops along the walking tour. JP Marié (Manager, UC Davis Putah Creek Riparian Reserve), Chris Rose (Executive Director, Solano RCD), Bryan Young (Natural Resource Supervisor, Sacramento Regional County Sanitation District), and Jeff Quiter (Farm Manager, Hedgerow Farms) provided insightful information as they led the participants on hayride tours along the hedgerows and past seed production fields.

“You did a great job rolling with the impacts of weather. Thank you for throwing down straw, shells, and gravel for us. ” — *Field Day Attendee*

Hedgerow Farms personnel, Joshua Scoggin (Associate Ecologist), Alejandro Ramirez (Wildland Collections), and Manolo Sanchez (Wildland Collections), led tour groups, gave demonstrations, and answered questions on seed processing in the yard and seed cleaning barn.

“I learned so much, I don’t know where to start. It widened my thinking about resource management, and the resources available to incorporate this into my work. Wonderful program. Appreciate all the work you put into it, and your dedication to this vital work. Inspiring!” — *Field Day Attendee*

With over 180 people in attendance, Field Day at Hedgerow Farms was a resounding success. The theme’s emphasis on community support brought people together — conservationists, restoration practitioners, naturalists, botanists, resource managers, horticulturalists, agency representatives, farmers, ranchers, homeowners, seed producers, scientists, consultants, students, and native plant enthusiasts — all united by their dedication to conserving grasslands and a deep appreciation for the complex role grasslands play in maintaining the delicate balance of our environment.

The community theme was evident; it was heartening to witness the collective dedication of the attendees, Hedgerow Farms staff, the presenters, the many exhibitors, and sponsors to preserving California’s unique ecological heritage,

“I was very impressed with how many young people were interested and attended.” — *Field Day Attendee*

We are especially grateful to Hedgerow Farms and their staff for their incredible generosity and effort in hosting this event, including setting up morning firepits to warm our hands, and creating straw bale bridges, and shell and gravel pathways to guide us through recently rain-soaked fields.

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We would like to recognize the Field Day Sponsors and thank them for their continued generous support of our Mission—*Thank you!*

Delta Bluegrass Co. | Hanford ARC | Hedgerow Farms, Inc.
Miridae Landscape Architecture + Construction | Pacific Coast Seed | Precision Seeding
Rocky Mountain Bio Products | S & S Seeds | UC Davis Department of Plant Sciences

Fields of wildflowers including lacy phacelia (*Phacelia tanacetifolia*) greet event-goers at Hedgerow Farms.

Community supporting grasslands, grasslands supporting community

continued

Many people, including those mentioned above, were integral in planning this event. We want to acknowledge the Field Day Team for their outstanding work in once again planning and executing Field Day. Their dedication, creativity, and attention to detail were evident in every aspect of the event, making it a resounding success. From the exciting activities to the seamless organization, their efforts truly made the day special for everyone involved.

From left: Joshua Scoggin, Hedgerow Farms Associate Ecologist, demonstrates equipment in the seed barn. All aboard for one of the hayride tours of the farm and surroundings!

Figure 1. Photo taken three days after burns were implemented. Photo shows the surface of a plot where litter has been charred and consumed; however, several seeds of wild oat (*Avena fatua*) on the soil surface remain undamaged.

The Effects of Fuel Load on Prescribed Fire: Implications for Seed Banks in California Annual Grasslands

by Robert Fitch[1], Matthew Shapero[2], Marc Mayes[3], Kaili Brande[4], and Frank W. Davis[4]

Abstract

Prescribed burning is a widely used management tool for promoting native species, reducing non-native species, enhancing forage, and reducing fuel loads in grassland ecosystems. Understanding the relationship between fuel load and fire behavior is crucial for achieving desired management outcomes. This study aimed to investigate how fuel load affects prescribed fire behavior and its subsequent impact on seed bank density in a California annual grassland. The research questions addressed in this study were: Q1: *How reliable is fuel load in predicting prescribed fire behavior?* Q2: *How does residence time affect soil surface temperature?* Q3: *Does surface temperature impact seed bank density?*

We demonstrated that fuel load was predictive of fire behavior under mild weather conditions and residence time could be used to predict the maximum temperature at the soil surface. The prescribed fire in this study did not correlate to changes in the seed bank density, likely due to short residence times. Practitioners wanting to use prescribed burns to control annual grasses should focus on increasing residence time and timing burns appropriately for when target species will be most susceptible. Land managers can use these results to plan prescribed burns in annual grasslands.

