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Impacts of competition and herbivory on native plants in a community-engaged, adaptively managed restoration experiment

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Abstract

Restoring biodiversity to degraded sites in the wildland–urban interface is challenging due to many factors, including competition with non-native species and increased herbivore pressure. In a unique collaboration between land managers, environmental educators, students, and academic ecologists, we tested the effectiveness of multiple restoration techniques in an adaptive management framework, modifying methods each year based on results in the previous years. We evaluated the impact of non-native species and rabbit herbivores on soil moisture and native plant growth. We added native seedlings to our site either immediately adjacent to existing native shrubs (potential nurse plants) or in the open. One native species, *Artemisia californica*, was significantly negatively influenced by the presence of an existing shrub and grew more in the open in both a wet and a dry year. Another native species, *Eriogonum fasciculatum*, experienced high mortality by rabbit herbivores when it was not protected by fencing. Fencing also increased abundance of non-native plants, so a combination of fencing and non-native removal without a nurse plant was optimal for restoration. Soil moisture was greater in the open than under existing native shrubs, indicating that existing shrubs decreased soil water available to seedlings. Data collected by trained students was indistinguishable from that collected by professional ecologists. Our use of community-engaged science demonstrates how scientific adaptive management experiments can include a diversity of participants and allow for immediate dissemination and implementation of results.

KEYWORDS

citizen science, coastal sage scrub, facilitation, inter-annual variation, Mediterranean-climate system, nurse plant, passive restoration

1 | INTRODUCTION

Increasing environmental degradation associated with land-use and climate change has increased the need for ecological restoration projects (Corlett, 2016; Suding, 2011). Restoration studies can be designed as community-engaged science, also known as citizen science, by involving non-scientists in scientific research as a way of tackling research questions that require extensive datasets and as a mechanism for engaging non-scientists in the scientific process while achieving specified learning outcomes (Bonney, Phillips, Ballard, & Enck, 2016; Cooper, Dickinson, Phillips, & Bonney, 2007; Silvertown, 2009). Effective projects can benefit both researchers and public participants as data needs and learning goals overlap (Bonney et al., 2009). Projects can be experimental, based on natural history observations, or related to environmental monitoring to generate hypotheses or make land management decisions (Miller-Rushing, Primack, & Bonney, 2012). Community scientists have successfully undertaken important work, with data they collect influencing local land policy and management decisions (Jordan et al., 2016). Here, we present results from a 3-year community-engaged study to experimentally evaluate methods for restoring a degraded site within a California State Park located in Orange County, CA. Our objective was to conduct community-engaged science in a collaborative, adaptive management framework to provide timely solutions to conservation challenges.

Increasing native biodiversity in degraded sites within the wildland–urban interface is a key management challenge. In highly diverse Mediterranean climate systems, much of the area originally covered by native species has been converted to human uses (Klausmeyer & Shaw, 2009; Underwood, Viers, Klausmeyer, Cox, & Shaw, 2009). Protected open space has been heavily impacted by global change factors, including increases in drought, temperatures, anthropogenic nitrogen deposition, and fire frequency (Lana et al., 2006; Syphard, Franklin, & Keeley, 2006; Vourlitis, Pasquini, & Mustard, 2009). Invasion of non-native species, primarily annuals, is an additional extreme impact to native Mediterranean-climate systems (Funk, Standish, Stock, & Valladares, 2016; Kimball et al., 2018; Minnich & Dezzani, 1998). In the coastal sage scrub system of Southern California, a combination of global change stressors can convert open space from a diverse, shrub-dominated habitat to low-diversity, invaded annual grassland (Kimball, Goulden, Suding, & Parker, 2014; Talluto & Suding, 2008). Loss of diverse coastal sage scrub vegetation means less habitat for threatened bird species such as the California gnatcatcher (VanTassel, Bell, Rotenberry, Johnson, & Allen, 2017). The system can be stuck in a degraded state as established non-native annual plants out-compete native shrubs at the seedling stage, making re-establishment of native shrubs difficult (Cox & Allen, 2011).

Restoration of degraded habitat typically involves removing non-native plants from the landscape and actively adding native plants, either from seed or as container plants (Cione, Padgett, & Allen, 2002; Kimball et al., 2015). Restoration may be described as "active" restoration, in which native plants are actively added to the landscape as non-natives are continually removed, or "passive" restoration, a more cost-effective method in which non-natives are removed to allow native communities to recover in the absence of competition with invasive species (DeSimone, 2013; Holl & Aide, 2011). Herbivory can decrease the establishment of native seedlings, so caging or fencing of seedlings is often necessary (Averett, Endress, Rowland, Naylor, & Wisdom, 2017; Sheffels, Sytsma, Carter, & Taylor, 2014). In coastal sage scrub, non-native grasses also experience herbivory, and herbivores may help to reduce the competitive effects of non-natives (DeSimone & Zedler, 2001; Wainwright, Wolkovich, & Cleland, 2012). In Mediterranean-climate systems, adult shrubs may act as "nurse plants" by creating moist microsites that increase germination and early growth of native shrub seedlings (Cuevas, Silva, Leon-Lobos, & Ginocchio, 2013; Navarro-Cano, Verdu, & Goberna, 2018; Padilla & Pugnaire, 2006). Alternatively, adult shrubs may compete with seedlings for limited water, decreasing seedling survival (Marquez & Allen, 1996; Noumi, Chaieb, Michalet, & Touzard, 2015). According to the stress gradient hypothesis, the role of competition versus facilitation varies depending on abiotic stress, with facilitation (the nurse plant effect) more common in high-stress environments and competition more common in high resource environments (Bertness & Callaway, 1994).

