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EXPERIMENTAL PLANTING OF NATIVE SHRUBS ON SANTA CRUZ ISLAND FROM SMALL NURSERY STOCK

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Abstract.—The natural vegetation of Santa Cruz Island was severely disturbed by nonnative herbivores for well over a century. As the livestock and feral ungulates (primarily sheep, cattle, and pigs) were removed from the island over the last 30 years, many of the native plant communities began to recover naturally. Recovery has been extremely slow in other areas, especially where nonnative annual grasses and fennel (*Foeniculum vulgare*) dominate several hundred hectares that were under intense agricultural use (pastures and farmed lands). We experimentally tested the feasibility of speeding up the recovery process in a postagricultural area of the island's Central Valley using active restoration techniques. We assessed how weed control via herbicide application and planting of small nursery stock without irrigation might contribute to restoring natural plant assemblages in 3 different areas of the Central Valley (valley bottom, upper south-facing slope, and midsouth-facing slope). In February 2009, we planted the same 21 species of native plants in experimental plots with and without weed control at each location. In December 2009, we planted 28 species in adjacent plots after 2 seasons of weed control. We assessed natural recruitment in weeded and unweeded plots that were not planted. At all 3 locations, a single early season herbicide treatment prior to planting had strong positive effects on the survival, cover, and reproduction of planted natives compared to no herbicide treatment; the effects persisted and grew stronger in the second and third years. Repeated herbicide treatments over 2 years before planting did not result in any additional significant positive effects on native survival or growth compared to only one herbicide treatment. We saw virtually no natural recruitment of native shrubs in unplanted plots. We found that typical coastal sage scrub species performed best at the upper slope site and poorly at the valley bottom site. Grasses and shrubs tolerant of poorly drained soil did better in the valley bottom. We found that planting native species from small nursery stock without irrigation is effective for a wide range of grassland and coastal sage scrub species. All of the restoration techniques we used are cost effective and can be scaled-up to restore large areas of postagricultural lands.

Resumen.—La vegetación natural de la Isla Santa Cruz fue gravemente alterada por herbívoros no nativos durante más de un siglo. Muchas de las comunidades de plantas endémicas empezaron a recuperarse naturalmente durante los últimos 30 años, cuando el ganado y los ungulados ferales (principalmente ovejas, vacas y cerdos) fueron eliminados de la isla. La recuperación ha sido extremadamente lenta en otras áreas, especialmente donde hierbas anuales no nativas y el hinojo (*Foeniculum vulgare*) dominan varios cientos de hectáreas que estaban bajo uso agrícola intenso (pastos y tierras labradas). Comprobamos experimentalmente la viabilidad de acelerar el proceso de recuperación en un área post-agrícola del Valle Central de la isla, usando técnicas de restauración activa. Evaluamos cómo el control de la maleza, a partir del uso de herbicidas y la siembra de pequeñas plantas de vivero sin irrigación, podrían contribuir a restaurar grupos de plantas naturales en 3 áreas diferentes del Valle Central (en el fondo del valle, ladera superior mirando al sur y ladera media mirando al sur). En febrero del 2009, plantamos las mismas 21 especies de plantas nativas en terrenos experimentales con y sin control de hierbas. En diciembre de 2009, plantamos 28 especies en terrenos adyacentes tras dos temporadas de control de hierbas. Evaluamos el reclutamiento natural de los terrenos con maleza y los que no tenían hierbas que no fueron plantados. Una sola temporada temprana de tratamiento con herbicida previa a la plantación tuvo fuertes efectos positivos en la supervivencia, cobertura y reproducción de las plantas nativas plantadas, en comparación con el tratamiento sin herbicida en las tres localidades. Los efectos persistieron y se hicieron más fuertes en el segundo y tercer año. Reiterados tratamientos con herbicida durante dos años antes de la plantación no tuvieron ningún efecto positivo adicional significativo en la supervivencia nativa o en el crecimiento, en comparación con el único tratamiento con herbicida. Vimos que no había ningún desarrollo natural de los arbustos endémicos en los terrenos sin plantar. Encontramos que las especies típicas costeras de breña de salvia obtenían un mejor resultado en la de la ladera superior y un menor resultado en el fondo del valle. Las hierbas y arbustos que toleraban las tierras pobremente drenadas tenían mejores resultados en el fondo del valle. Descubrimos que plantar especies nativas de pequeños viveros sin irrigación es efectivo para un amplio rango de praderas y especies de breña de salvia costera. Todas las técnicas de restauración que usamos se pueden aplicar para restaurar grandes áreas de tierras post-agrícolas.

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Successful large-scale restoration of native shrub and grassland communities in postagricultural lands in coastal southern California requires the restoration of natural ecosystem processes. Every project area has a different history of disturbance and, therefore, different processes in need of restoration. Because many restoration projects occur on postagricultural land in southern California, the majority of projects require actions in 4 main areas: (1) allowing disturbed soil to regenerate a natural soil profile by ending soil disturbance (tilling, rooting, etc.); (2) controlling or eradicating invasive nonnative plants that outcompete native plants and alter natural nutrient and water cycles; (3) removing overgrazing by nonnative herbivores such as sheep, cattle, or goats; and (4) reintroducing native plants where there are no longer native propagules present (D'Antonio and Vitousek 1992, Stylinski and Allen 1999, Corbin and D'Antonio 2004, Cox and Allen 2008, Eliason and Allen 2008, Yelenik 2008, Yelenik and Levine 2010). Addressing each of these issues (and often others) may be crucial to successful restoration. A variety of restoration approaches have been used on the California mainland with widely varying success (Cox and Allen 2008). What works on one site may fail at another. Adaptive approaches (collecting experimental, monitoring data and adjusting techniques) are important in restoration (Erskine Ogden and Rejmánek 2005). Small- and medium-scale experimental pilot studies are valuable for fine tuning techniques that can then be applied at larger scales. The object of this study is to evaluate techniques that are most likely to lead to successful, cost-effective restoration across large areas of postagricultural landscape on Santa Cruz Island (SCI).