Key Words

prescribed fire, fuel load, seed bank density, non-native species, annual grasslands

Introduction

Wildfire is an important ecosystem process in grasslands; therefore, land managers use prescribed burning as a management tool to promote native species, reduce non-native species, enhance forage, and reduce fuel loads (DiTomaso et al. 2006; Stromberg, Corbin, and Antonio 2007). The body of wildfire research has developed numerous robust fire models for predicting fire behavior for example; fuel load (biomass per unit area) is positively correlated with fire line intensity (energy output of flames) and rate of spread (how fast the fire moves) in herbaceous fuel beds when using standard surface spread models (Jolly 2007). Both fire intensity and spread rate are important considerations when planning burns. Studying how fuel load changes these parameters in the field in a prescribed fire context is an important first step toward linking fire behavior to ecological impacts and achieving management goals.

Common burn objectives include reducing the seed bank of non-native plants and promoting native plant species. However, prescribed burning has not always resulted in effectively reducing target non-

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native weed cover, and often the establishment of native plants is transient, only lasting two or three years before reverting back to pre-burned conditions (Melgoza, Nowak, and Tausch 1990; Brooks 2002; DiTomaso et al. 2006).

Species targeted for weed control include undesirable, invasive annual grasses; barbed goat grass (*Aegilops triuncialis*) (DiTomaso et al. 2001), Medusa head (*Elymus caput-medusae*) (Berleman et al. 2016), and downy brome (*Bromus tectorum*) (Kessler et al. 2015). In California annual grasslands, grasses often produce copious amounts of thatch which can collect their seed rain so that large portions of their seed banks are contained within the thatch layer and/or at the soil surface (Heady 1956; J. W. Bartolome 1976; Young et al. 1981). Annual grasses are adapted to low-intensity, frequent fires, and recover quickly after prescribed burns (Melgoza, Nowak, and Tausch 1990; D'Antonio and Vitousek 1992; Brooks et al. 2004; Diamond, Call, and Devoe 2012). Thus, low-temperature fires could actually enhance the germination of annual grasses. The length of time for the fire front to pass from one point to another is the residence time where fires with a longer residence time expose the soil to prolonged heating (Rothermel and Deeming 1980; Odion and Davis 2000). In order to kill seeds or plants, the prescribed fire must reach a hot enough temperature and burn long enough to expose plants or seeds to elevated temperatures (Sweet, Kyser, and DiTomaso 2008), resulting in a "kill-off." Killing the plants before their seeds become viable or killing the seeds on the landscape reduces their seed bank density (DiTomaso et al. 2006). However, very hot grassland fires can also kill desirable perennial bunch grasses (Schellenberg et al. 2020) and can cause negative ecological effects such as making the soil hydrophobic, reducing next year's forage, reducing soil organic matter, and volatilizing soil nutrients (DiTomaso et al. 2006). The amount of energy released onto the landscape per unit area greatly influences these ecological processes through soil heating (DeBano, Neary, and Ffolliott 1998; Neary et al. 1999; Odion and Davis 2000). Therefore, the temperature the soil surface reaches during a prescribed burn may be an important factor in determining the effectiveness of reducing the seed bank of annual grasslands.

Seed banks are important drivers of community assembly post-disturbance and are considered reservoirs of biodiversity (Thompson 2000; Gioria et al. 2021). Many studies analyze changes in plant cover and biomass pre- and post-fire, and while certainly linked to the number of individual plants, changes in the seed bank density (number of individuals) can provide key insights. For example, propagule supply is critical for determining the invasibility and regeneration of plant communities in California, and so, the seed bank represents a significant factor in determining the amount of available propagules, especially in annual plant-dominated systems (D'Antonio et al. 2001; Thomsen et al. 2006).

Previous grassland prescribed fire studies focused on examining the effect of burn season (fall or spring or summer) where the amount of aboveground biomass varies due to plant phenology, and could potentially alter fire behavior (Menke 1992; Meyer and Schiffman 1999; DiTomaso et al. 2001). However, few studies have examined the effects of prescribed fire on changes in seed bank density in California (Brooks 1999; Meyer and Schiffman 1999; Dyer 2002). Thus, our goal was to study how fuel load changes prescribed fire behavior and to understand the resulting changes in the seed bank density of a California annual grassland.