We report on a 3-year ecological study to evaluate techniques for restoration of degraded coastal sage scrub in a collaboration between an academic institution, a California State Park, the non-profit partner to the park, 20 local fifth grade teachers from five local school districts, and 1,085 fifth grade students. We employed an adaptive management framework to modify our research questions and experimental design each year (Figure 1), using data to iteratively modify management actions (Kimball & Lulow, 2019; Walters & Hilborn, 1978; Williams, 2011). We asked the following research questions: (a) Did the removal of non-native species or the exclusion of herbivores increase "health" (stomatal conductance, growth, and survival) of native shrubs? (b) Did established adult shrubs facilitate seedling survival and growth and did the effect of a nurse plant vary depending on the amount of rainfall during the growing season? We hypothesized: (a) Native shrubs will have greater establishment and growth in weeded plots due to increased soil moisture and in fenced plots due to decreased herbivory; (b) Native shrubs will have greater survival and growth when planted adjacent to adult native shrubs than when planted in open spaces. The facilitative effect of a nurse plant will be stronger in a dry year. Here, we present results of our collaborative ecological study to address the challenge of increasing native shrub establishment and cover in degraded sites.

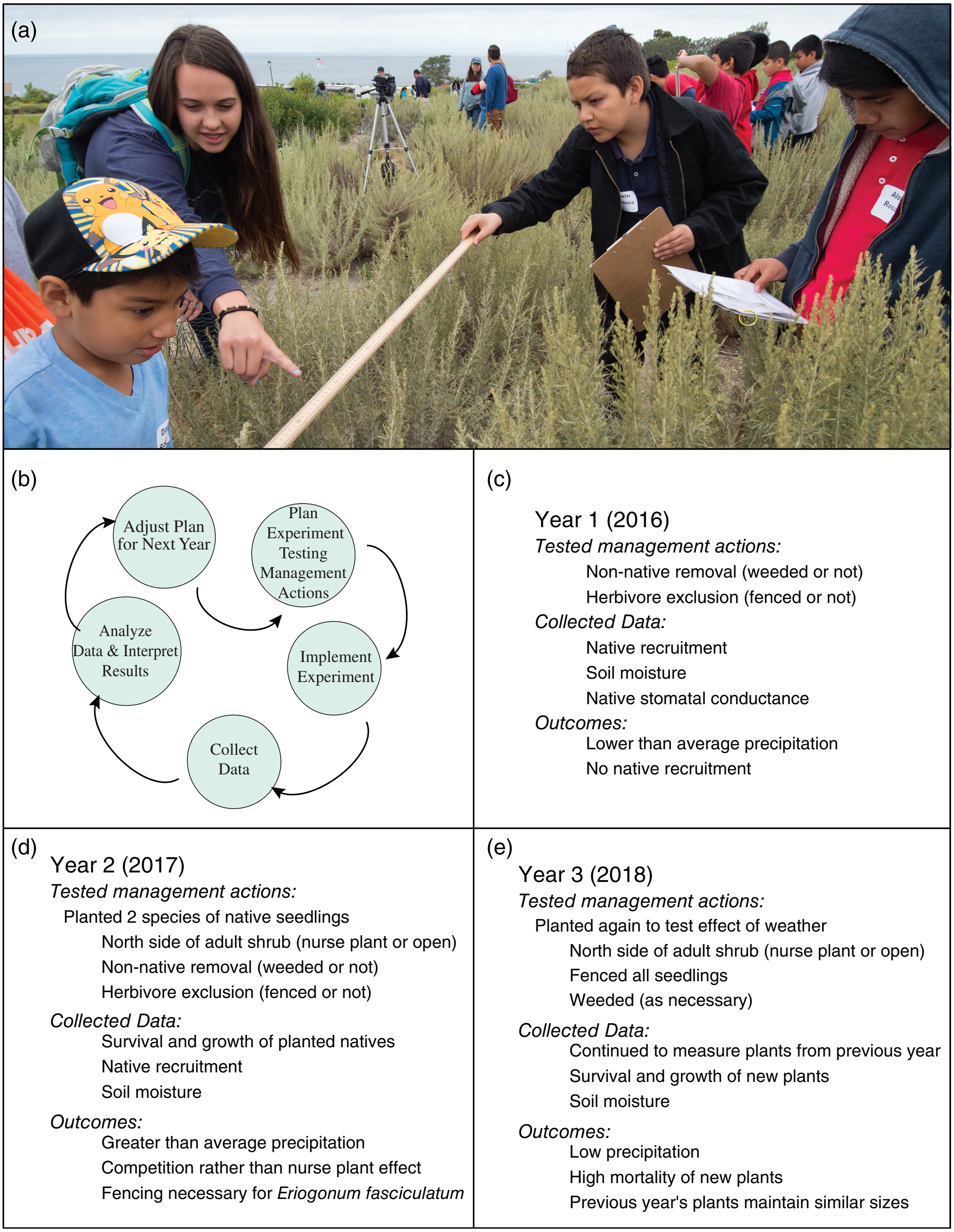

FIGURE 1 A, Photograph of undergraduate student intern supervising fifth grade students in the collection of ecological data at our study site (photo credit: Steve Zylius, UCI). B, Iterative adaptive management framework; C, Year 1 management actions, description of data collected, and outcomes; D, Year 2 actions based on outcomes from the previous year, description of new data collected, and outcomes; E, Year 3 actions based on outcomes from the previous year, description of new data collected, and Year 3 outcomes

2 | METHODS

The study was conducted in the Moro Canyon area of a California State Park (33°33′52″ N 117°49′16″W). The total area of the site is 0.261603 ha, and the experimental plots were roughly evenly distributed across the site, based on the availability of existing native shrubs. Documented disruption to native plants at the site began in the early 1800s, when the canyon was used for cattle grazing. In the 1950s, the area was used as a seasonal trailer park that evolved into year-round trailer homes until the land was acquired by CA State Parks in 1979. In the 1990s, the park began to implement restoration in parts of Moro Canyon. In 2016 when our study began, the study area was dominated by a few non-native, invasive species, primarily non-native annual grasses in the genus *Bromus* and non-native forbs such as *Brassica nigra*. Estimates of cover pre-restoration indicated that non-native species made up approximately 80–85% of the vegetation at the site. The remaining cover included some scattered native shrubs, primarily *Artemisia californica*, but also *Rhus integrifolia*. Audubon cottontail rabbits, *Sylvilagus audubonii*, were observed in abundance regularly at the site and appeared to be responsible for most herbivory. Rainfall in the area (Corona Del Mar Station 169) averaged 30.25 cm per growing season (July 1 to June 30, averaged from 1959 to 2017), and the 3 years of the study were characterized by extreme variation, from dry to wet to very dry (20.29, 38.74, and 11.68 cm).