The vegetation on California's Channel Islands is similar to that of the nearby mainland. Forest, woodland, scrub, grassland, riparian, and coastal vegetation communities can all be found on one or more of the Channel Islands (Junak et al. 1995). However, the islands' long isolation from the mainland has resulted in numerous endemic species and subspecies occurring on the islands, and only a subset of the mainland flora is present. Until quite recently, SCI had large populations of sheep, cattle, and feral pigs that decimated the native plant communities through overgrazing and rooting. Over the years, many nonnative invasive plants were accidentally or intentionally introduced to the island as well (Junak et al. 1995). A few areas of the island, including most of the Central Valley, were used for agriculture, including vineyards in the late 1800s and early 1900s. There has been significant natural recovery of native plant populations since nonnative herbivore removal on SCI and on nearby San Miguel and Santa Barbara islands (Corry and McEachern 2009); however, introduced nonnative weeds continue to dominate the postagricultural areas.

Nonnative annual grasses and fennel (*Foeniculum vulgare*) now dominate the Central Valley and other large areas including the lower Christy and Sauces drainages, parts of the isthmus, and the east end of the island. In the 1990s, a fennel control experiment was conducted in the Central Valley and succeeded in eliminating some dense patches of fennel (J. Randall personal communication). However, nonnative grasses and forbs quickly moved in and replaced the fennel. There has been very little colonization of these annual grasslands by native shrubs despite abundant intact habitat (and presumably abundant propagules) on the hills to the north (coastal sage scrub) and the south (chaparral). The ability of the annual grasses to modify the habitat in ways that favor their own persistence and exclude other species (e.g., by generating deep thatch and altering soil moisture and nutrient cycling) does not require continued disturbance (D'Antonio and Vitousek 1992). These postagricultural areas will likely remain dominated by annual grasses for decades or longer if left alone (Eliason and Allen 2008).

We set out to determine what types of actions would be needed to effectively restore native shrub and grassland communities in the Central Valley of SCI. Some form of weed control is necessary for restoring native communities in annual grasslands (Cox and Allen 2008). Without weed control, annual grasses inhibit germination and establishment of native seedlings by outcompeting them for light (Eliason and Allen 1997) and water (Davis and Mooney 1985, Eliason and Allen 1997). This is true both for naturally dispersed propagules and planted or seeded restoration sites. The amount of weed control required (one or multiple rounds of treatment) and the best technique (herbicide, tilling, mowing) vary by site and depend on the goals of the restoration project.

For this experiment, we chose to reintroduce native plants from nursery stock in small plugs (76 cm^3) as opposed to the much larger 1-gallon pots (3000 cm^3) commonly used in restoration. Smaller stock is preferred for larger projects because the plugs (1) are easier to plant, (2) require significantly less nursery space and fewer supplies, (3) require less soil disturbance when planting, (4) are less expensive per unit, and (5) are easier to transport to remote areas. We also conducted a companion experiment testing the efficacy of direct seeding, but the results are not included here.

We developed our planting palette based on observations in nearby intact native vegetation. We limited ourselves to perennial native species occurring in and around the Central Valley on south-facing slopes and in valley-bottom locations, and we included SCI and northern Channel Islands endemics. We simultaneously repeated the experiment in 3 areas: high on a south-facing slope, in the valley bottom, and midway up the south-facing slope. By introducing a wide variety of species at multiple locations, we expected to develop recommended planting palettes for the different areas that would each be a subset of the 28 species we used.

The goal of the experiment described here was to determine an effective strategy for restoring nearly 200 ha of disturbed habitat in the Central Valley and similar areas of SCI. Specifically, we asked (1) whether native shrubs are reinvading the dense annual grasslands in the Central Valley, (2) whether native shrubs will reinvade after fennel and annual grasses are suppressed, (3) how much weed control is needed to successfully reintroduce native shrubs and grasses from small nursery stock, (4) whether different species will grow better in different areas of the Central Valley, and (5) whether large-scale restoration of shrub and grassland habitats is feasible in the Central Valley. To answer these questions, we implemented a medium-scale experiment using a range of weeding and planting treatments at 3 locations in the Central Valley. We used only planting and weed-control techniques that can be implemented on a large project. Our findings are applicable to coastal sage scrub and grassland habitats on other disturbed areas of the island and on the mainland in California.

METHODS

Study Site

The study site is on Santa Cruz Island, located approximately 40 km off the coast of Santa Barbara, California. At 250 km^2, it is the largest of the 8 islands that make up the Channel Islands. The study site is located in the Central Valley of SCI at an elevation of approximately 80 m.

SCI has a Mediterranean climate with cool, wet winters and warm, dry summers. The relatively tall ridges surrounding the Central Valley limit marine influence on the climate, leading to much warmer daytime temperatures and colder nighttime temperatures than areas along the coastline. With the exception of occasional hail and infrequent snow on the tallest peak, all precipitation on SCI falls as rain primarily between October and April (averaging 502 mm per water year). The prevailing wind direction is WNW, with only occasional episodes of sustained winds over 4.5 $m \cdot s^{-1}$ (~10 mph). The Central Valley is occasionally affected by “Santa Ana” wind events, when very dry and hot easterly winds cause temperatures to spike and humidity to plummet.

