SANTA CATALINA ISLAND EXPERIMENTAL RESTORATION TRIALS: DEVELOPING APPROPRIATE TECHNIQUES

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Abstract—Since 1999 the Catalina Island Conservancy has implemented eleven native plant restoration trials on 34 ha of abandoned agricultural fields in Middle Canyon on Santa Catalina Island. The trials were designed to evaluate the extent to which native plant communities can be established within weedy fields without intensive human inputs. Through an iterative series of native plant restoration trials we have found that non-native plants (weeds) and animals (deer [*Odecoileus hemionus*] and bison [*Bison bison*]) have a greater impact on the site than expected. Annual weed control, adding propagules (e.g., seeds) and planting seedlings without protection are insufficient to tip the balance in favor of native plants. These conclusions are reflective of the heavily disturbed old agricultural field conditions of Middle Canyon and will be applicable to other disturbed sites where we may want to do restoration on Catalina Island. Subsequent trials that took those limitations into consideration (e.g., more frequent weed control and planting seedlings into protected conditions) provided species-specific information about growth rates, water requirements and survivorship that will make subsequent restoration efforts much more efficient and appropriate. The specific trials cover a variety of native plant communities including native bunch grass, coastal sage scrub, chaparral, oak woodland and ephemeral streamside ‘riparian’ plant communities. The primary conclusions from each trial are described in this paper.

Keywords: chaparral, coastal sage scrub, oak, restoration, Santa Catalina Island

INTRODUCTION

Very little native plant restoration work on the Channel Islands has been published, particularly the southern Channel Islands (O’Malley 1991). On Santa Cruz Island restoration efforts have focused on strategies for removing dense stands of fennel (*Foeniculum vulgare*) and on Santa Barbara Island the National Park Service worked on restoring eroded sites with weed cloth and seeding (Halvorson 1993). During the 1990s in southern California, coastal sage scrub restoration was the subject of several studies and restoration and mitigation projects (Bowler 1990, Marquez and Allen 1996, Eliason and Allen 1997). These studies demonstrated that annual grasses and legumes reduced biodiversity and limited natural regeneration of native species in disturbed coastal sage scrub sites. Nitrogen deposition, fragmentation and isolation from stands of native vegetation (e.g., seed sources) also reduced the biodiversity and regenerative capacity of coastal sage scrub species (Allen et al. 1998). The conclusion from these authors was that ‘passive,’ wait and see strategies were not suitable for restoring coastal sage scrub and chaparral plant communities on disturbed sites in southern California. Research has demonstrated that exotic disturbance (e.g., plowing) can alter successional processes and can lead to the persistence of early seral stage plant communities or weed-dominated landscapes (Stylinski and Allen 1999). As such, when the opportunity came to restore the disturbed fields in Middle Canyon, we knew that we not only had to do more than wait and see if adjacent native plants would colonize the site, but also work to reduce the risk that this population of non-native plants would serve as a source for invasion into adjacent intact native areas.

The Santa Catalina Island Conservancy, established in 1972, assumed ownership of 88% of Santa Catalina Island in 1975. Initial management efforts focused on maintaining the ranching and hay farming activities in Middle Canyon. In the mid-1990s, however, the Conservancy began to engage in active conservation including removal of non-native pigs and goats and restoration of degraded sites. In 1998 we wrote a restoration plan and in 1999 initiated restoration trials on the 34 ha of old agricultural fields (Stratton 1998). While over eleven restoration trials were established over a four-year period, this paper will concentrate on four of those trials and describe how they arose from previous trials and elaborate on the implications of their results. The primary challenges to restoration of native plant communities in Middle Canyon on Catalina Island were browsing and trampling by deer (*Odecoileus hemionus)* and bison (*Bison bison*), competition by weeds, unpredictable rainfall and altered soil conditions. The trials were designed to address these concerns while also minimizing maintenance requirements. These trials represent experimentation with 6,500 seedlings and 1.5 million seeds of 48 species from five plant communities: native bunch grass, oak woodland, coastal sage scrub, chaparral and ephemeral stream 'riparian' vegetation.

MATERIALS AND METHODS

Site Description

The project site, Middle Canyon, is a broad canyon in the central portion of Santa Catalina Island at 215 m elevation which was leveled and used to grow oats for over 50 years. The 34 ha of old agricultural fields are bisected by a dry stream bed with some mixed 'riparian' vegetation, however most of the side streams have been filled in. The site is surrounded on the north by south-facing slopes dominated by coastal sage scrub and on the south, by steep north facing slopes with oaks, mixed chaparral and disturbed annual grassland vegetation. The vegetation in the old agricultural fields is dominated by *Bromus diandrus, Bromus hordeaceus, Avena fatua, Vulpia myuros, Sysimbrium officionale, Raphanus vulgare, Medicago polymorpha, Meliotis indica* and scattered stands of *Foeniculum vulgare, Marrubium vulgare* and *Phalaris aquatica*. The soil is deep, silty, gray clay. Average rainfall for the period 1948 to the present is 325 mm/year. Three out of the last five years have been below average rainfall (Fig. 1). Precipitation follows the Mediterranean pattern and falls from late December through March.

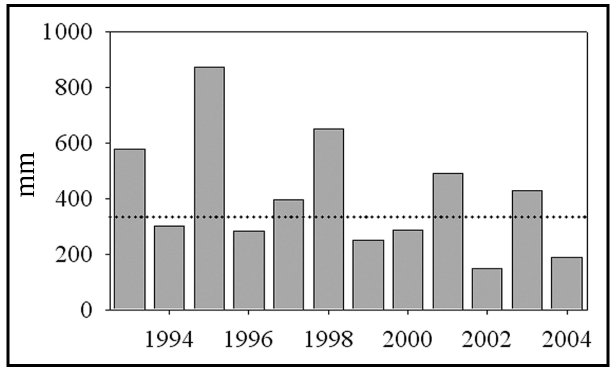

Figure 1. Annual precipitation Middle Canyon, Santa Catalina Island, July 1992 to June 2004. Dotted line reflects mean annual precipitation since 1948.