The study was designed and conducted in an adaptive management framework by a combination of ecologists, science educators, undergraduate student interns, and fifth grade students (Table 1, Figure 1). We identified fifth grade students as collaborators because the content was aligned with fifth grade Next Generation Science Standards and students at this age are capable of working independently in a wilderness area. We employed multiple methods to ensure data quality, since that is a concern with community-engaged science (Bonney et al., 2009; Silvertown, 2009), especially when K-12 students are involved in data collection (Delaney, Sperling, Adams, & Leung, 2008). First, all fifth grade students watched videos of staff ecologists describing the importance of the study and demonstrating data collection methods. Second, teachers introduced ecological concepts and the study design through a 1.5-hour in-class curriculum, aligned with Next Generation Science Standards. Third, data sheets were carefully designed to provide student support and to ensure data quality. Fourth, students conducted an initial site visit to become familiar with the area prior to data collection. Total time of student preparation prior to data collection varied from a minimum of 6 hours to a maximum of 11 hours depending on teacher and school. Undergraduate interns began training in plant identification, data collection, and outdoor education each October. By the time data collection began each spring, interns and fifth grade students were comfortable with the site and worked together during field trips. Measurements of soil moisture and stomatal conductance were taken with a Campbell Scientific Hydrosense II fitted with CS659 water content sensor and Decagon Devices SC-1 Leaf Porometer, respectively. Since these instruments display values on a screen, data quality is best ensured through training in proper use of the instruments, which was covered during field training sessions. Seedling size, measured with a meter stick, may be more subjective. To quantitatively assess the quality of shrub size data, we had three groups (professional ecologists, undergraduate interns, and fifth grade students) measure the same 31 seedlings on two consecutive dates in May 2018. We used mixed-model, repeated measures analysis of variance (ANOVAs) to determine whether the height, length, and width measurements or the estimated shrub volume calculated from these measurements varied significantly based on the type of data collector, with the individual plant as the repeated subject in the analyses.

The first year (2015–2016 growing season) of this study, we tagged 28 similarly-sized individuals of the dominant native shrub, *Artemisia californica*, and randomly assigned each to an herbivore-exclusion treatment (fenced or not) and a non-native removal treatment (weeded or not) in a full-factorial design with seven replicates. Fences were erected in a 1-m diameter surrounding the canopy of the shrub. Removal of all non-native species was conducted in a 1-m diameter surrounding the canopy of the shrub by hand

TABLE 1 The type of researcher, the organization with which they are affiliated, and the number of participants in each year of the study

Type of researcher	Type of organization	Participants Year 1	Participants Year 2	Participants Year 3
Professional environmental scientists	State Park	1	1	1
	University research center	4	4	4
Professional science educators	Non-profit partner to State Park	4	4	4
	University School of Education	4	3	3
Undergraduate student interns	University research center	14	16	20
Fifth grade teachers	5 local school districts	3	7	18
Fifth grade students	5 local school districts	74	330	600

weeding twice (Jan. and April) each year, similar to management practice in this region.