We ask three questions: Q1: How reliable is fuel load at predicting prescribed fire behavior? Q2: How does residence time affect soil surface temperature? Q3: If residence time affects surface fire temperature, does this result in changes to the seed bank density? We predict, H1: Fuel load will be positively related to rate of spread and flame height, H2: Residence time will be positively related to soil surface temperature, and H3: Increasing surface temperature will be negatively correlated with seed bank density.

Methods

We took advantage of a planned burn studying the effects of prescribed fire and grazing in annual grassland at the UC Sedgwick Reserve, Santa Ynez, CA (Mayes et al. in prep). The study location (34.701739, -120.036030) has a Mediterranean climate with cool wet winters and hot dry summers. The area is partly on Salinas (Pachic Haploxeroll) and Shedd (Typic Xerorthent) soils. The vegetation community at the study site is comprised predominantly of wild oats (*Avena barbata* and *A. fatua*) with non-native forbs including short pod mustard (*Hirschfeldia incana*), filaree (*Erodium* spp.), and prickly lettuce (*Lactuca serriola*). Though native plants are present, they account for much less cover and include purple needlegrass (*Stipa pulchra*), saw toothed goldenbush (*Hazardia squarrosa*), and doveweed (*Croton setiger*).The study location was previously tilled and grazed as part of cattle ranching and farming in the 1900s. The site was selected as being a representative California annual grass rangeland, a large open area for conducting burning operations, for the relatively flat ground (8.4±0.33% average slope across the entire study location, mean±sd), and the nearby access road.

In September 2020, 12 vegetation strips, each 10m x 30m, were established on similar topographic and slope positions. To create different fuel loads, strips were treated with one of four fuel modification treatments by mowing with a tractor set to different blade heights, with one treatment being unmowed and undisturbed. Treatment fuel loads were then mapped using a high-resolution (10 cm) remote sensing approach (Mayes et al. 2023) calibrated to in-situ grass clip-plot measurements (Bartolome, Frost, and McDougald 2006). The average fuel loads ± standard deviation post-mowing were: undisturbed plots-1992±43 lbs/acre, followed by 1425±87 lbs/acre, 1200±152 lbs/acre, and 1148±85 lbs/acre. Five 1m x 0.5m plots were established within each strip. To measure surface fire temperature, one metal tag was nailed to the soil surface in the center of each plot underneath the thatch. Each tag was painted with a series of paint strips (Tempilaq ®) that melt at different temperature thresholds (Brooks 2002). Temperature thresholds were: 107, 149, 177, 246, 316,

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343ºC. After the burn, the metal tags were inspected to determine which paints melted in order to estimate the maximum temperature at the soil surface. To measure rate of spread, steel t-posts were placed at 10m intervals alongside treatment strips as distance markers, and during the burn, researchers used stopwatches to determine the timing of the advancing flame front from one post to the next (Rothermel and Deeming 1980). Flame height was measured by taking photographs of flames at each t-post and then inspecting photos (Rothermel and Deeming 1980). We measured residence time as $t_r = D R^{-1}$ min, where D is flame height (m) and R is rate of spread (m/min) (Rothermel and Deeming 1980). Residence time, flame height, and rate of spread were then averaged across their respective intervals at the strip level, n=3 per fuel modification treatment. Soil surface temperature was measured at the plot level, n=15 per fuel modification treatment.

In order to measure seed bank density, three 5cm x 10cm soil cores were taken directly adjacent to the plot; this was done in order to not disturb the fuel structure and to ensure fire behavior was not altered within the plot. The samples were combined into a single composite sample per plot, n=15 per fuel modification treatment level.

On October 21, 2020, a series of separate fires were started at one end of each strip using drip torches and were allowed to run through the strip. The burning operation started at approximately 1000 and ended at 1500. During the burn, weather conditions were monitored using handheld Kestrel© anemometers and the average conditions were: 74.2ºC, 51.9% relative humidity, 0.739mph wind speed, and 4.77mph wind gusts. Fires were started as heading fires meaning the fire spreads in the same direction as the prevailing wind, in order to more accurately simulate wildfire conditions.