Oak Watering Trial

The oak watering trial, established in 1999, was designed to test three different watering options and whether or not the addition of soil components collected under mature trees and added to planted seedlings contributed to success. Because no research had been done on the island on the water requirements of our endemic oaks (*Quercus pacifica*), we decided to test the value of some strategies used in arid environments to provide water only to the roots of the tree. Research on central valley oaks, where rainfall is higher, had already demonstrated that competition for moisture from weeds reduced growth and survivorship of oaks, so there was the possibility that island oaks would require more water (McCreary and Tecklin 1997). We directed water to the roots of the tree via a vertical pipe installed adjacent to the seedling or with 'driwater,' a slow release polymer that releases water as bacteria break down the globules, in order to promote deep root growth without encouraging surface weed growth (Sawaf 1980, Mathew 1987, Bainbridge and Virginia 1989). The driwater product was selected because it can last up to three months and conformed to our policy of selecting techniques that reduce human intervention and effort relative to monthly hand irrigation. Twelve plots of 14 seedlings each of *Quercus pacifica* were planted in January 1999. Four plots each were randomly assigned to one of three watering treatments: "Driwater" at the root zone for 2.5 years during the dry months, monthly deep pipe watering to the root zone (4 L/month) or no additional watering (controls).

The second factor of the trial, importance of adding native soil from mature oaks, was crossed with the initial factor by adding soil to every other seedling in each plot. Many studies have demonstrated that the presence of appropriate microbial symbionts in the soil can greatly improve the nutrient status and plant performance of many native species (Aldon 1978, Trappe 1981, Read et al. 1985, St. John 1985, Bloss 1986). Plants can be inoculated by adding soil from mature individuals of the same or similar species in their native habitat (Schiechtl 1980, Bainbridge and Virginia 1989). Because the fields had such a long history of disturbance there was a chance that the native soil biota had been destroyed. Adding native soil to the root zone at the time of planting was a straightforward way of evaluating the potential benefits of inoculation on oaks which are known to have species-specific ectomycorrhizal symbionts. The one-year old seedlings were planted within 2 m of each other and were protected from herbivory with 1.2 m tall tree tubes. Initially a 1-m circle around each seedling was hand cleared with hoes but later we added wood chips to maintain weed free circles. The benefits of the use of tree tubes and the size of the weeded zone were determined by studies conducted by McCreary and Tecklin (1997) on blue oaks. Seedling height and survivorship were monitored in the spring and fall for three years and then only in the spring of the ensuing years. Data were analyzed using ANOVAs on percent survivorship and seedling height. Photosynthetic measurements of a sub-sample of saplings from all treatments were conducted during the treatment application (2^{nd} year) and after treatments were discontinued (3^{rd} year).

Acorn Trials

Based on the results from the oak watering trial, an acorn planting trial was established in 2001 to evaluate species-specific differences in germination for *Q. pacifica* (n = 768), *Q. macdonaldii* (n = 144), *Q. tomentella* (n = 144) and *Q. chrysolepis* (n = 144). The goals of this trial were to evaluate germination requirements and rates for the four oak species on the island under two experimental conditions: pre-augering holes (to 75 cm and refilling) to facilitate tap root development in the dense clay soils and adding oak-leaf-mulch to acorns to provide inoculum and protection to young sprouts. On a longer time frame, the eight plots of 50 planting sites were arranged topographically at the mouth of (four plots) and adjacent to (four plots) side canyons feeding into a larger field in order to evaluate whether there were any subterranean water patterns that the oaks would respond to. The fields had been leveled so there were no visible side streams from the side canyons feeding into the main stream bed; however we thought that the leveled fields may disguise underlying water patterns. We do not expect the trees to reveal these differences for many years until the roots are deep enough. All planting sites had a tree tube surrounded by a 1-m^2 weed mat to funnel water to the ground. Acorns were planted in January 2001 and height and survivorship were monitored in the spring and fall. Data were analyzed with two-way ANOVA analyses on mean germination, survivorship and height.

Coastal Sage Scrub Trial

In 1999 a coastal sage scrub trial was established to evaluate the use of wood chips as weed inhibitors. Wood chips not only reduce light to the soil surface, but can act as a carbon source for soil microbes causing them to take up available nitrogen and reduce soil nutrient availability (Zink and Allen 1998). Weedy species are generally able to take advantage of available soil nutrients faster than native species, so by reducing nutrient availability we could potentially benefit native species (Allen et al. 1998). Eight plots with 58 plants per plot of four different species (*Rhus integrifolia, Isocoma menziesii, Epilobium canum, Artemisia californica*) were planted with and without wood chips. Weed cover, seedling height, canopy area (x and y diameter measurements) and survivorship were monitored in the spring and fall of the first year and the spring in the ensuing four years. This trial was one of the first trials and no provisions were made for protection from herbivory because the site was surrounded by native coastal sage dominated hillsides.

Chaparral and Coastal Sage Scrub Trial

The chaparral and coastal sage scrub trial, established in 2002, was the result of lessons learned from previous trials about the importance of fencing and weed control and an effort to increase knowledge about the growth rates, survivorship, germinability and site requirements of 38 native plant species. Identifying the relationship between site and species is an important goal of restoration ecology and was an important part of this trial (Aber 1987). The two plant communities, coastal sage scrub and chaparral, were separated into ‘early’ and ‘late’ successional species mixes (Table 1) based on both physiognomic form and site preference, as well as personal observations and descriptions of island plant associations (Holland and Keil 1990, Landis 1997, Knapp 2005). In general, early successional coastal sage scrub species are herbs or sub-shrubs with small, airborne seeds, while later successional coastal sage species may grow on more developed soils and be woody shrubs (Holland and Keil 1990). Chaparral species that follow disturbance (e.g., fire) are characterized here as ‘early’ successional for their ability to grow on less developed soils and tolerate full sun and drier conditions, while the late seral stage chaparral mix is characterized by species typically associated with oak and cherry dominated chaparral growing in well developed soils in moister canyons and north-facing sites (Keeley 2000, Knapp 2005; Table 1).

A goal of this trial was to explicitly understand the relationship between the site and the species as a component of a plant community in order to evaluate the extent to which we will be able to skip successional stages. Consequently within each of the plant communities one additional treatment

Table 1. Specie mix lists by plant community showing initial (2002) seedling and seed density per plot.