Data collection in Year 1 (spring 2016) included repeated measurements of adult *A. californica* stomatal conductance and soil moisture. Stomatal conductance measurements were taken at three different points on the shrub and later averaged after no significant difference was detected based on position of measurement. Soil moisture was recorded at 50 cm away from the base of the shrub on the north and south side of each shrub to capture any differences in soil moisture due to shading. Measurements were taken five times during the growing season (late January through May).

In Year 1, there were no native seedlings that naturally recruited in our study plots suggesting a lack of a seed bank, so we amended this project in Year 2 to include planting seedlings of two native shrub species, *Artemisia californica* and *Eriogonum fasciculatum*. Both of these species are dominant members of the coastal sage scrub community and are early colonizers of degraded grassland sites (DeSimone & Zedler, 2001; Rundel, 2007). We modified our study on individuals of native *A. californica*, to address our second research question, regarding whether adult shrubs act as nurse plants facilitating seedling establishment. Tagged *A. californica* individuals were used as the nurse plants for half of the plots in which seedlings were planted. The other half of the seedlings were planted in open areas within the study area.

We collected seeds of *A. californica* and *E. fasciculatum* from within the State Park in September 2016. We germinated seeds in the university greenhouse, transplanted seedlings into 10 cm pots, and planted seedlings at the site in January 2017. For testing the nurse plant effect, we planted seedlings 50 cm away from the base of the tagged shrub on either the NE or NW side of the existing shrub to maximize possible facilitative effects of shading (Nobel & Zutta, 2005). One seedling of each species was planted in each plot and randomly assigned to either the NE or NW direction, planted at least 50 cm from each other. In addition, 28 new plots were established in open areas not occupied by adult *A. californica* individuals. The 28 seedling-only plots were randomly assigned to one of the four combinations of weeded or not and fenced or not ($N = 7$ per treatment). Seedlings were watered immediately after planting and again after 1 week, and not watered again due to high rainfall in that year (spring 2017).

We conducted repeated measurements of seedling size, soil moisture, and % cover of non-native plants in all experimental plots. Size measurements, taken at the base of the shrub, included height (H), width at the widest point (L), and width at a 90° angle from the widest point ($W_{90°}$). Shrub volume, assumed to be cylindrical based on previous work estimating volume for these species (Griffoul 2016), was calculated using the formula $V_{\text{shrub}} = \pi * ([W_{90°} + L]/4)^2 * H$. We recorded any dead seedlings each time seedling size was measured. We calculated growth of each seedling as the linear slope of height over time during the 2017 growing season. Soil moisture was measured on the north and south side of each plot, capturing areas with and without seedlings.

In Year 3 of the study (January 2018), we added 14 more plots containing *E. fasciculatum* and *A. californica*, again adjusting the experimental design (Figure 1). We established additional plots in 2018 to determine whether the influence of a nurse plant varied depending on weather during the year of establishment. Year 2 (spring 2017) was very wet, so we wanted to know if there would be a shift from competition to facilitation with a change in seasonal rainfall. Of these 14 plots, seven contained an adult *A. californica* individual while the rest were established in an open space without nurse plants. This year we fenced all plots, since most *E. fasciculatum* seedlings did not survive in unfenced plots during the previous year (2017). The other difference was that we used plants grown from seed in 2016, so the seedlings were now 1 year older and larger, having spent their entire first year growing in pots.

Data were analyzed by repeated measures ANOVAs, with herbivore treatment (excluded with fencing or unfenced control), weeding treatment (weeded or control), date of measurement, and all interactions included in the model. Plot number was included as a random factor in the model to control for spatial variation, since two seedlings were planted in each plot. We used logistic regression to determine whether seedling survival varied depending on nurse plant, fencing, weeding, species, or a combination of factors. We used mixed-model ANOVAs to determine whether the slope of height over time varied with species (*A. californica* or *E. fasciculatum*), nurse plant (yes or no), fenced (yes or no), weeded (yes or no), and all interactions. The majority of *E. fasciculatum* seedlings in unfenced plots died during 2017, so by 2018 low sample sizes in those plots meant that Year 3 analyses included all interactions for four of the five main effects (date, species, nurse plant, and weeded) and only included the main effect of fencing, which effectively tested the influence of fencing on *A. californica*. Dead seedlings were recorded during all data collection events, and we calculated the number of days that seedlings were alive, or the "lifespan" of the plants. The majority of seedlings planted in 2017 were alive on the last census date, so we used the number of days between planting and the last census to calculate lifespan for the purposes of determining whether treatment influenced the amount of time that plants were able to survive. We tested whether lifespan varied depending on treatment using mixed model ANOVA with species (*A. californica* or *E. fasciculatum*), nurse plant (yes or no), fenced (yes or no), weeded (yes or no), and all interactions as fixed factors, with plot as a random factor. For new plants added to the site in Year 3, only species and nurse plant were included as factors, since all Year 3 plants were fenced and weeded. Soil moisture data from the seedling plots established in Years 2 and 3 were analyzed similar to plant size data, but with the addition of location of measurement (north or south) as an additional fixed factor. Separate linear regressions for each species were used to determine whether the average slope of height over time varied depending on average soil moisture in each treatment.

