

Landscape restoration in southern California forblands: Response of abandoned farmland to invasive annual grass control

EDITH B. ALLEN,^{a,*} Robert D. COX,^a TRACY TENNANT,^a SHEILA N. KEE,^a AND DOUGLAS H. DEUTSCHMAN^b
^aDepartment of Botany and Plant Sciences, and Center for Conservation Biology, University of California,
Riverside, California 92521, USA

^bDepartment of Biology, San Diego State University, San Diego, California 92182, USA

(Received 10 September 2005 and in revised form 7 January 2006)

ABSTRACT

A large-scale experiment using 1-ha plots was done to control invasive Mediterranean annual grasses, primarily *Bromus* spp., in farmlands abandoned for 20 years in southern California. Treatments were a grass-specific herbicide, and herbicide plus dethatching. Dethatching was done to improve the contact of herbicide with newly growing grass seedlings, and to remove litter that may potentially affect germination of native annuals. Native annuals had increased richness in response to grass control, but had low cover in all but two of six years when precipitation was adequate. Dethatching did not improve forb response. Two exotic species of *Erodium* were the greatest beneficiaries of exotic grass control, but the positive response of native forbs in spite of *Erodium* dominance suggests a competitive hierarchy of less intense interaction between the native forbs and *Erodium* than between native forbs and exotic grasses. After five years, grasses began to recover from the herbicide treatments, indicating the need for periodic management of exotic grasses to maintain richness and cover of native forbs. Shrubs that occur on adjacent hills did not recolonize during these six years, suggesting that the valley bottoms may have always been forblands rather than shrublands. The study shows that restoration can be used to rediscover the former vegetation of long-disturbed landscapes.

Keywords: competitive hierarchy, dethatching, forbland, herbicide, invasive annual forbs, invasive annual grasses

INTRODUCTION

Invasions by exotic plant species have become a major problem for land managers of nature reserves in many areas, and restoration serves as an important feedback to maintain the natural condition of impacted landscapes (Naveh, 1998, 2005). Exotic plants may replace native species over large landscapes, where they reduce the space available for natives and may cause increased scarcity and endangered status of rare species (D'Antonio and Vitousek, 1992; Pavlik et al., 1993; Pysek et al., 1995; Carlsen et al., 2000; Bar et al., 2004). One of the most invulnerable vegetation types in southern California is the coastal sage scrub (CSS), which grades to annual forbland where native shrub cover is sparse or

absent. CSS and associated forblands have been subject to fragmentation, heavy grazing, frequent fire, and air pollution, all of which promote weed invasion (Minnich and Dezzani, 1998; Allen et al., 2000; Allen, 2004). The dominant invasive species are from the Mediterranean, including species of the grass genera *Avena*, *Hordeum*, *Bromus*, and *Schismus*, and the forbs *Brassica* and *Erodium* (Rejmanek et al., 1991).

In some vegetation types invasive annual species decline after cessation of disturbance during succession. However, long-term observations of CSS sites show that, once established, the exotic grasses and forbs

*Author to whom correspondence should be addressed. E-mail: edith.allen@ucr.edu

persist and are not replaced by the former native species (Zink et al., 1995; Styliniski and Allen, 1999; Allen et al., 2000; Allen, 2004). Experimental studies showed that invasive annual grasses were competitive with native species, and that grass control is necessary before natives will reestablish (Nelson and Allen, 1993; Eliason and Allen, 1997; Cione et al., 2002; Gillespie and Allen, 2004). However, grass control allows not only native species, but also exotic forbs to colonize. The conversion of exotic grassland to exotic forbland creates a competitive hierarchy (sensu Shipley and Keddy, 1994) of matrix species in which the native restoration species must establish. In one study a reintroduced native forb was better able to establish in a matrix of exotic forbs than exotic grasses; even though exotic forbs could not be controlled, the control of exotic grasses was sufficient to enable native plant reestablishment (Gillespie and Allen, 2004).

Restoration will be most successful when fragments of native vegetation persist in the landscape, as species that reinvade naturally must come from the local species pool (Bell et al., 1997; Palmer et al., 1997). Predicting the composition of the restored vegetation type depends upon the availability of a suitable reference area. Where the disturbance has been extensive or long-term, reference areas may no longer exist. For instance, the sites under study occurred in valleys that have been in agriculture for a century, and there is no record whether the vegetation may once have been CSS or native annual forbland. The forbland has only recently received attention as a former dominant vegetation type in semiarid regions of California (Hamilton, 1997; Schiffman, 2000). A restoration experiment can be done to determine which species are most likely to colonize a site and therefore to determine what the former native vegetation type was.