Annual rainfall amounts and timing varied widely during the first 4 years of the study. The 2008–2009 season (the first year we planted) was drier than average (208 mm). Significant rain fell the week before planting in early February (53.8 mm), but very little rain fell after planting (25 mm in total, with the largest event dropping 7 mm). Rainfall in 2009–2010 (the second year of planting) was about average (478 mm). Most of the rain fell in December, January, and February after planting. The summer of 2010 was very cool, with many overcast days and a general lack of hot, dry Santa Ana events. The 2010–2011 rain season was above average (651 mm), with storms spaced throughout the growing season. The 2011–2012 season was drier than average (320 mm), with soaking early season rains, an especially harsh midwinter drought, and some soaking spring rains. The midwinter drought, which occurred from late January through mid-March, featured only one rainfall event over 2 mm (6 mm in mid-February) and had 8 days with high temperatures over 26.7 °C.

The postagricultural areas of the Central Valley are currently dominated by invasive, nonnative annual grasses and fennel (*Foeniculum* *vulgare*). There are several other nonnative plant species and a few native grass and shrub species that are locally dominant. We chose 3 experimental locations. Each was formerly plowed, had relatively consistent fennel density with few native plants, and was dominated by either slender wild oat (*Avena barbata*) or ripgut brome (*Bromus diandrus*).

Experimental Design

The same experimental design was used at 3 locations. *Happy* is located in the valley bottom adjacent to an incised ephemeral drainage. The topography is generally flat with a slight (~1%) west-facing aspect. The soil is a clay loam and includes some microtopography, probably the remnants of pig rooting. *Sneezy* is located on a moderately steep (~10%), south-facing slope on the north side of the Central Valley. The soil is a sandy clay loam with some rocks and pebbles. *Clumpy* is close to the valley bottom and has a slight (~1%) south-facing slope and clay loam soil. It is farther from the stream channel than *Happy* and below *Sneezy*.

We used a randomized complete block design with 6 treatments and 6 blocks per location for a total of 36 plots per location and 108 plots total. Each plot was 7 × 7 m, with a 2-m buffer between plots and between blocks. Each block at *Sneezy* and *Clumpy* contained 6 plots in an east–west row on contour with the slope. Blocks were arranged 2 across and 3 down. At *Happy*, each block was 2 plots wide and 3 plots long, with the long axis in the east–west direction. Blocks were arranged end to end, east to west. The corners of each plot were marked with steel rebar and color-coded flags.

The 6 treatments were No Spray/No Plant (no weed treatment and no outplanting of native plants; control); No Spray/Plant Yr 1 (weeds not treated with herbicide and native seedlings outplanted in year 1); Spray Yr 1/No Plant (all weeds sprayed once, and fennel cut and then sprayed multiple times, but no native seedlings outplanted); Spray Yr 1/Plant Yr 1 (all weeds sprayed once, fennel cut and then sprayed multiple times, and native seedlings outplanted in year 1); Spray 2 Yrs/No Plant (all weeds sprayed multiple times the first season and one time in the second season, and no native seedlings outplanted); and Spray 2 Yrs/Plant Year 2 (all fennel cut down and all weeds sprayed multiple times the first season and one time in the second season, and native seedlings outplanted in year 2). These final 2 treatments are referred to as the "year 2 plots." Buffers between plots were not sprayed or otherwise treated.

In the 4 sprayed treatments (total of 72 plots), fennel and all other plants, both native and nonnative, were sprayed with the herbicide glyphosate (1% Roundup) in January 2009. All plants, including fennel in the year 2 plots, were again sprayed with herbicide (1% Roundup) in April 2009 to kill a second crop of annuals, and a third time in November 2009 to kill newly sprouted annuals. Fennel in all 4 sprayed treatments was sprayed with triclopyr (1% Garlon 4 Ultra) in May 2009 and again in August 2009 (2% Garlon 4 Ultra). Fennel was cut down, and the stems were removed from the plots before the first herbicide treatment (resprouts were sprayed).

Each No Spray/Plant Yr 1 and Spray Yr 1/Plant Yr 1 plot was planted with 140 native plants of 21 species between 10 and 12 February 2009. The mix of plants (Table 1) was determined by a combination of seed availability, success in propagation, and a desire to emphasize species we thought would do best. The number of plants per plot was calculated based on our desired spacing (~50 cm). This spacing is denser than most coastal sage scrub restoration sites that are planted. Our reason for the extra-dense planting was to balance expected higher-than-normal mortality due to some plants being too small at the time of planting. The planting mix for *Clumpy* was slightly modified (Table 1) compared to the other 2 sites due to the number of plants available when it was planted (last). A total of 5040 plants were installed in year 1.

Each Spray 2 Yrs/Plant Yr 2 plot was planted with 130 plants of 28 species on 16 and 17 December 2009 (2340 plants). When more plants were ready in early January 2010, we added 10 additional plants to each plot to bring the total up to 140 plants per plot (Table 3) and 2520 total plants in year 2. Additionally, on 7 December 2009, we planted 5 acorns of *Quercus pacifica* and 5 acorns of *Q. agrifolia* into each Spray 2 Yrs/Plant Yr 2 plot.

All plants were grown from seed collected on Santa Cruz Island. Seed was collected and immediately sown or stored in a freezer for 2–5 days to kill any invertebrates collected with the seed. After sprouting, seedlings were

TABLE 1. Planting list (same for No Spray/Plant Yr 1 and Spray Yr 1/Plant Yr 1 treatments).