3 | RESULTS

The identity of the data collector did not significantly influence height measurements ($F_{2,30} = 0.64$, $p = .53$, Tables S1 and S2). Measurements of shrub length at the widest point and width (90° from widest point) were less reliable, and varied significantly depending on the data collectors (length $F_{2,30} = 7.89$, $p = .002$; width $F_{2,30} = 9.48$, $p = .001$). This is presumably because it was difficult to identify the exact point at which the shrub was widest. When all three measurements were combined to estimate shrub volume, the identity of the data collectors did not significantly influence results, indicating the two measurements, although taken at slightly different locations by different groups of researchers, combined to provide reliable information on shrub size (volume $F_{2,30} = 0.95$, $p = .40$).

In Year 1 (2016), soil moisture was not significantly impacted by fencing or weeding, and decreased through the growing season in all plots at approximately the same rate (Figure S1, Table S3). Stomatal conductance of existing adult *A. californica* increased and then decreased significantly through the growing season (Figure S1, Tables S3 and S4). There was a significant date-by-fenced-by-weeded interaction, such that on some measurement days, fenced and weeded shrubs had the greatest stomatal conductance, while on other dates this treatment combination had the lowest value (Figure S1, Tables S3 and S4). The first year was extremely dry and no native seedlings established naturally, which led us to plant seedlings in Year 2 of the study.

During the 2017 (Year 2) growing season with more than average precipitation, there were a number of non-native plants observed in the study plots (Figure S2, Table S5). Non-native cover, consisting primarily of the annual forb *Brassica nigra*, was highest in fenced and un-weeded plots, followed by control plots (Figure S2, Table S5). Open plots without nurse plants had higher non-native cover than plots with nurse plants (Figure S3, Table S5). The weeding of invasive species had no influence on native seedling survival (weed $X^2 = 0.02$, $p = .887$), despite the abundance of non-natives in un-weeded plots in Year 2. However, there was a strong positive effect of fencing on native seedling survival, due to the much greater survivorship of *E. fasciculatum* seedlings in fenced plots compared to unfenced plots (fence $X^2 = 17.23$, $p < .0001$). *Artemisia californica* seedlings survived in significantly greater numbers than *E. fasciculatum* seedlings when not fenced (Table S12, species-by-nurse interaction $X^2 = 14.40$, $p = .0001$). *Artemisia californica* seedlings grew taller over time in both fenced and unfenced plots, while *E. fasciculatum* seedlings grew taller in fenced plots only (Figure 2, Tables S6 and S7).