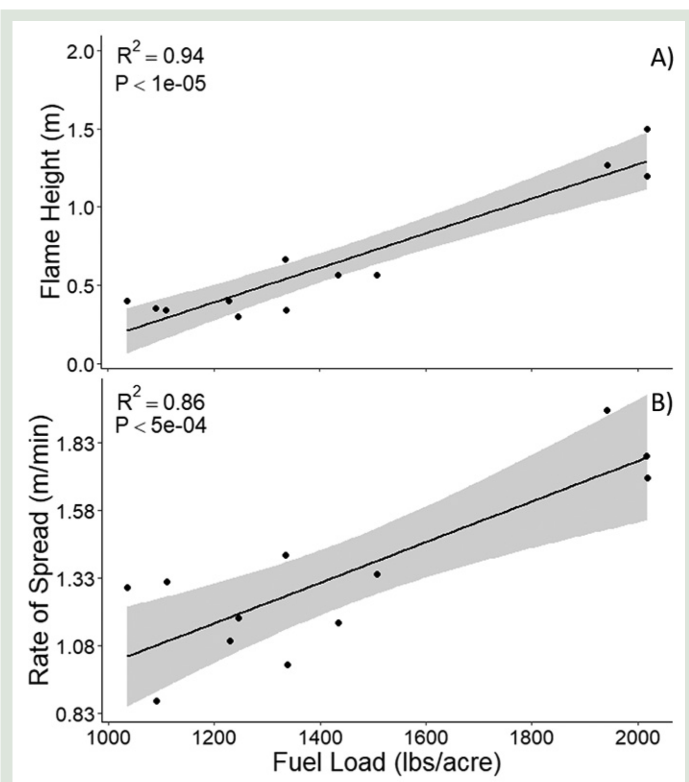

Figure 2. Linear regressions for flame height A) and rate of spread B) by fuel load. Grey shaded regions are 95% confidence intervals.

Post-burn seed bank samples were taken following the same protocol. Seed bank samples were grown at the UCSB greenhouses and were sown onto 1ft x 1ft x 1in garden trays over a bed of potting soil and allowed to germinate for three months. All annual grass seedlings were combined together as "annual grass" and forbs were identified to species when possible. Germinants were counted and culled bi-weekly. Thus, seed bank density represents the number of living seeds per plot area before and after the burn. In order to understand the effect of the prescribed burn on seed bank density, we calculated the change in seed bank density as delta (post burn - pre burn = delta), where negative numbers indicate a decrease in seed bank density (seeds were killed) and positive numbers indicate an increase in seed bank density (germination was stimulated). To analyze our data, we used simple linear regression models with block included as a fixed factor to control for variability in replicating mowing across the experiment. To answer: Q1: How reliable is fuel load at predicting prescribed fire behavior, we analyzed the relationship between fuel load and flame height and rate of spread. Q2: How does residence time affect the soil surface temperature, we regressed soil temperature by residence time. Q3: How does surface temperature affect seed bank density, we regressed delta by soil temperature.

Results

The primary species that germinated in trays were overwhelmingly non-native annual grasses (87% total germination) followed by several forb species in low quantities (combined 12% total germination) e.g., shortpod mustard (*Hirschfeldia incana*) and *Centaurea* species. Few native species germinated across the entire experiment (<1%); and therefore, were removed from the analysis in order to present data for only non-native annual grasses and forbs combined. Q1: Fuel load was a strong predictor of both flame height ($F_{3,8} = 57.43$, $P < 0.00001$, $R^2 = 0.94$, Figure 2A) and rate of spread ($F_{3,8} = 24.43$, $P < 0.0005$, $R^2 = 0.86$, Figure 2B). Q2: There was a significant positive relationship between residence time and surface temperature ($F_{3,8} = 4.64$, $P < 0.005$, $R^2 = 0.50$, Figure 3). Q3: There was no significant relationship between surface temperature and changes in the seed bank density ($F_{3,54} = 2.59$, $P = 0.15$, Figure 4). To test if residence time affected seed bank density we also used a simple linear regression; however, there was no significant relationship ($F_{3,54} = 3.73$, $P = 0.24$).

Discussion

Q1- How reliable is fuel load at predicting prescribed fire behavior? As predicted, fuel load was predictive of flame height and rate of spread in prescribed fire. More fuel on the landscape per area can increase fuel continuity which is an important property for carrying fire in grassland ecosystems that can be patchy due to disturbances from gophers or grazers creating gaps in the fuel bed (Brooks et al.