Species and plant community	Seedling density/ plot	Seed density/ m^2	Species and plant community	Seedling density/ plot	Seed density/ m^2
Coastal Sage Scrub: Early	106	620	Chaparral: Disturbance dependent	90	319
Achillea millefolium	10	52	*Adenostoma fasciculatum*	12	70
Artemisia californica	9	70	*Arctostaphylos catalinae*	6	26
Baccharis pilularis	10	90	*Ceanothus arboreus*	10	1
Encelia californica	15	36	*Ceaothus megacarpus*	12	20
Eriophyllum confertiflorum	5	17	*Comarostaphylis diversifolia*	2	12
*Galium angustifolium**	0	18	*Dendromecon harfordii*	6	2
Gnaphalium californicum	10	18	*Eriogonum giganteum*	12	35
Hazardia squarrosa	10	70	*Malacothamnus fasiculatus*	0	18
*Hemizonia clementina**	0	35	*Mimulus aurantiacus*	15	70
*Hemizonia fasciculata**	0	35	*Salvia mellifera*	15	70
Isocoma menziesii	12	35	*Xylococcus bicolor*	0	1
Lessingia filanginifolia	10	35	Chaparral: Late seral	82	286
Lotus argophyllus argenteus	10	18	*Crossosoma californicum*	8	35
*Lotus dendroideus**	0	2	*Heteromeles arbutifolia*	2	25
*Lupinus succulentus**	0	4	*Keckiella cordifolia*	15	70
Lupinus truncatus *	0	1	*Lonicera hispidula*	1	18
Mimulus aurantiacus	5	86	*Prunus ilicifolia lyonii*	10	2**
*Plantago erecta**	0	18	*Quercus pacifica, Q.mac.*	10	1**
Coastal Sage Scrub: Late	60	290	*Rhamnus pirifolia*	8	45
*Castilleja affinis**	0	35	*Rhus integrifolia*	10	15
Eriogonum giganteum	10	85	*Salvia apiana*	15	70
Heteromeles arbutifolia	2	4	*Symphoricarpos mollis*	1	2
Lupinus albifrons	5	52			
Malacothamnus fasciculatus	1	13			
Malosma laurina	10	35			
Rhus integrifolia	10	7.5			
Salvia apiana	10	35			
Salvia mellifera	10	35			
Scrophularia villosa	2	18			

* Planted in seed mix only, not as seedling (annual).

** Hand-planted large seeded species.

component was added to refine our understanding of plant community site requirements. The chaparral mixes were planted on a ridge shaped and a valley shaped portion of the site in a full factorial. These sites differ mostly in topographic shape (concave, convex) and in soil moisture level and their elevation difference is slight (50 m). Mycorrhizae are an important component of many native plant communities in southern California because they facilitate the uptake of nutrients and, possibly, moisture (Allen and Allen 1984). Coastal sage scrub species host multiple vesicular arbuscular mycorrhizae (VAM), while chaparral species have specific symbioses with ectomycorrhizal associates that are difficult to introduce (St. John 1992). The coastal sage species mixes (early and late seral) of this trial are fully factored with mycorrhizal inoculation (with and without) in both the seed and seedling components of the study (Table 2).

The hypotheses for this trial were that the early seral coastal sage scrub and the disturbance dependent chaparral species mixes should perform better than the late stage species mixes for each plant community because of species growth rates and tolerance for full sun and disturbed conditions. We expected seedling plots to do better initially, but for seeded plots to eventually form more natural, diverse patches with denser overall cover. Within the chaparral trial ridge/valley dichotomy, we expected the moister conditions in the valley to better support the late stage chaparral species mix than the ridge site and for there to be no difference for the disturbance dependent palette. We hypothesized that the mycorrhizal inoculation would benefit both the early and late seral stage coastal sage scrub plots if it were viable. We did not have enough inoculum or time to evaluate the viability of the inoculum *apriori*.

Based on experience in earlier trials we implemented a number of practical restoration techniques in order to learn more species-specific information. In particular, the 3.24-ha trial site was fenced with an 2.4 m tall deer-proof fence based on our experience with herbivory and trampling in earlier restoration trials. The site was selected because it was dominated by harding grass (*Phalaris aquatica*), a perennial non-native species that was planted as an erosion control measure and forage plant on a disturbed hillside adjacent to the level fields. A grass-specific herbicide, Fusilade (Fluazifop-p-butyl 13%; Xeneca, Inc.), was used to selectively control the grass in order to establish a mat of dead grass tufts which would reduce the space for invasion by other potentially more problematic species. No grasses were planted in the trial so that we could continue to apply the herbicide over the plots as needed after the plants were installed. The primary factors in this study were replicated in seeded plots and seedling plots with each plot being 12 x 12 m. Seed density ranged from 290 to 600 seeds/m^2 and seedling density ranged from 58 to 113 plants/plot to accommodate seedling growth (Table 1). There were a total of 64 plots; 32 each of seed and seedling and four replicates of each factoral combination (Table 2). Additionally, the first year of establishment (2002) was a very dry year, so an additional factor was added to the trial when half of the seedling plots were watered once a month for the four summer months with 9-L water jugs. The jugs were set to drip slowly on each plant.

Table 2. Coastal sage scrub and chaparral trial design diagram. Full factorial trial with two different plant communities (coastal sage and chaparral) in early and late seral forms as seeds and seedlings with vesicular arbuscular mycorrhizae (VAM) as a treatment for coastal sage scrub, and site location (valley and ridge) for chaparral. Each cell (factorial combination) is replicated four times as 12- x 12-m^2 plots.

	Seed	Seed	Seedlings	Seedlings
Coastal sage scrub: *Early*	VAM	No VAM	VAM	No VAM
Coastal sage scrub: *Late*	VAM	No VAM	VAM	No VAM
Chaparral: *Disturbance dependent*	Valley	Ridge	Valley	Ridge
Chaparral: *Late seral*	Valley	Ridge	Valley	Ridge

The planted seedlings were each tagged with individual metal tags. Plant height, survivorship and x and y diameter (canopy area) were monitored in the seedling plots, and eight randomly assigned 1-m^2 plots were monitored in the seeded plots. In each of the 8-m^2 plots, cover was estimated for all species as well as for bare ground and dead harding grass mat. For native species that were seeded, stems were counted in each m^2 plot. Analyses were performed using Minitab software to perform one and two way ANOVA tests. In the seedling plots percent total native cover by plot is the sum of the projected canopy areas of each individual plant measured (based on the average x and y diameters and the formula for the area of a circle) divided by the total area of the plot. Area data for individual plants formed a skewed curve and was transformed using log base 10, however the percent total native cover per plot formed relatively balanced curves and were not transformed for this analysis. Total native plant cover for the seeded plots is the sum of all native plant cover estimates in a 1-m sub-plot averaged across the eight sub-plots per plot.

RESULTS

Oak watering trial

Survivorship was high for all treatments: Driwater (85%), deep pipe (91%) and no water controls (93%). Survivorship did not differ significantly between watering treatments, although it was highest for those receiving no water. While the treatments were being applied (through January 2002), the deep pipe seedlings had the highest growth, however the driwater seedlings had the lowest growth (Fig. 2). After 2002 all seedlings stabilized at the same heights. The additions of native soil to the planting holes had no effect on height, but apparently slightly aided survivorship (94% with soil and 85% without [$P = 0.03$]). In 2003 seedling heights averaged 1.7 m, reflecting a growth rate of approximately 42 cm per year.