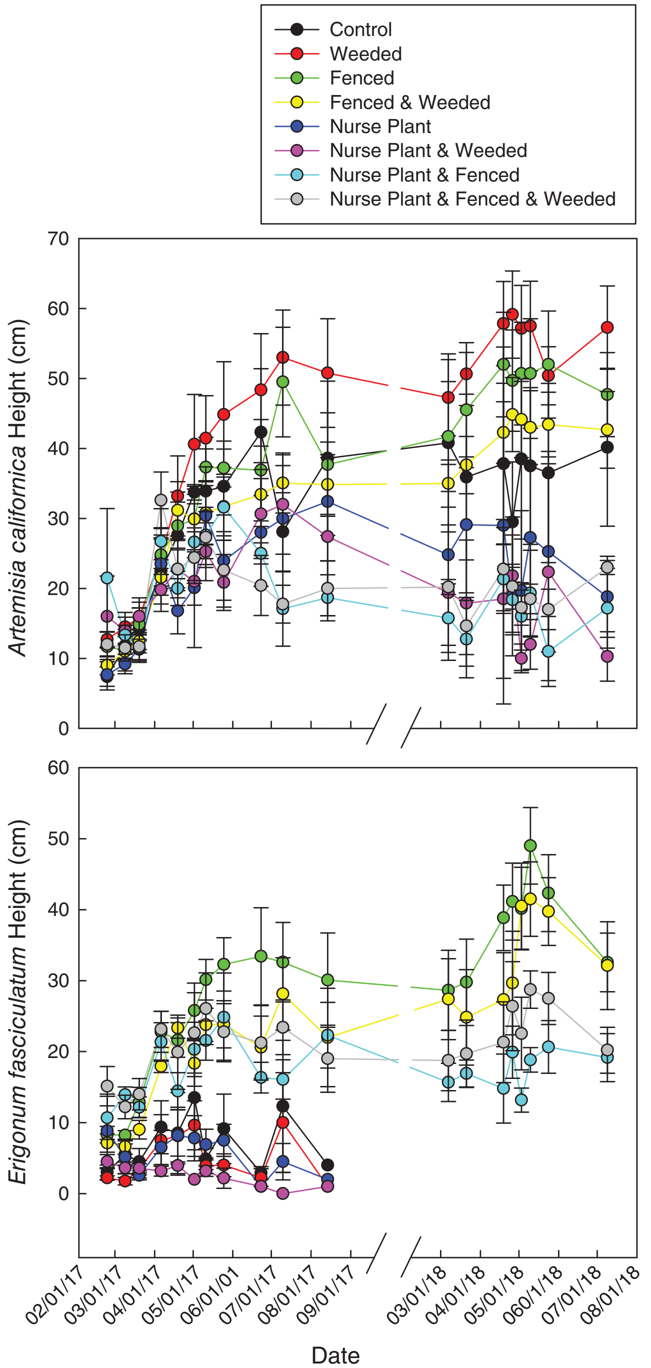

FIGURE 2 Average height of *Artemisia californica* (top) and *Eriogonum fasciculatum* (bottom) seedlings planted in the different treatments during the 2017 and 2018 growing seasons (Years 2 and 3 of the study). Values are means + or − 1SE. Lines that stop before the last point indicate treatment combinations in which all individuals died before the end of the study

Seedlings of both species had lower survival when planted adjacent to a "nurse" plant than when planted in open plots (nurse $X^2 = 4.43$, $p = .035$). *Eriogonum fasciculatum* seedlings grew largest in the plots without nurse plants and with fencing (Figure 2, Figure S4). Analyses of the slope of height over time indicated that *A. californica* seedlings planted in plots without a nurse plant, without fencing, and with weeding grew significantly more than some of the other seedling treatments (Figure 2, Table 2, Figure S2 and S4, Table S7). Results consistently indicated competitive, rather than facilitative, interactions between adult plants and seedlings. The majority of seedlings (58%) planted at the site in 2017 were still alive in 2018, but lifespan was significantly shorter for *A. californica* planted adjacent to nurse plants and for unfenced *E. fasciculatum* (Figure 2, Table S8 and S9). In contrast, year-old potted plants that were added to the site in 2018 had very low survivorship (38%), and both species had higher survivorship in open plots than in plots with a nurse plant ($X^2 = 6.90$, $p = .001$). *Artemisia californica* individuals planted in 2018 survived longer than *E. fasciculatum* individuals (species $F_{1,11} = 17.57$, $p = .0015$).

TABLE 2 Results from analysis of variances on the effects of treatment on planted native seedling growth (the slope of height over time during the 2017 growing season)

Effect	DF (numerator, denominator)	*F* value	Pr > *F*
Species	1, 46	3.93	0.0534
Nurse	2, 46	4.94	**0.0114**
Species*nurse	2, 46	2.05	0.1409
Fenced	1, 46	0.01	0.9131
Species*fenced	1, 46	7.53	**0.0086**
Nurse*fenced	1, 46	0.94	0.3384
Species*nurse*fenced	1, 46	0.18	0.6745
Weeded	1, 46	0.05	0.8166
Species*weeded	1, 46	1.15	0.2895
Nurse*weeded	1, 46	0.07	0.7885
Species*nurse*weeded	1, 46	0.44	0.511
Fenced*weeded	1, 46	0.1	0.7583
Species*fenced*weeded	1, 46	0.13	0.7221
Nurse*fenced*weeded	1, 46	5.34	**0.0254**
Species*nurse*fenced*weeded	1, 46	0.03	0.8748

Note: Significant factors and interactions ($p < .05$) are in bold text.