The persistence of invasive species may be a major limiting factor for restoration of some native vegetation types (Corbin et al., 2004), and a restoration experiment tests the stability of the system when it is carried out over the long term. Restorationists generally work under the premise that the best control for exotic species is to replace them with desirable native species. However, where exotic plants have dominated for a long time, it is not clear whether the native species will persist once they have been restored. A long-term study was done to observe the colonization process and stability of the native vegetation over six growing seasons.

The choice of vegetation management technique must be based on availability, prior knowledge of success, and limitations of the particular site. In this study we worked closely with land managers to select a grass-specific herbicide combined with dethatching of exotic

grass litter. Grass-specific herbicide was successful in controlling exotic annual grasses and consequently enabling shrub establishment in a previous experiment in coastal sage scrub (Cione et al., 2002). Mulch control reduced exotic vegetation, but did not increase native forbs at a forbland site in central California (Meyer and Schiffman, 1999). *Bromus* spp. may have increased germination in light compared to dark under warm temperatures (Zaady et al., 2003), so the response to decreased mulch is equivocal. Spring or summer fire reduced exotic grasses and promoted native forbs in annual forbland and perennial grassland (Meyer and Schiffman, 1999; Gillespie and Allen, 2004). Fire was not used here because of regulatory restrictions. Domestic grazing controlled exotic grasses and promoted native forbs in northern California (Weiss, 1999), but grazing was not recommended in the drier climate of southern California where the exotic forb *Erodium cicutarium* overcompensated in response to clipping (Kimball and Schiffman, 2003).

A restoration experiment was done during six growing seasons in southern California to control exotic grasses. The objectives were to (1) examine the species composition of abandoned farmland following exotic grass control, (2) determine whether a competitive hierarchy exists for stands dominated by exotic grasses vs. exotic forbs with respect to native reinvasions, and (3) examine the stability of the native vegetation following exotic grass control during the six growing seasons. The large scale of the invasion requires a landscape approach, which we have undertaken by applying treatments to 1-hectare size plots. The treatments allowed us to determine whether both native shrubs and forbs would colonize, and what components of the vegetation must be reintroduced rather than passively recolonize following exotic grass control.

METHODS

The study was carried out in Crown Valley in the Western Riverside County MultiSpecies Habitat Reserve (33°39'18"N, 116°59'49"W). The area has a Mediterranean-type climate with 270 mm precipitation annually (30-year mean), most falling between November and April. During the six growing seasons of this study the precipitation was near average only during July 2002–June 2003, at a record low of 75 mm in 2001/02, and below average in the other seasons (Fig. 1). Soils are primarily decomposed granites in the valley bottoms, with a rolling topography consisting of rocky granitic outcroppings. The dominant vegetation on the hills is coastal sage scrub (CSS), a semi-deciduous shrubland of ca. 1 m height (DeSimone and Zedler, 1999). The shrubs

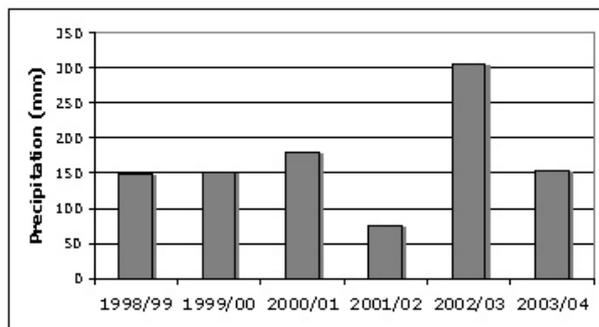


Fig. 1. Growing season precipitation (July–June) during the study (California Irrigation Management Information System, Temecula East station, www.cimis.water.ca.gov).

consist primarily of *Artemisia californica*, *Eriogonum fasciculatum*, and *Ericameria palmeri*, while the native forbs include *Amsinckia menziesii*, species of *Cryptantha*, *Lupinus*, *Castilleja*, and several dozen other species (see Hickman, 1993, for species authorities). Few perennial native grasses occur on site except in gullies or run-on areas where a few patches occur under higher soil moisture. The valley bottoms as well as shrub understories on the hills are dominated by exotic annual grasses and forbs introduced from the Mediterranean, especially species in the genera *Bromus* and *Erodium*. The land has been dry-land farmed and grazed by cattle since the 1880s, with valley bottoms largely converted to wheat. It was abandoned from agriculture in the mid-1980s and annexed to the Reserve to increase habitat for rare and endangered species. The original vegetation type of the valley bottoms is not known, whether they were forblands or shrublands. Native forblands may occur in the region in fine-textured bottomland soils, and forblands are increasingly recognized as a vegetation type that has largely disappeared from California (Hamilton, 1997; Schiffman, 2000). One goal of the research was to observe whether shrubs or only native forbs would recolonize following the treatments.