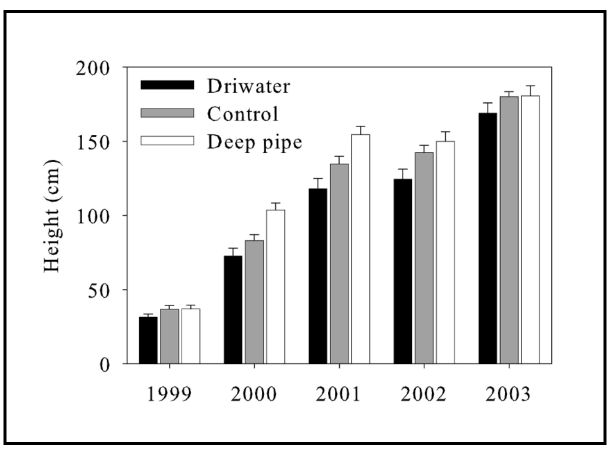

Figure 2. Oak watering trial growth (1999 to 2003) by treatment: Driwater polymer, no water control and monthly deep root watering through vertical pipe (n = 56/treatment); Middle Canyon, Catalina Island.

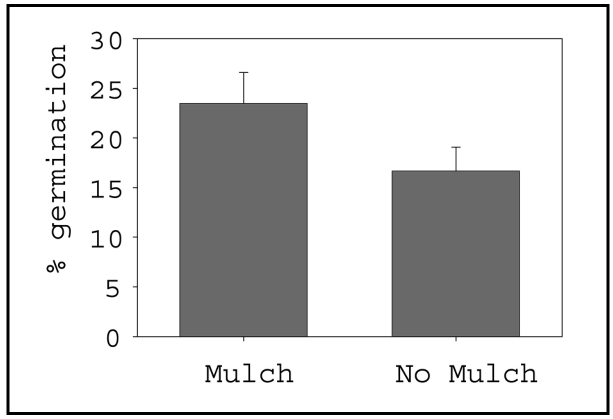

Figure 3. Percent acorn germination 2001: with and without leaf duff (mulch) (n = 633/treatment); Middle Canyon, Catalina Island.

Acorn trial

The oak-leaf mulch added to the acorn planting sites enhanced germination across all species, however differences were not statistically significant (23% vs. 17%; Fig. 3). Germination was highest for *Q. tomentella* (45%) and lowest for the most common island oak species, *Q. pacifica* (14%) (Fig. 4a). Survivorship increased in the second year from a mean of 80% to 90% (Fig. 4b). During the relatively wet year of 2003, all species more than doubled their height while they barely grew during 2002 when rainfall was only 147 mm (Fig. 4c). There was no effect of planting site *vis-à-vis* pre-augered holes or proximity to side canyons.

In 2003 a follow-up *Q. pacifica* acorn planting project was established in the same site using acorns that were considered to be low viability due to their light weight after storage in the nursery for three months (e.g., they flunked the sink/float test) (Bernhardt and Swiecki 2001). Interestingly, these acorns (n = 2,400), planted in 2003, also germinated at a rate of 13%.

Coastal sage scrub mulch trial

Rhus integrifolia had significantly higher survivorship (69%, $P < 0.001$) than the other three species in this trial (43.5% [*Isocoma*], 36% [*Epilobium*], 9.3% [*Artemisia*]) however the most significant result is that three of the four species were either shorter or no taller than when they were planted in 1999 (Fig. 5). Only *Isocoma menziesii* overcame the browsing pressure after three years of suppressed growth. In 2003, two years after the wood chip application was discontinued, there

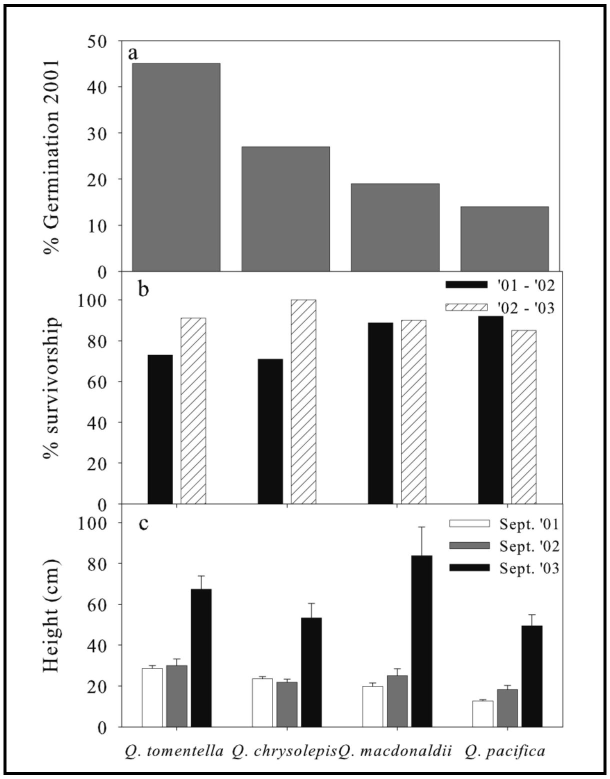

Figure 4. 2001 acorn germination by four oaks species (a), seedling survivorship in two ensuing years (b) and growth (c), Middle Canyon, Catalina Island.

were no differences in height or survivorship due to the application of wood chips to the plots. During the time the wood mulch was being applied, plants in the mulched plots were shorter and more browsed than those surrounded by non-native grasses and annuals.

Coastal sage scrub and chaparral trial

Results are presented in terms of percent survivorship relative to the initial number planted in January 2002 and in terms of total percent native cover which reflects the sum of the cover of planted species relative to the absolute area of the plot. Survivorship of planted seedlings between the eight different treatment combinations ranged from 45% to 53% and does not differ significantly when analyzed with all eight treatment combinations ($P = 0.674$). Total native cover in the seedling plots differs significantly between communities ($P < 0.005$; Fig. 6). Notable is the lack of difference in native plant cover between plant communities in 2002 indicating that initial planting densities were equal. Also interesting is the lack of growth

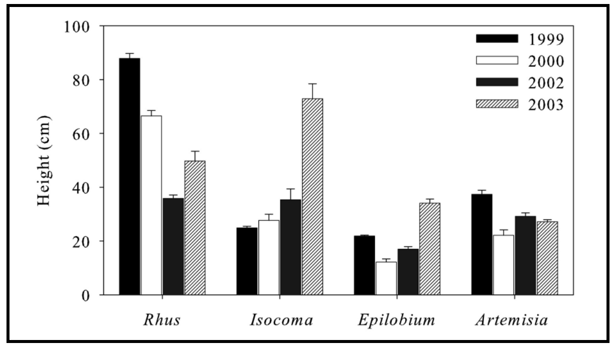

Figure 5. Coastal sage scrub mulch trial seedling growth (1999 to 2003 by species, ($n = 442$ total), Middle Canyon, Catalina Island.

between spring 2003 and spring 2004 year relative to the growth from 2002 to 2003. In the seeded plots native plant cover did not differ significantly between treatments, although the valley chaparral sites had the lowest native plant cover overall ($P = 0.067$; Fig. 7). While seeded species average cover was 5% total, volunteer natives from the seed bank germinated and contributed 75% (10 to 20% absolute cover) to the total percent native cover of 15 to 20%. Dominant native volunteer species included *Sanicula arguta, Lupinus bicolor, Lotus purshianus,* and *Ambrosia psilostachya*.