		Plant Yr 1 plots		Plant Yr 2 plots[a]
Family	Species	*Happy/ Sneezy*[b]	*Clumpy*[b]	All locations[b]
Fabaceae	*Acmispon dendroideus* var. *dendroideus*	2	2	0
Asteraceae	*Artemisia californica*	3	3	13
Asteraceae	*Artemisia douglasiana*	10	8	15
Asteraceae	*Baccharis pilularis*	10	10	5
Asteraceae	*Baccharis salicifolia*	10	10	11
Alliaceae	*Bloomeria crocea*	1	1	0
Poaceae	*Bromus carinatus*	12	12	5
Convolvulaceae	*Calystegia macrostegia* ssp. *macrostegia*	0	0	4
Ranunculaceae	*Clematis ligusticifolia*	1	1	3
Poaceae	*Elymus condensatus*	13	13	4
Poaceae	*Elymus glaucus*	5	5	8
Onagraceae	*Epilobium canum*	6	6	5
Polygonaceae	*Eriogonum grande* var. *grande*	14	15	16
Polygonaceae	*Eriogonum arborescens*	12	15	8
Asteraceae	*Grindelia camporum* var. *bracteosum*	9	9	11
Asteraceae	*Hazardia detonsa*	5	8	3
Asteraceae	*Hazardia squarrosa* var. *grindelioides*	6	4	0
Rosaceae	*Heteromeles arbutifolia*	0	0	2
Asteraceae	*Isocoma menziesii* var. *vernonioides*	10	7	4
Fabaceae	*Lupinus albifrons* var. *douglasii*	3	3	5
Asteraceae	*Malacothrix saxatilis* var. *implicata*	3	3	1
Cucurbitaceae	*Marah macrocarpus*	0	0	1
Phrymaceae	*Mimulus aurantiacus* var. *pubescens*	0	0	2
Asteraceae	*Pseudognaphalium californicum*	0	0	1
Asteraceae	*Pseudognaphalium microcephalum*	2	2	0
Rhamnaceae	*Rhamnus pirifolia*	0	0	3
Anacardiaceae	*Rhus integrifolia*	0	0	5
Poaceae	*Stipa lepida*	3	3	5

[a]All Plant Yr 2 plots also had 10 acorns planted (5 each of *Quercus pacifica* and *Q. agrifolia*).
[b]Plants per plot.

transplanted into small plugs (50-plug trays) and allowed to establish for 4–18 weeks before planting. Plants ranged from 3 to 15 cm tall when planted. We used Sunshine #5 soilless mix (peat moss and fine perlite) in seed flats and plugs. Three slow-growing species planted in year 2 (*Heteromeles arbutifolia, Rhus integrifolia,* and *Rhamnus pirifolia*) were sown in fall and winter 2008 and transplanted into liners (~30-cm deep and 8-cm diameter) in early 2009. No seed, plant material, or soil were imported to the island. All nursery supplies and tools were new and free of soil.

Planting holes were made in moist soil via a steel breaker bar with a diameter similar to the plugs. In year one, a small area (~10-cm diameter) of annual grass thatch and any living grass was removed around each planting hole, mainly to allow the planters to see the holes. In the second year, we minimized disturbance of existing thatch during planting. We did not plant within about 30 cm of fennel plants or existing native grasses but otherwise planted on a grid with approximately 50 cm between plants. In plots with dense fennel or native grass, plants were planted much closer together on average. Plantings were never irrigated after planting in either season, and we did no replacement plantings after the initial planting.

Monitoring Design

We estimated the percent cover by species in all plots in October 2008 before we carried out any experimental manipulations. We estimated the percent cover to the nearest percent (any species present with <0.5% cover was given a cover score of 0.1%) by species for all green or senesced plants found within each 7 × 7-m plot. We used a similar methodology in February 2013 to assess relative cover. Instead of identifying plants to species, we classified them as native shrubs, grasses, or forbs and nonnative annual grasses, forbs, or perennials.

We carried out posttreatment monitoring in each plot on 6–8 May 2009, 6–8 October

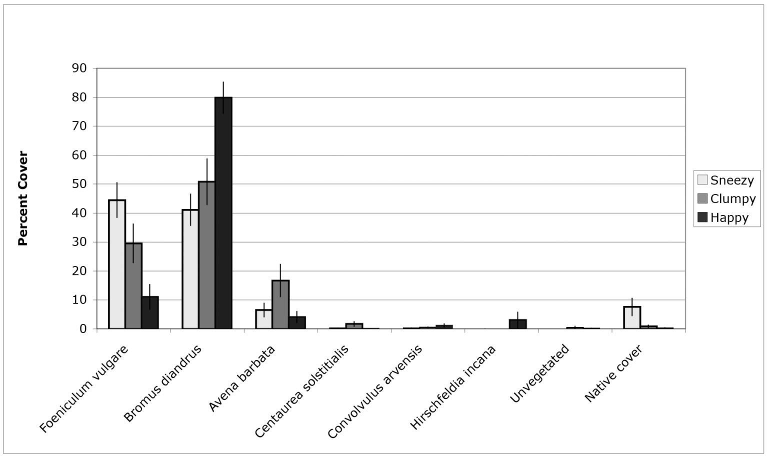

Fig. 1. Vegetation cover in experimental plots prior to manipulations. Error bars represent ±2 standard errors.

2009, 12–16 May 2010, 5–8 October 2010, 5–8 November 2011, and 23–27 September 2012. Four sample quadrats, each 1 × 2.5 m, were randomly located in the 10 contiguous locations within the central 5 × 5-m core of each plot. Within each sample quadrat, we estimated the percent cover for every species to the nearest percent (any species present with <0.5% cover was given a cover score of 0.1%). The cover estimates from the 4 quadrats were averaged for each plot. To determine initial survival rates of planted plants, we counted the number of planted plants alive in the planted plots in the spring and fall following planting.

For the preproject monitoring, we considered dead or senesced plants as part of the vegetated cover. For all other monitoring, we counted only living plants and considered dead or senesced plants as part of the "unvegetated" cover. All plants were identified to species except needlegrasses (*Stipa pulchra* and *S. lepida*), which were present in some of the plots but, in some seasons, were very difficult to tell apart. Therefore, we clumped both species together into the "*Stipa* spp." category. All taxonomy follows Baldwin et al. (2012).