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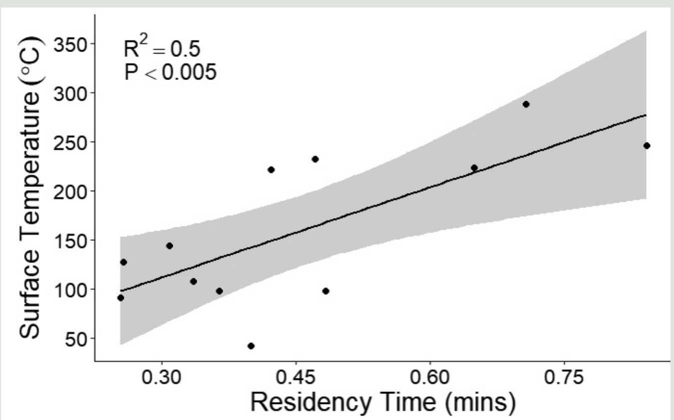
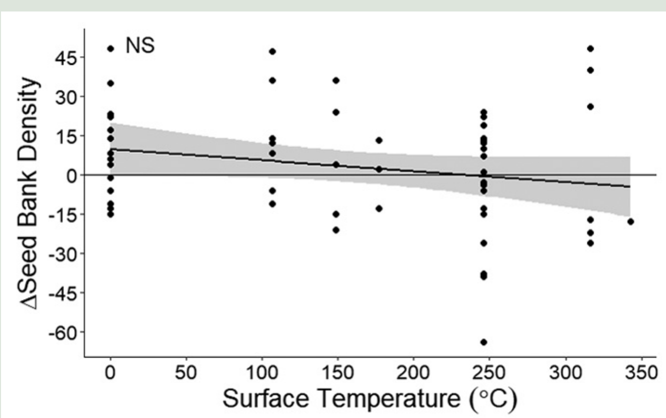
2004; Jackson and Bartolome 2007; Jolly 2007). Based on our treatment methodology, different fuel loads were created via mowing at different blade heights; thus, part of the strong relationship we observed was being driven by the actual height of the vegetation. We cannot disentangle the effect of fuel mass per area in our treatments from the height of the fuel bed; however, both are expected to be positively correlated (shorter vegetation has less mass). Therefore, fuel load here captured the effect of biomass and height of the fuel bed. These field-based results support a statewide effort that found reducing fuel load using grazing also reduced flame height when using surface spread models (Ratcliff et al. 2022). The next step in studying prescribed fire should empirically compare modeled fire behavior (flame height and rate of spread) with results like this field study in order to determine how accurate or inaccurate models developed for wildfire are at predicting prescribed fire behavior. Our results suggest that fuel load is predictive of flame height and rate of spread for prescribed fires taking place in relatively mild weather conditions in the late fall for fine herbaceous fuels primarily consisting of annual grasses. However, fire behavior is also driven by weather, topography, fuel type, and fuel moisture content. Topography interacts with weather to influence wildfire spread by driving wind flow patterns, providing physical barriers, and influencing convective heating during the fire (Povak, Hessburg, and Salter 2018). The relative abundance of fuel types (fine herbaceous or coarse woody) and their arrangement determines the fuel bed's capacity to carry fire and influences flame height (Westerling et al. 2003; Gedalof, Peterson, and Mantua 2005). Fuel moisture (water content inside living and dead plant tissue) is driven by weather and plant physiology (Jolly and Johnson 2018) where larger fuels require longer dry periods than fine fuels before they become flammable (Gedalof 2011). We did not manipulate these factors in this study but they are nonetheless essential elements to consider when applying this work to other contexts that may vary in topography, fuel structure, or occur under different weather conditions.





From top: Figure 3. Linear regression for soil surface temperature by flame residence time. Grey shaded regions are 95% confidence intervals. Figure 4. Linear regression for the change in seed bank density by surface temperature. Grey shaded regions are 95% confidence intervals.

Q2- How does residence time affect soil surface temperature? As predicted, residence time was positively correlated with maximum temperature experienced at the soil surface. We acknowledge that temperature is not a perfect representation of energy output, and measuring temperature at the soil surface does not measure soil heating (penetration of heat into the soil). However, soil organic matter at the soil surface can be rapidly consumed and nutrients within the top 1–2 cm of the soil could be volatilized away as a gas from the soil or made more readily available for plant uptake. All these factors have important ecological consequences and are temperature-dependent reactions (DeBano, Neary, and Ffolliott 1998; Neary et al. 1999). Understanding the temperature the soil reaches during a prescribed burn can at least be linked to other ecosystem processes, as studying actual soil heat penetration requires more technical knowledge and expensive equipment (Odion and Davis 2000). Therefore, practitioners could use residence time to predict how hot the soil could potentially reach during a burn and then determine if any resources would be at risk.