Within each plant community mix were two treatments: mycorrhizal inoculation (VAM and

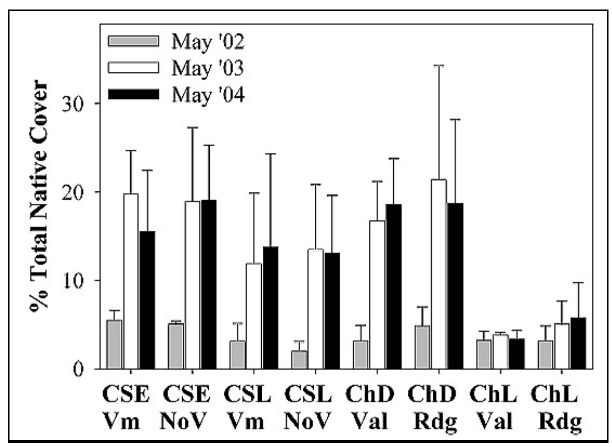

Figure 6. Percent cover by native plants in planted seedling plots of the Coastal Sage Scrub/ Chaparral seral stage trial (2002 to 2004), Middle Canyon, Catalina Island. Abbreviations: CSE = Coastal Sage Scrub, Early seral stage; CSL = Coastal Sage Scrub, Late seral stage; ChD = Chaparral, Disturbance dependent mix; ChL = Chaparral, Late seral stage. VM = inoculated with vesicular arbuscular mycorrhizal inoculum and No V = not inoculated; Val = valley site and Rdg = ridge site.

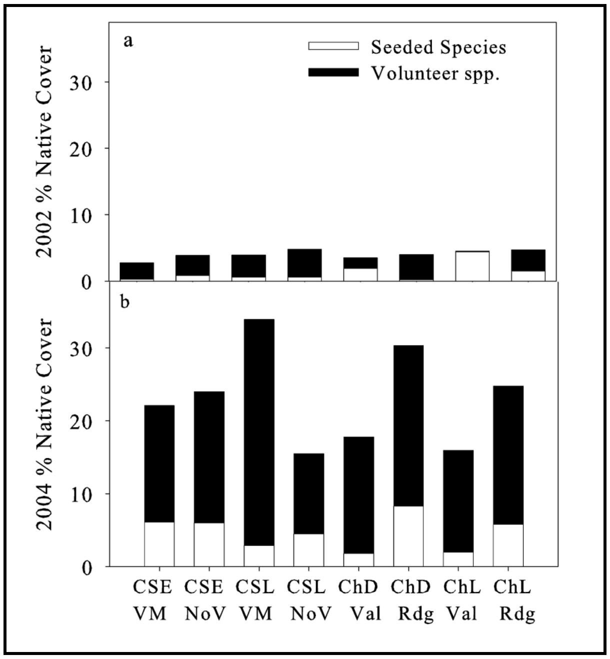

Figure 7. Percent cover by native species in the seeded plots of the Coastal Sage Scrub/ Chaparral seral stage trial: 2002 (a) and 2004 (b), Middle Canyon, Catalina Island. Abbreviations same as in Fig. 6.

NoVAM) for the coastal sage scrub and valley versus ridge planting site for the chaparral. Separate two-way ANOVAS were run for these two factors based on survivorship and total percent canopy area. For the seedling plots, both disturbance dependent and late stage chaparral plant average community survivorship were significantly higher on the ridge site than in the valley (64% vs. 42%; disturbance dependent chaparral) and 54% vs. 41% (late seral chaparral; $P < 0.02$). There were no significant differences in total percent cover for chaparral sub-treatments (valley vs. ridge). There were also no significant differences in survivorship or cover for the coastal sage scrub mycorrhizal treatments.

The role of summer watering in 2002 on long term growth and survivorship is illustrated by considering its impact at the plant community level. Spring 2002 monitoring occurred before the watering treatment was implemented, and there were no differences in canopy cover or survivorship between plant communities (Fig. 8a for cover, survivorship not shown, but similar). In 2004 there were significant differences in survivorship and canopy cover ($P < 0.002$; Fig. 8b), and mean total percent cover for watered plots across treatments was 16% for watered plots and 9.6% for unwatered plots. Only the late stage chaparral plots had a reverse pattern with higher plant cover, 6% in unwatered, versus 3%, in the watered plots.

Weed control efforts were applied across the entire site but had differential effects depending on the site soil moisture and seed bank characteristics. Figure 9 presents cover of dead mats of harding grass (a) and living green grass (b). The cover of living harding grass was low and dead grass mats cover was high in 2002 after focused pre-treatments and very little rain. In 2003, after a wet year, cover by green harding grass was significantly higher (Fig. 9b). Relatively low levels of dead mat and live grass in 2004 reflect disintegration of initial dead grass clumps and effective weed control under intermediate rainfall conditions during the 2004 early spring. Higher levels of living grass in the valley sites reflect higher soil moisture availability; soil moisture in the valley averaged 9.7% in July 2004 and 7.8% on the ridge sites based on 60 gravimetric soil moisture measures.

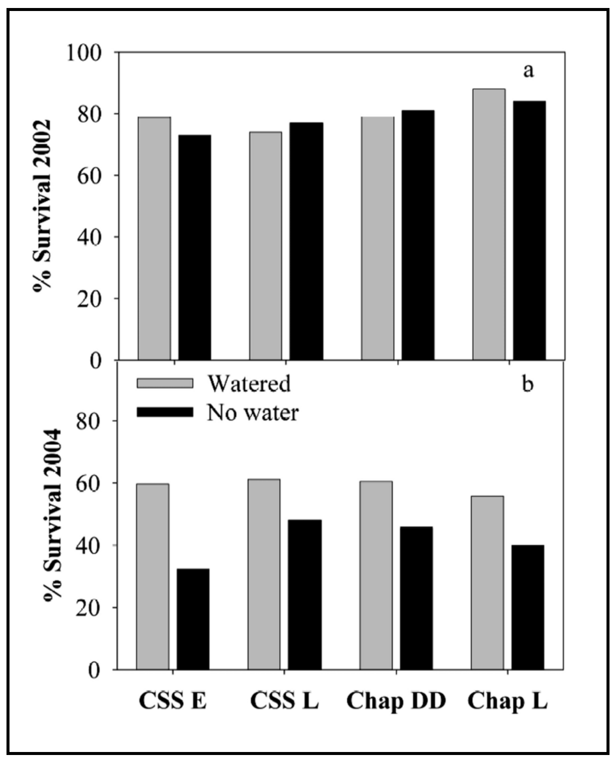

Figure 8. Impact of summer watering (2002) on survivorship by species mix in Coastal Sage Scrub/ Chaparral seral stage trial: 2002 (a) and 2004 (b), Middle Canyon, Catalina Island. Abbreviations same as in Fig. 6.