Statistical Analyses

The individual 7 × 7-m plots were the experimental unit for all analyses. The 6 treatments were the 6 spray/no spray and plant/no plant combinations. Data were analyzed with a 2-way ANOVA in Excel to test for differences in total native cover between the 6 treatments and differences in planted native cover between the 3 treatments that included planting. We found no strong block effects in any of the analyses. Each of the 3 locations was analyzed separately. We used a linear regression (in Excel) to explore the relationship between native and nonnative plant cover within individual plots.

RESULTS

Prior to experimental manipulations in October 2008, all of the locations were dominated by nonnative plant species (Fig. 1). Ripgut brome, *Bromus diandrus,* was the dominant plant species at 2 of the locations and was a close second to *F. vulgare* at the other (Fig. 1). Fennel cover was highest in *Sneezy* (44.4%), lowest in *Happy* (11.0%), and intermediate in *Clumpy* (29.5%). There was very little unvegetated area at any of the locations (Fig. 1). Total native cover was highest in *Sneezy* and very low in *Happy* and *Clumpy* (Fig. 1). There were no native shrubs in any plot. Only 9 native plant species were encountered and only needlegrass, *Stipa* spp., had an average cover >0.5% at any of the sites (7.0% in *Sneezy* and 0.8% in *Clumpy*).

One round of herbicide treatment had a strong negative effect on nonnative cover for one year at *Sneezy* (Fig. 2). Multiple rounds of herbicide over 2 seasons had a strong negative effect on nonnative cover for 2 years in *Sneezy* (Fig. 2). By 2013, nonnative cover in the year 2 treatments had increased to near preproject

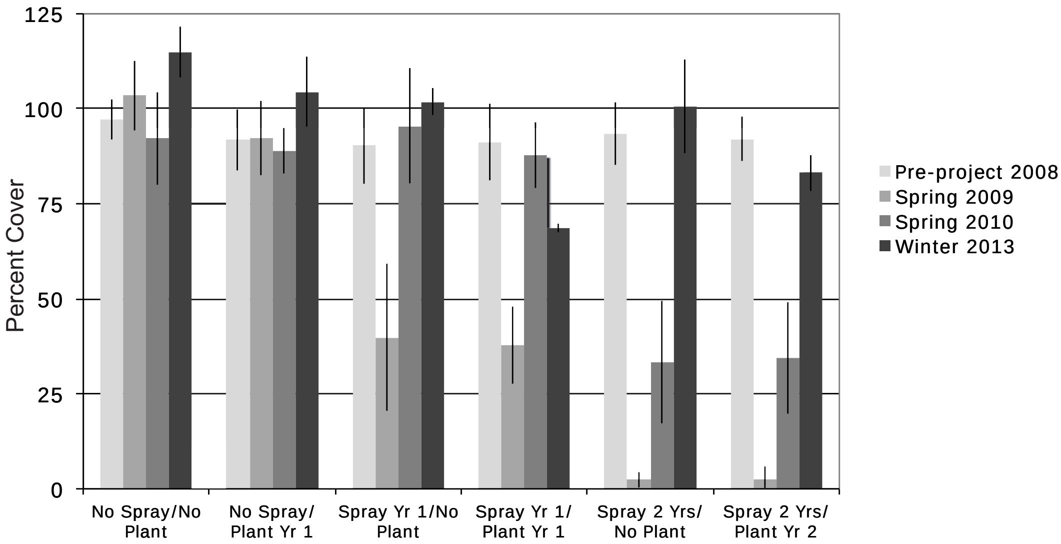

Fig. 2. Total nonnative cover in *Sneezy*. Error bars represent ±2 standard errors.

TABLE 2. First-year survival of planted natives in spring and fall.

	No Spray/Plant Yr 1		Spray Yr1/Plant Yr 1		Spray 2 Yrs/Plant Yr 2	
	May	October	May	October	May	October
Sneezy	42%	23%	63%	59%	62%	55%
Clumpy	39%	18%	44%	43%	51%	45%
Happy	38%	14%	52%	39%	39%	28%
Overall	40%	18%	53%	46%	51%	43%

levels (Fig. 2). Nonnative cover followed similar patterns at *Happy* and *Clumpy*.

Initial survival of planted natives was lowest in the No Spray/Plant Yr 1 treatment at all locations (Table 2) after 3 months (May) and 8 months (October). Initial survival in the Spray 2 Yrs/Plant Yr 2 treatment was similar to the Spray Yr 1/Plant Yr 1 treatments in *Clumpy* and *Sneezy* and lower in *Happy* (Table 2). Initial survival of year 2 plantings in *Happy* was lower than at the other 2 locations.

The estimated total native cover (planted plus nonplanted natives) varied greatly be tween locations and treatments in fall 2012 (Fig. 3). Nonplanted natives include perennial species that were in the plots at the beginning of the study and were not sprayed or survived spraying and native seedlings that sprouted during the experiment (from the seed bank or from seed produced in the plots in the first year). All 3 planted treatments had higher total native cover than the 3 nonplanted treatments at all 3 locations (Fig. 3). We found a total of 2 native shrub individuals established in unplanted plots (both were *Eriogonum arborescens* in Spray 2 Yr/No Plant plots at *Sneezy*). Differences between treatments were statistically significant at all 3 locations (2-way ANOVA df = 5,25; *Sneezy* $P < 0.001$; *Clumpy* $P < 0.001$; *Happy* $P < 0.001$).

The average cover of planted natives in all planted treatments increased at all locations between fall 2009 and 2012 (Fig. 4). The largest year-on-year increases were between 2010 and 2011. The No Spray/Plant Yr 1 treatment continues to have the lowest planted native cover at each location. The Spray Yr 1/Plant Yr 1 treatment always had the highest average cover, though the difference was slight at *Sneezy* and moderate at *Clumpy*. Differences between treatments were statistically significant at all 3 locations in September 2012 (2-way ANOVA df = 2,10; *Sneezy* $P < 0.001$; *Clumpy* $P = 0.001$; *Happy* $P = 0.05$).