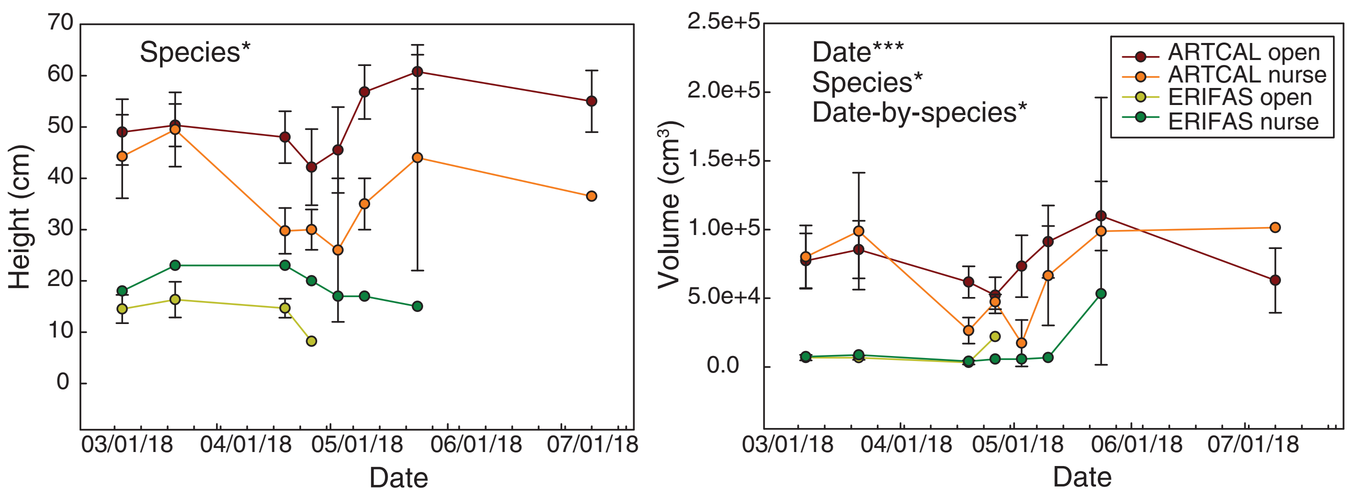

FIGURE 3 Height and volume of new plants added to the site in 2018 and measured through the 2018 growing season. Lines that stop before the last point indicate treatment combinations in which all individuals died before the end of the study. Significant factors are listed inside each panel, where $^*p < .05$, $^{***}p < .001$. Full model results are presented in Table S10

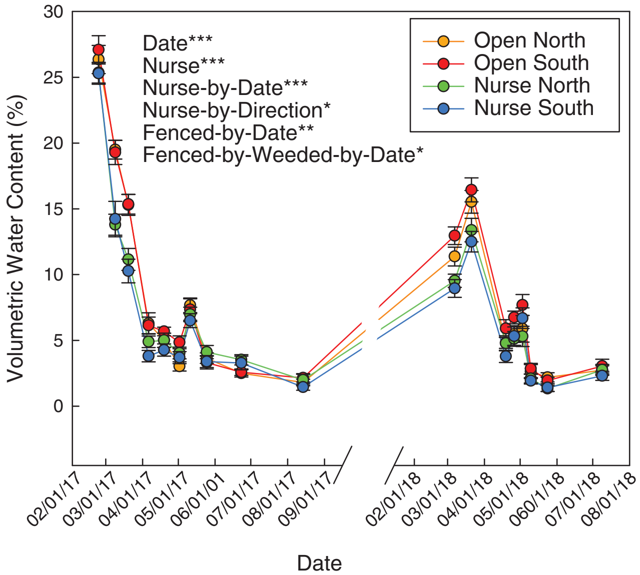

FIGURE 4 Soil moisture over time, from Feb. 2017 through Aug. 2018, in open plots and in nurse plant plots. Significant factors are listed inside the panel, where *$p < .05$, **$p < .001$, and ***$p < .0001$. Full model results are presented in Table S13

There was no significant effect of nurse plant ($F_{1,11} = 1.72$, $p = .22$) or a species-by-nurse plant interaction for the lifespan of 2018 seedlings ($F_{1,11} = 1.45$, $p = .25$). The presence of a nurse plant did not significantly influence height over time or volume over time for the plants added to the site in 2018 (Figure 3, Tables S10 and S11).

Soil moisture varied through time, but was generally higher in plots without nurse plants (Figure 4, Table S13). Measurements taken on the south side of open plots were higher than measurements taken on the south side of plots with nurse plants, while differences between nurse and no nurse plots were not significant for measurements taken on the north side of the plots. There was a significant nurse-by-date interaction, because plots containing nurse plants had significantly lower soil moisture during wet times but not during dry times of year. Growth of *A. californica* seedlings in each treatment was significantly positively influenced by average soil moisture ($R^2 = 0.75$, $p = .005$, $N = 8$), but this relationship was not significant for *E. fasciculatum* ($R^2 = 0.17$, $p = .31$, $N = 8$).

4 | DISCUSSION

Existing *A. californica* shrubs competed with seedlings of *A. californica* and *E. fasciculatum*, rather than acting as "nurse" plants in both a very wet and a very dry year, contrary to our hypothesis and to other studies indicating that resource availability influences the relative importance of competition and facilitation (Maestre, Callaway, Valladares, & Lortie, 2009). In the first year, weeding alone was not sufficient to restore a degraded site with limited scattered native shrubs, another result that contradicted other studies conducted in similar systems, in which non-native removal increased the establishment and growth of natives (Cione et al., 2002; Eliason & Allen, 1997; Kimball et al., 2015). The adaptive management framework allowed us to adjust our actions by adding seedlings, which was critical to increasing native cover at our site. Our finding that excluding herbivores was necessary for the successful establishment of *E. fasciculatum* but not *A. californica* demonstrates that the susceptibility of native seedlings to herbivory can vary by species, which has been found in other systems as well (Sigcha, Pallavicini, Camino, & Martinez-Ruiz, 2018).

Plant height measurements taken by fifth grade students and undergraduate interns were not different from that collected by professional ecologists, providing confidence in the quality of our data and corresponding with other studies in which well-trained students and community members collected data of the same quality as professional scientists (Bois, Silander, & Mehrhoff, 2011; Delaney et al., 2008; Galloway, Hickey, & Koehler, 2011; Hidalgo-Ruz & Thiel, 2013). Although the length and width measurements, individually, differed amongst groups (with the undergraduate-student collected data different from the fifth graders and professional ecologists), this was likely due to difficulties in standardizing the exact position from which the two measurements should be taken. When length and width measurements were combined to estimate shrub volume, there was no significant difference in volume by type of data collector, indicating the two measurements on average provided repeatable estimates of shrub size. We recommend that practitioners working with community members conduct training sessions, statistical comparisons of measurements collected by community members and professionals, user-friendly datasheet design, and careful supervision of community scientists by professional scientists, because these techniques are known to increase accuracy (Feldman, Zemaite, & Miller-Rushing, 2018; Tulloch, Possingham, Joseph, Szabo, & Martin, 2013). In particular, the students reported that watching videos of ecologists demonstrating data collection techniques helped them to use equipment and record data correctly. In addition, videos of ecologists describing the study and thanking them for their participation led them to be careful because they understood that their data were important.