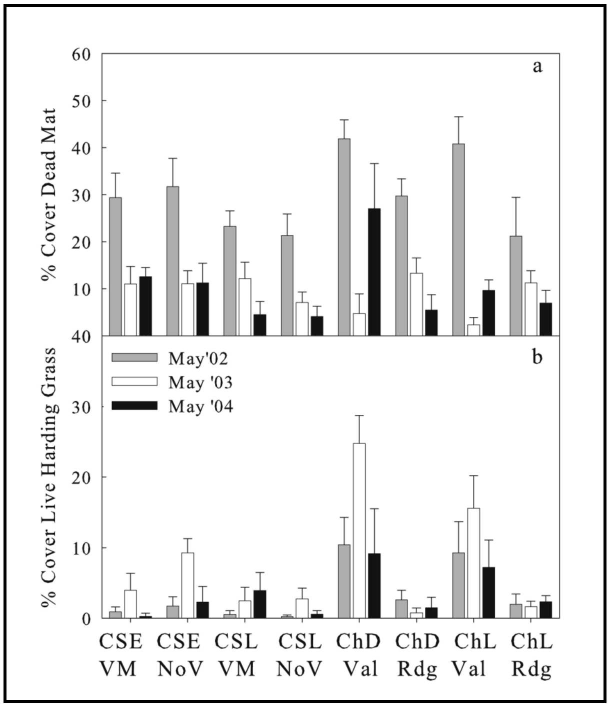

Figure 9. Cover of dead harding grass (*Phalaris aquatica*) mat (a) and live harding grass (b) 2002 to 2004; Middle Canyon, Catalina Island. Abbreviations same as in Fig. 6.

Cover by other weedy species, particularly *Vicia benghalensis, Vulpia myuros, Medicago polymorpha, Sisymbrium officionale, Trifolium hirtum, Erodium spp.* and *Sonchus asper* increased significantly since the trial was initiated. During the wet year (2003) 150 person-hours were invested in hand weeding to remove *Vicia* and *Medicago polymorpha* thickets from 10,000 m^2 (2 acres).

Table 3 provides information on average survivorship and canopy cover for watered and unwatered seedlings, and suggests that during normal rainfall years there is little to no need to water these generally drought tolerant plants. Some species that performed well in the seedling trial also germinated well in the seed trial. *Achillea millefolium, Eriogonum giganteum, Lessingia filaginifolia, Lotus argophyllus, Salvia apiana* and *S. mellifera* were all found more than 10 times in the seeded plots and had mean cover values greater than 5% of the plot (Table 3). Within the seedling trial the species with survivorship higher than 60% include *Achillea millefolium, Adenostoma fasciculata, Baccharis pilularis, Ceanothus arboreus, C. megacarpus, Eriogonum giganteum, Isocoma menziesii, Lessingia filaginifolia, Malacothamnus fasciculatus, Quercus macdonaldii, Salvia apiana,* and *S. mellifera* (Table 3). Fire-following chaparral species seeds were given pre-planting treatments that included soaking in warm, smoky water for 48 h to break the seed coat; nevertheless, there is little evidence that these species germinated.

DISCUSSION

Oak Watering Trial

This trial demonstrated that oak seedlings can survive equally well with and without regular watering. Monthly watering did enhance growth rates but was not required for successful establishment of seedlings nor did it imbue any long-term height advantage. Increased survivorship by those seedlings that received native oak soil at the time of planting indicates the possibility that the treatment had an effect. Conclusive evidence (e.g., with root colonization analyses) have not been conducted because the difference in survivorship is less than 10% at this stage (94% vs. 85%). In practical terms, the trial demonstrated that when bison and deer are present tree tubes staked with metal stakes (rather than oak stakes) are vital to growth and survivorship. Tree tubes stimulate apical growth and appear to create an ameliorated growing microclimate (McCreary and Tecklin 1997). Based on personal observations wood chip mulch is relatively successful at inhibiting weed growth around the bases of the seedlings and is much easier to implement than regular hand scalping of the land with hoes. Wood chip mulch also greatly reduces the need for regular applications of herbicide (Bernhardt and Swiecki 1997).

Acorn Trials

The acorn trials demonstrated that the germination rate for the island's most common oak species, the endemic *Q. pacifica*, is 13% while that of other island oak species ranges from 20 to 40%. Although we didn't weigh the acorns before planting, *Q. pacifica* acorns were much smaller than the other species, so they may have had fewer resources for resisting desiccation and supporting growth under Catalina's relatively dry conditions. Adding leaf litter to the planting sites increased germination rates by 20% for all species (Stratton 2001).

Table 3. Seedling survivorship and average cover (m^2) in 2004 in watered and un-watered plots. Seed germination success in seeded trial reflected in the number of plots where seedlings were encountered. Table shows seeded species and native volunteer species from the site.