The average cover by species varied widely between the 3 locations in the Spray Yr 1/

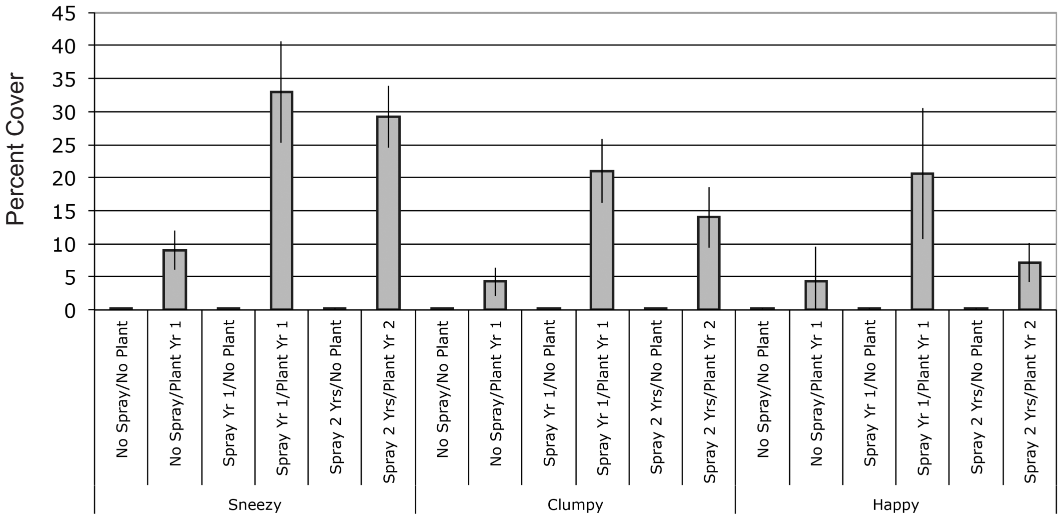

Fig. 3. Native vegetation cover in experimental plots in September 2012. Error bars represent ±2 standard errors.

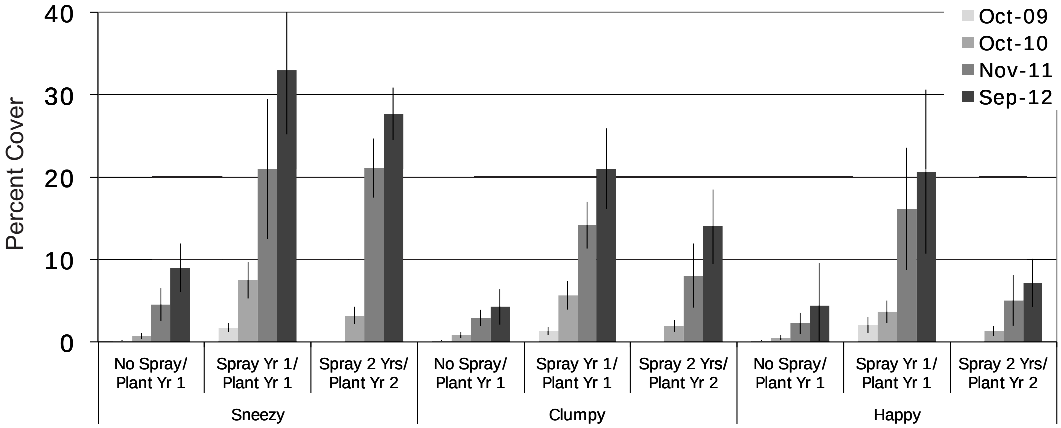

Fig. 4. Percent cover of planted natives at all 3 sites in the fall. Error bars represent ±2 standard errors.

Plant Yr 1 treatment in fall 2012 (Fig. 5). For example, *Artemisia douglasiana* and *Baccharis pilularis* are both doing best in *Happy*, whereas all other species are doing poorly compared to the other locations (Fig. 5). Species characteristic of coastal sage scrub (*Artemisia californica, Eriogonum arborescens, Hazardia detonsa, Isocoma menziesii, Elymus condensatus,* and *Lupinus albifrons*) are doing best in *Sneezy* (Fig. 5). Sampling in the fall biases these estimates against species that are dormant at that time of year, such as *Bromus carinatus, Elymus glaucus,* and *Stipa lepida.* Cover of other species that are partially senescent, such as *Eriogonum grande, Grindelia camporum,* and *Epilobium canum,* is also under estimated compared to peaks in the spring or summer.

We found that as the total native cover increased in plots, the total nonnative cover tended to decrease (Fig. 6). The effect was strongest in plots that had large shrubs with dense canopies (*Eriogonum arborescens* and *Lupinus albifrons*) and where native plant recruitment from seed produced by the outplanted plants led to dense patches of native grasses (*Bromus carinatus* and *Elymus glaucus*) and small shrubs (*Eriogonum grande*).