It was somewhat surprising that weeding of non-natives did not improve native seedling growth or survival, because non-native annuals are known to compete with native seedlings for water and other resources (Dyer & Rice, 1999; Moyes, Witter, & Gamon, 2005). The 2017 season was unusually wet, resulting in large numbers of germinating annuals, and weeding may not have been conducted frequently enough to reduce competition comparable to control plots. Although analysis of non-native cover showed a significant decrease with weeding, soil moisture measurements indicated no significant difference between weeded and un-weeded plots. In contrast, 2016 and 2018 were such dry years that none of the plots contained many weeds. In the first year (2016), removing non-native annuals did not have an effect on surface soil moisture measurements, yet plots in which weeds were removed and herbivores were fenced resulted in adult shrubs with higher stomatal conductance values in March. The higher conductance values suggest that these adult plants may have had greater access to moisture at depth, or that a combination of excluding herbivores and removing non-native annuals may have positively influenced plant health. Our findings suggest that practitioners will likely need to spend much more time weeding in wet than in dry years in order to reduce competition with non-natives.

Existing native shrubs have been found to act as "nurse" plants in other Mediterranean-climate systems, facilitating the establishment of additional natives (Gomez-Aparicio et al., 2004). One study in Joshua Tree National Park, California, found that *E. fasciculatum* had increased germination under nurse desert shrub species (Woods & Miriti, 2016). We found a positive relationship between average soil moisture and growth of *A. californica* seedlings, so it does seem that differences in soil water availability influenced seedling growth. Surface soil moisture was lower in plots with nurse plants on the side where seedlings were planted, indicating competition for water may have reduced seedling growth.

One alternative possibility for why we saw reduced plant growth when seedlings were grown adjacent to an adult shrub is that our nurse plant species, *A. californica*, may release allelopathic compounds that limited seedling growth (Ferreira & Janick, 2004; Halligan, 1976). Root exudates can limit growth of conspecific plants even more (Bais, Weir, Perry, Gilroy, & Vivanco, 2006), which could explain the stronger negative nurse plant effect on *A. californica* seedlings compared to *E. fasciculatum* seedlings. Regardless of cause, results lead us to recommend that native seedlings not be planted adjacent to existing *A. californica* individuals for restoration of this system.

The native species that we selected to include in our experiment, *A. californica* and *E. fasciculatum*, varied greatly in their response to herbivore exclosures. *Artemisia californica* was likely less palatable to herbivores due to the same secondary metabolites that may impede growth of seedlings (Halligan, 1975). Herbivory is frequently a challenge to restoration, and excluding herbivores was critical to the survival of *E. fasciculatum* individuals. One study on shrub seedling recruitment in Coastal Sage Scrub found significantly more *E. fasciculatum* seedlings in caged open areas than in caged scrub habitats, indicating that herbivory varies with habitat (DeSimone & Zedler, 1999). Rabbit herbivory is likely to be higher in the wildland–urban interface, where rabbits forage on irrigated lawns and predator population sizes have been reduced (Lewis et al., 2015). The rabbit species at our site, *Sylvilagus audubonii*, was more abundant adjacent to exurban neighborhoods than in undeveloped areas in a study conducted in SE Arizona (Bock, Jones, & Bock, 2006).

Restoring native cover and diversity at the wildland–urban interface and in environments with limited and highly variable rainfall can be especially challenging. Community-engaged science provides an opportunity to build an informed local population with a personal investment in restoration outcomes. Our results provided practical information to local land managers (plant seedlings away from existing native shrubs; fence *E. fasciculatum* seedlings), and raised questions regarding the applicability of the resource-gradient hypothesis in our study system (competition rather than facilitation occurred in both a wet and a dry year). The process of data collection included over 1,000 fifth grade students from more than 10 schools, 40 undergraduate students, and several staff from three different organizations, promoting knowledge exchange within a collaborative adaptive management framework.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

AUTHOR CONTRIBUTIONS

S.K. and J.L. conceived of and designed the study. J.L., S.L., K.M., H.K., C.H., and R.S. conducted the educational part of the study, including designing and leading the fifth grade programs. P.T., K.S., and L.N. oversaw the ecological data collection and coordinated details of field work. S.K. analyzed the data and wrote the manuscript. J.L., P.T., and K.S. contributed heavily to the text of the manuscript, and all authors reviewed and edited the manuscript.

ETHICS STATEMENT

The authors received Internal Review Board approval for the educational portion of this project (published elsewhere). This ecological portion of the study required no approval from a university ethics board.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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