Species (total number planted)	% survival of seedlings with H_20	% survival of seedlings without H_20	Average individual cover (m^2) with H_20	Average individual cover (m^2) without H_20	# sub-plots with germinants in seed trial and % of seeded sites
Achillea millefolium (123)	52	43	0.26	0.29	10 (16%)
Adenostoma fasciculatum (110)	54	66	0.13	0.19	0
Arctostaphylos catalinae (48)*	17	4	0.05	0.01	0
Artemisia californica (72)	60	43	0.47	0.49	23 (36%)
Baccharis pilularis (80)	90	53	0.25	0.17	3 (4.6%)
Camarostaphylis diversifolia (52)*	7.6	4	0.12	0.07	0
Ceanothus arboreus (80)	80	75	0.13	0.14	0
Ceanothus megacarpus (97)	73	51	0.16	0.19	0
Crossosoma californicum (68)	57	29	0.08	0.06	0
Dendromecon harfordii (24)*	8	25	1.3	0.39	0
Encelia californica (120)	55	30	0.44	0.43	5 (7.8%)
Eriogonum giganteum (174)	91	68	0.57	0.31	26 (20%)
Eriophyllum confertiflorum (40)	50	30	0.1	0.07	8 (12.5%
Gnaphalium californicum (81)	5	3	0.2	0.16	1 (1.5%)
Hazardia squarrosa (78)	86	26	0.2	0.1	1 (1.5%)
Heteromeles arbutifolia (48)*	21	8	0.02	0.04	0
Isocoma menziesii (98)	92	43	0.29	0.20	0
Keckiella cordifolia (120)	39	41	0.07	0.38	0
Lessingia filaginifolia (83)	78	48	0.15	0.26	8 (12.5%)
Lonicera hispidula (8)	50	25	0.31	0.04	2 (3%)
Lotus argophyllus argenteus (80)	40	20	0.77	0.61	13 (20.3%)
Lupinus albifrons (40)	35	45	0.24	0.09	6 (9.4%)
Malacothamnus fasciculatus (8)	75	50	0.78	0.72	2 (3%)
Malsoma laurina (156)*	37	17	0.3	0.11	0
Mimulus aurantiacus (170)	73	27	0.17	0.11	0
Prunus ilicifolia lyonii (32)	60	24	0.04	0.15	5 (7.8%)
Quercus pacifica (49)	62	43	0.04	0.02	1 (1.5%)
Quercus macdonaldii (29)	92	82	0.13	0.07	Na
Rhamnus pirifolia (63)	45	22	0.05	0.09	2 (3%)
Rhus integrifolia (156)	70	53	0.1	0.08	7 (5.4%)
Ribes viburnifolium (29)	29	13	0.01	0.18	0
Salvia apiana (162)	73	52	0.25	0.24	22 (17%)
Salvia mellifera (201)	77	70	0.97	0.63	6 (4.6%)
Scrophularia villosa (16)	0	0	0	0	0
Symphoricarpos mollis (7)	50	67	0.07	0.07	0
Seeded only species					
Hemizonia fasciculata					54 (84%)
Galium angustifolium					1 (1.5%)
Lotus dendroideus					0
Lupinus succulentus					0
Lupinus truncatus					0
Plantago erecta					14 (22%)
Trifolium wildenovii					0
Volunteer native species in seed plots					
Ambrosia psilostachya					23
Amsinckia menziesii					40
Clarkia epilobioides					1
Dichelostema capitatum					2
Eremocarpus setigerus					12
Gnaphalium bicolor					10
Lotus hamatus					9
Lotus purshianus					8
Lupinus bicolor					97
Sanicula arguta					114
Uropappus lindleyi					3

* Primarily planted in D-16 pots as very small seedlings.

Coastal sage scrub mulch trial

These seedlings were unprotected from herbivory, and the most important result to come from this trial is that unprotected palatable seedlings in Middle Canyon are extremely vulnerable to browsing and trampling pressures. Four years after planting, two species were shorter than when they were planted, one grew 5 cm, and one was recently established and grew this past year (Fig. 5). Bison trample the seedlings and deer browse them, and seedlings in plots with wood chips were the most damaged because they were not hidden from deer within the weeds. Survivorship ranged from 60% for *Rhus integrifolia* to less than 10% for *Artemisia californica*. The effect of mulch on soil nutrient levels and their subsequent effect on plant growth could not be evaluated because of heavy herbivory, an impact that was also seen in other trials. During the period from 1999 through 2002 several trials were initiated to establish native perennial grasses in the weed-dominated fields, and only those grass plants protected in tree tubes and herbicided annually with round-up survived and produced seed. Deer and bison as well as competition from weeds impacted these perennial grass trials as well as several stream bed restoration efforts using willows and annual hand weeding. Results from the riparian trials showed that willows are a desirable forage plant and stream bed weed cover of annual grasses and legumes reduced natural regeneration of native species. A non-quantified observation from several of these trials was that more palatable species were able to grow, flower and fruit only when hidden within the foliage of a less palatable species. In the coastal sage scrub mulch trial *Epilobium canum*, a palatable species, wound its way into the *Isocoma menziesii* shrub where it was protected by *Isocoma*'s sharp leaves and in the willow trials the only willows which grew beyond 61 cm tall were those growing within established stands of *Baccharis salicifolia*, a much less palatable species.

Coastal Sage Scrub and Chaparral Trial

The variation in rainfall over the three years of the coastal sage and chaparral trial significantly affected the results. The impact of the summer watering was wide ranging. Notably, *Dendromecon harfordii* and *Adenostoma fasciculatum* were negatively affected by summer watering and several species did not benefit significantly, including *Quercus macdonaldii, Salvia mellifera, Lupinus albifrons, Keckiella cordifolia and Ceanothus arboreus* (Table 3). Other, apparently hardy species, *Baccharis pilularis, Hazardia squarrosa, Isocoma menziesii, Mimulus aurantiacus* and *Rhamnus pirifolia,* more than doubled their survivorship with the four water additions (Table 3). In a non-drought year, provision of additional water may not benefit seedlings to the same extent. In a study by Padgett et al. (2000) on the impact of varying irrigation regimes on coastal sage scrub she found that water can reduce survivorship of many native species and lead to monospecific dominance by *Artemisia californica*. The risks of irrigation include root pathogens, overgrowth of shoots relative to roots and the development of superficial surface roots at the expense of deep roots (Perry 1987, Lauenroth et al. 1978, Elberse and Breman 1990). Although the moderate additions of water in this trial benefited many species, irrigation may not be helpful in years with normal rainfall or in sites with dense, clay soils where root pathogens flourish.

Although canopy measurements are presented for 2004, two years after planting canopy size did not differ significantly between 2003 and 2004 due to the lack of precipitation during the 2004 growing season. As such, predictions about total canopy cover in future projects can be made for growth estimates in wet and dry years. Knowledge about which species readily germinate in the field from seed can also be helpful for planning restoration in areas that are more difficult to access or in which a greater diversity is desired with lower levels of planting effort.

Within the four major plant community plot types the late seral stage chaparral, dominated by very slow growing woody species, had the lowest percent total native plant cover in 2004 and 2003. Interestingly, survivorship was similar between all plant communities and treatments. Over the long term, however, the late successional chaparral species may attain full plot coverage because many are trees and large shrubs rather than sub-shrubs. In the coming years it may be useful to add a weed control experimental component to evaluate the importance of long-term weed control for these different plant communities. Non-native plants such as *Trifolium hirtum* and annual grasses (e.g. *Bromus diandrus, B. madritensis* and *Avena fatua*) are known to competitively suppress coastal sage scrub species in areas restored from seed and in planted seedling trials (Eliason and Allen 1997). It is not known, however, how long weeding efforts must be sustained to achieve a diverse coastal sage or chaparral plant community in southern California, and such efforts must be weighed against the expense of maintaining such trials (Schultz 1996).