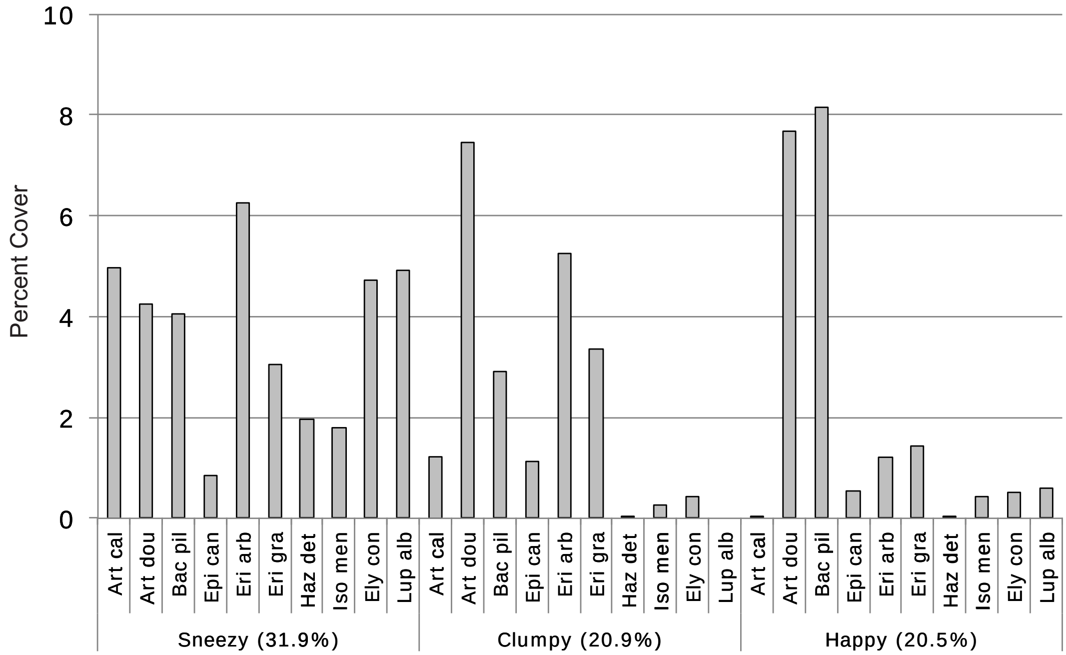

Fig. 5. Vegetation cover of 10 native species in Spray Yr 1/Plant Yr 1 plots in fall 2012. Numbers in parentheses are total native cover for each location.

Discussion

The first of our study questions concerns whether native shrubs are reinvading the Central Valley on their own. We found no evidence that this is occurring. We found no new native shrubs in any of the control plots over the 4 years we monitored. We did not test the mechanism limiting establishment of natives in the Central Valley, though we suspect that in the areas where we conducted this experiment, any native seeds in the plots would either be inhibited from germinating by the thick annual grass thatch or die after germinating from competition with annual nonnatives (Yelenik and Levine 2010).

We also asked whether suppressing weeds would lead to natural recruitment of native shrubs and grasses. We did find 2 shrubs (both *Eriogonum arborescens*) in weeded and unplanted plots: one each in year 3 and 4 of the monitoring. This recolonization rate, 2 plants in a total of 1764 m^2, is much too slow for us to expect that suppressing weeds will be a sufficient strategy for restoration of native habitats in the Central Valley. Again, we did not test the mechanism limiting establishment of natives in the Central Valley where we suppressed weeds, though our results suggest that there is little or no seed bank of native shrubs and that there is very little seed rain (significant seed sources are approximately 40 m from *Sneezy*, >100 m from *Clumpy*, and >200 m from *Happy*). However, it is possible that native species germinated and died before they were large enough for us to detect and that competition is a more important mechanism. Further, given that there was significant seed production in adjacent planted plots by the second year, which production led to subsequent establishment of additional native plants in those planted plots, we might expect higher rates of seed rain in the adjacent unplanted plots than in most areas of the Central Valley.

We are confident that native species will need to be introduced as part of an active restoration project in the Central Valley because native species will not reinvade on their own (Erskine Ogden and Rejmánek 2005, Yelenik 2008, Yelenik and Levine 2010). The most common way to reintroduce native species is from seed or nursery stock. We

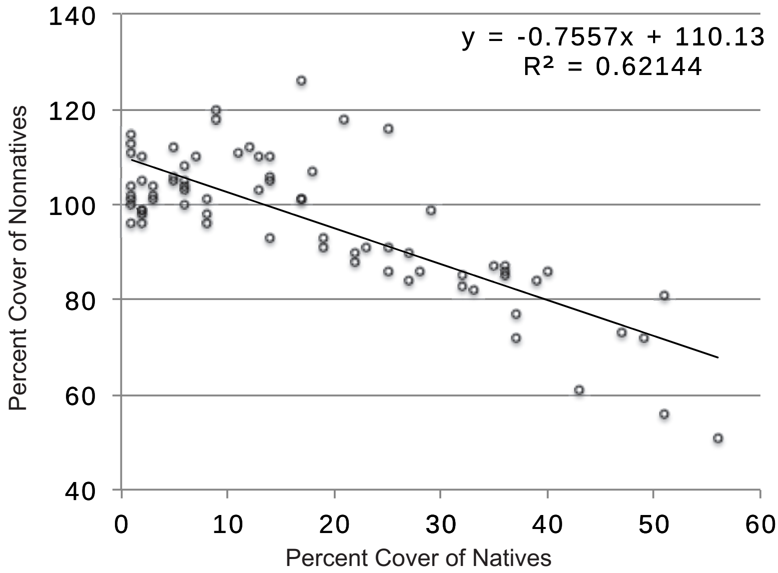

Fig. 6. Linear regression of total native cover versus total nonnative cover in February 2013. All plots in *Sneezy, Clumpy,* and *Happy* with at least 1% native cover are included.

have identified several challenges to direct seeding in the Central Valley, including the lack of and prohibition of using commercially available mainland-sourced seed (and hence greater difficulty and cost in collecting sufficient seed on-island), the need to remove thatch (which then releases more weeds from the seed bank and creates bare soil surfaces which dry quickly between rains), and the need for fortuitous wet years with well-timed rain. However, our results from a companion experiment suggest that seeding some species may be feasible (unpublished data). Given the risks though, we still question the utility of relying on seeding alone.

Our third question was how much weed control is needed to successfully reintroduce native shrubs and grasses from small nursery stock. Planting directly into habitat dominated by fennel and annual grass without weed control is probably not a viable approach. We saw very high mortality of planted plants, and cover estimates are consistently lower in plots without weed control than in plots where we controlled weeds before planting.