Q3- How does surface temperature affect seed bank density? Despite the effect of residence time on soil temperature, surface temperature was not related to changes in seed bank density. The near absence of native species in the seed bank is most likely due to their actual lack of abundance across the landscape. The study location has a history of disturbance, and combined with the dominance of non-native annual grasses, native species have been largely replaced and no longer exist within the seed bank. These results support the body of literature that native species are severely propagule-limited in California annual grasslands with histories of disturbance (Turnbull, Crawley, and Rees 2000; Nolan, Dewees, and Ma Lucero 2021). There are three possible explanations for the weak response of non-native species observed in the seed bank: 1) The fire did not reach lethal temperatures; 2) Flame residence time was too short in order to adequately expose seeds to elevated temperatures; and/or 3) Since the burn was conducted in fall, annual grass seeds dispersed onto the ground where they are potentially protected from heat. The prescribed fire did produce temperatures (150–200°C for annual grasses) hot enough to kill seeds (Daubenmire 1968; Sweet, Kyser, and DiTomaso 2008) of the majority

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of the species present at our site (Figure 3). Fine herbaceous fuels ignite quickly, combust rapidly, and sustain less heat than woody fuels. Photos taken of plots after the burn indicated that patches of thick thatch, though completely burned above, had unburned pieces at the soil level (Figure 1). Thus, the fire spread across the surface of the thatch where fuel particles were fully consumed before igniting deeper layers. Therefore, heat was not sustained despite reaching a lethal magnitude of temperature at the soil surface. Thus, the flame residence time was likely too short to kill these annual grasses. Lastly, these fires burned as heading fires (with the wind direction to increase spread) in the fall after grass seeds dispersed, which would be atypical for prescribed fire for invasive species control. If the prescribed burn was conducted in Spring when seeds were still attached to the culms (vertically suspended), and conducted as a backfire (burning against the wind which increases residence time), then seeds would have been openly exposed to the flames for longer without the insulating effect of a thick thatch layer (Kyser et al. 2008; Berleman et al. 2016). These results support timing burns with plant phenology while seeds are high in moisture content and on the culms before being dispersed on the ground where they could find refuge from the heat of the fire (Meyer and Schiffman 1999; Kyser et al. 2008). We observed a large amount of variation in the change of seed bank density related to surface temperature where the hottest temperatures had both increases and decreases in the seed bank (Figure 4). A likely explanation is fine-scale heterogeneity of fuel where the metal tags might have been exposed to flames but seeds at the sampling location of the cores were not, which could explain why we did not find clear patterns. However, non-native annual grasses are adapted to low-intensity, frequent fires; therefore, this prescribed fire could be considered comparable to natural conditions where we would then not expect to see grasses killed (D'Antonio and Vitousek 1992; Keeley and Brennan 2012). Thus, this work supports the grass-fire-cycle as a stable ecosystem under mild fire conditions (D'Antonio and Vitousek 1992).

Conclusions

Our study offers insights for prescribed burning in California annual grasslands. We demonstrated that fuel load was predictive of fire behavior under mild weather conditions as expected, and that land managers can use these data to help plan prescribed burns in annual grasslands. Residence time could be used to predict the maximum temperature at the soil surface so managers can weigh risks of very hot temperatures with their management objectives. The prescribed fire in this study was able to generate lethal temperatures on the soil surface. However, the seed bank density did not change, likely due to the short residence time of the flames as well as the late-season timing of the burn where grass seeds had already dispersed. Practitioners wanting to use prescribed burns to control annual grasses should focus on increasing residence time of the fire through using back burns or adding woody fuel, as well as timing burns appropriately for when target species will be most susceptible (Berleman et al. 2016; DiTomaso et al. 2006; Bender 2018). The prescribed fire in fall under relatively mild weather conditions did not impact the germination of annual grasses which is critical for forage production, an important consideration for ranchers wanting to control fuel build-up while maintaining productive lands (Stechman 1983).

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Back cover: Pepperwood Preserve's Three Tree Hill beneath a cloudy October sky (October 2021). *Photo credit: Makayla Freed, Pepperwood Preserve.*