The effect of the treatment within the coastal sage plant community (VAM or no VAM) was not significant for survivorship or growth; however the lack of impact of mycorrhizal treatment should be further investigated before drawing conclusions about the lack of potential benefits from mycorrhizae in restoration. In particular, soil and root analyses of root infectivity rates could provide information about whether the treatment was effective in colonizing roots. Following the survivorship patterns in treatments over time could also provide information about the biological impact of the mycorrhizal treatments if consistent differences by treatment benefits become apparent. Future trials should be conducted to further develop Conservancy expertise in the use of mycorrhizae in restoration, and toward that end several trials using translocated soil and leaf duff have already been implemented. In oaks the transfer increases acorn germination rates and improves survivorship, but does not affect growth rates (Stratton and Herrera 2004). Assays of root pieces have not been conducted, so results to date are correlative in nature.

The valley versus ridge planting site treatment for the two seeded chaparral plot types gave the surprising result that native plant growth was higher in the more exposed ridge sites for both the disturbance dependent and late stage chaparral plant communities (Fig. 7). This may have been due to the lack of competition on the ridges from harding grass and other weeds found in the valley site that had a greater impact on newly germinating seedlings than on planted one-year old seedlings. While having an effective method for controlling what appeared to be the dominant weed on the site (harding grass), was valuable, we weren't fully prepared for the abundance and variety of non-native plants that germinated from the seed bank. Furthermore, the theory that the mats of dead grass would keep out other noxious weeds has only been partially upheld. While it does reduce the availability of germination sites for plants, it does not prevent decumbent, vine-like species from using the open space to increase cover. *Vicia bengalensis, Medicago polymorpha, Polygonum arenastrum, Meliotis indica* and *Anagalis arvensis* were particularly successful at spreading over the mat during the wetter 2003 year. Mustards (*Sisymbrium officionale, Hirschfeldia spp, Brassica nigra*) and *Sonchus oleraceous* did not grow over the mat areas and did not germinate directly in a site occupied by harding grass clumps (living or dead). Hence, the presence of the dead mats reduced the competitive ability of certain non-native weeds by reducing their density.

Seed germination rates of 2 to 5% in the field were very low relative to the seedling survivorship but were comparable to similar seeding trials in coastal sage scrub communities (Eliason and Allen 1997). Possible explanations for the low germination of most of the seeded plots include granivory by doves, quail and starlings, desiccation of germinants under the dry 2002 conditions, and improper germination conditions. While pre-treatment of fire-following chaparral species with a 48-h soak in smoky water was implemented, more work needs to be conducted on inducing seed germination for wild-sown seeds (Stratton and Herrera 2004). The risk of using nursery dormancy-breaking pre-treatments is that seeds will germinate before ambient conditions are appropriate for seedling growth. Future field seed germination trials should also include an experimental component to keep granivorous animals out of the plots. Seed pre-germination treatments for fire-following species, particularly *Xylococcus bicolor*, are still being developed by the Catalina Island Conservancy Native Plant Nursery and others.

In terms of restoration techniques, these trials have provided useful species-specific information relative to watering treatment and growth rates on different sites. It has also shown the value and importance of fencing and weed control to seedling growth and establishment. With about 50% average survivorship across the different plant community successional stage treatments, it appears that it is possible to jump start the restoration of a particular site to later seral communities when plants are established from seedlings. Due to variations in species growth rates it may take many years before self-sustaining, weed resistant communities are developed. Despite hand planting acorns and cherry seeds and raking in seeds of other species, native plant cover and diversity in seeded plots is still quite low after three years. Another iteration of this portion of the trial in a wet year with experimental protection of seeds from birds and rodents, and varying seeding densities, will be necessary to evaluate if diverse native plant communities can be established from seed alone.

CONCLUSIONS

Despite the fact that these trials were surrounded by native vegetation on adjacent hillsides, the plants were still the target of deer and bison for forage and scratching, resulting in a great deal of time and money spent protecting plants from herbivory through fencing, caging and tree tubes. Future restoration efforts need to consider the impact of local herbivores and make use of these methods of protection and/or consider techniques to hide plantings of more palatable species within the canopies of less palatable species as occurred in the coastal sage scrub mulch trial and the willow trial. Several of the old fields on the island are being naturally colonized by species that are more able to resist browsing (e.g., *Baccharis pilularis*, *B. salicifolia*, *Artemisia douglasiana*, *A. californica*), and, in lieu of fencing, these plants could be used to harbor a diverse planting of associated species more vulnerable to herbivory. Fencing is expensive and requires maintenance, but alternatively allows for the relatively rapid establishment of a diverse plant community. The comparison between the low growth rates of the unfenced coastal sage scrub mulch trial and the fenced coastal sage and chaparral trial's high rate of plant establishment and growth support this conclusion.

The second primary finding is that restoration on Catalina and in southern California is greatly affected by annual precipitation, with the growth of weeds and native plants highly correlated to rainfall. In 2002, a very dry year (145 mm rainfall), weed control was a non-issue and native plant growth was minimal while in 2003 when rainfall was above average (406 mm) many new weeds germinated and became well established. In addition, oak seedlings more than doubled in height during the wet year and barely grew during the dry year. Weed control strategies are important in sites with dense weedy seed banks, particularly moist sites, so restoration budgets must include time, money and flexibility to respond during wet years. On the other side of the moisture coin, our research indicates that native plants are very hardy and can become established even in dry years without additional water. During extremely dry years (e.g., 2002) some species may benefit from intermittent, deep summer watering, but it is not required for establishment in our silt-clay soils.

The use of native soil and leaf duff from mature oak trees has benefited planted seedlings and increased the germination rate of acorns by 20%. Our effort to use mycorrhizal inoculum grown from local stock was not successful, but the increase in survivorship among oaks with the addition of native soil suggests that it is valuable to continue to research the potential benefits of mycorrhizae.

Finally, several trials with seeded components demonstrated that seeding alone is insufficient to convert non-native dominated areas to native plant communities, but the success of several native species (Table 3) indicate that using a combination of seeding and planted seedlings could, together, increase the diversity of native plantings with reduced input. Overall, this series of iterative trial has provided species-specific information about growth rates, survivorship and germination for over 48 species under varying conditions. The trials have highlighted the key challenges to restoration on Catalina and have resulted in information that will hopefully be used to further refine restoration efforts for native plant communities across southern California.

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