We saw very good survival, growth, and reproduction (we observed flowering in over half of the planted species) from several species even in a very dry year, after treating fennel and applying only one round of annual weed control. We saw a very similar response from planted natives after 2 seasons of annual weed control. After 4 growing seasons, we are convinced that the native cover in weeded treatments is still increasing, as is seed production. We found evidence that the native plants were suppressing nonnatives, indicating that the restoration process will be sustainable in the long term.

We were surprised that nursery stock installed after 2 years of weed suppression did not perform any better than those installed after one year of weed suppression. We expected there to be significant benefits to multiple rounds of herbicide treatment over 2 years in terms of reducing nonnative competition and increasing growth of native plants. Further, with over 25 cm of rain after planting (versus less than 3 cm the first year), we expected much higher survival and growth. It may be that the vigorous growth of the remaining weeds in the wetter year suppressed the growth of planted natives. It is also possible that the extra herbicide treatments had some detrimental effect on growing conditions, such as a reduction in beneficial microbes (Irvine et al. 2013). We conclude that the extra time and cost for 2 years of weed control is not worthwhile.

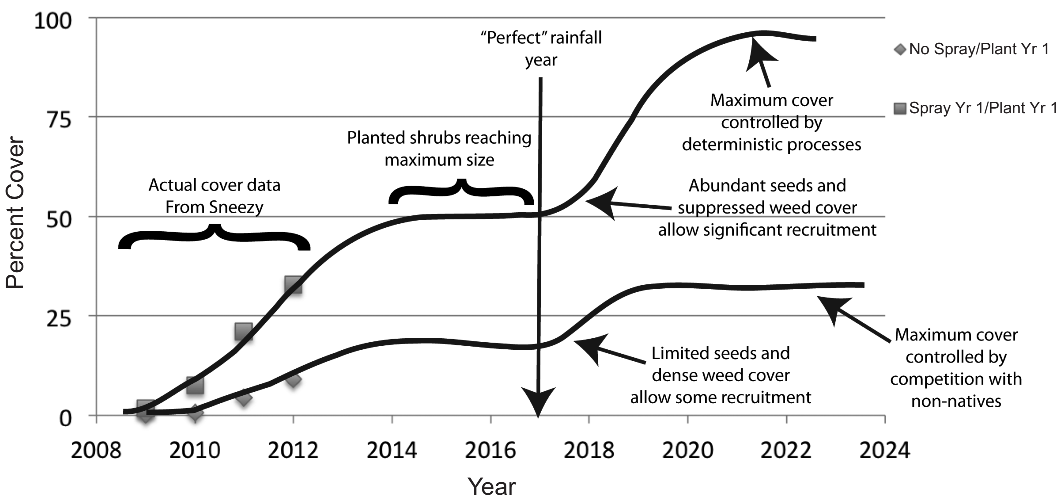

Fig. 7. Hypothetical long-term trends in native cover with and without weed treatment.

Our results indicate that different areas within the Central Valley will support different suites of native species. Our study design used only one site each in the 3 general areas (high on the slope, midslope, and valley bottom). Because we did not replicate the experiment at multiple locations within each general area, we cannot be sure that this pattern is not just an artifact of the particular locations we chose. Nevertheless, our findings are consistent with observations of vegetation patterns in less disturbed areas elsewhere in the Central Valley, and they provide a useful starting point for fine-tuning planting palettes in future projects. Coastal sage scrub species, especially *Artemisia californica, Eriogonum arborescens, Hazardia* spp., *Lupinus albifrons,* and *Elymus condensatus,* should be emphasized on the south-facing slopes. *Baccharis pilularis, Artemisia douglasiana,* and perennial bunchgrasses will probably be good species in the valley bottom areas. Midslope areas will be a transition between these 2 vegetation types where the above species will overlap and others, such as *Eriogonum grande,* will likely do best. We did not test the mechanisms that led to differences in species' performance at different locations, but we suspect soil texture and moisture patterns (better drained soils on the slopes) played an important role.

Our study suggests that restoring large areas of shrubland habitat in the Central Valley of Santa Cruz Island can be done using limited weed control and planting. Though we did see survival and growth of native plants without weed control, we believe that in the long term, a weeding strategy, along with planting, will be needed to restore self-sustaining habitats.

There are 2 general ways to predict long-term responses with short-term data. A common approach is to fit monitoring data to curves and extrapolate into the future. However, attempting to predict such trajectories is fraught with ecological pitfalls (Zedler and Callaway 1999, Matthews and Spyreas 2010). Stochastic processes (e.g., weather, fire) can dramatically change ecological trajectories in restoration projects. Successional processes are probably important on most restoration sites, though they are usually difficult or impossible to predict and can be responsible for sites diverging dramatically from observed short-term trajectories (Matthews and Spyreas 2010). Once we consider the myriad ways these nondeterministic and deterministic processes might interact with each other over several decades, it is clear why our predictive powers are limited. Nevertheless, there is almost always a practical need to use available monitoring data either to predict the long-term "success" of a restoration or mitigation project or, as in this case, to determine what restoration approach will yield the best long-term results in future projects. Based on the data we have collected, we strongly believe native plants will need to be reintroduced, and we hypothesize that an approach of short-term weed suppression and planting from small nursery stock will be more effective than planting alone for restoration of the Central Valley (Fig. 7).

We wanted to test the feasibility of using small nursery stock without irrigation to restore shrublands in annual grasslands given the unique challenges associated with restoration on Santa Cruz Island. Our results after 4 years suggest that (1) several species introduced from small nursery stock do not need much rain after planting to establish successfully; (2) planting small nursery stock when there are no annual weeds alive (i.e., after a grow-kill cycle) creates a sufficient window for native plants to establish; (3) planted natives may begin to outcompete annual grasses after 2 or 3 years; and (4) different areas of the Central Valley will support different plant communities.

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