The treatments agreed upon with the Reserve managers were application of the grass-specific herbicide Fusilade II®, and dethatching plus Fusilade II®. The dethatching treatment was done to remove the exotic annual grass thatch from the previous year. This has the effect both of exposing the soil surface for potential improved germination of native seed (Meyer and Schiffman, 1999) and of increasing herbicide contact with newly germinating exotic grasses that would otherwise need to grow taller than the prior season's litter before herbicide would be effective.

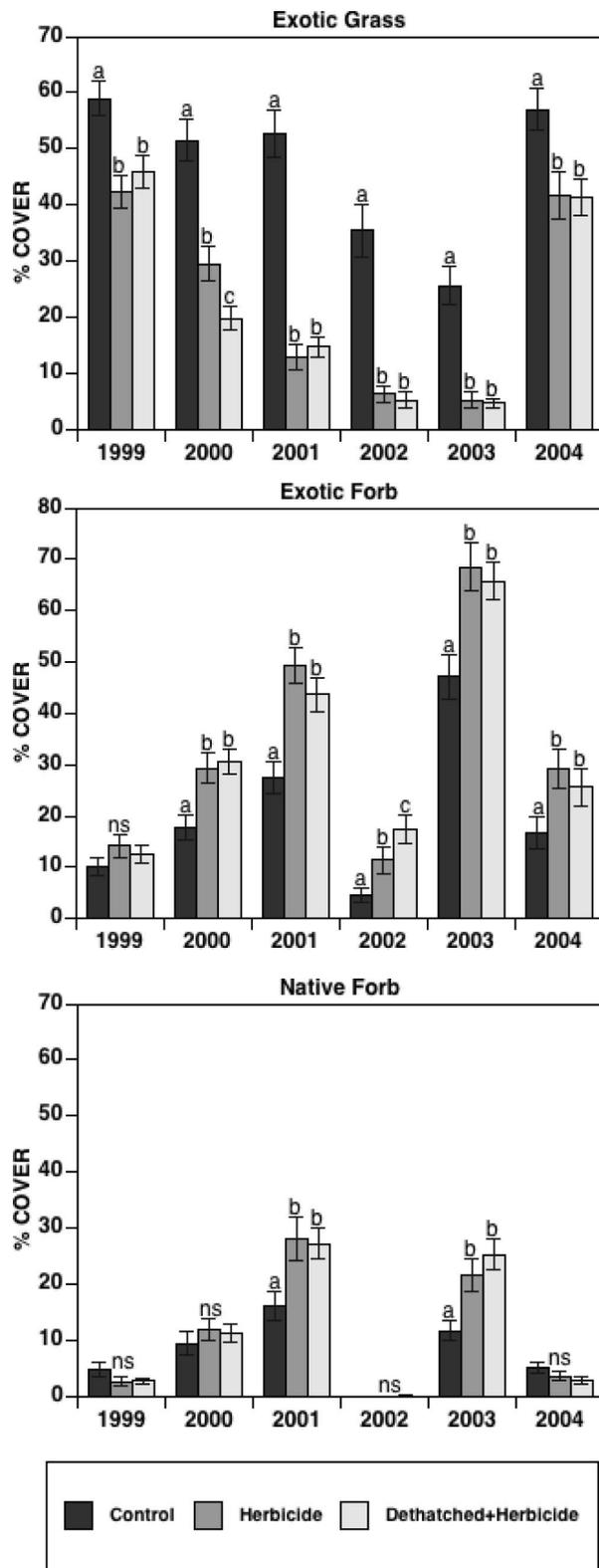
The experimental design was a randomized block design with three replicates of 1-ha plots of each of the

following treatments: (1) untreated controls, (2) grass-specific herbicide, and (3) grass-specific herbicide plus dethatching, for a total of nine 1-ha plots. Fusilade II® was applied at the lowest level of the manufacturer's recommended dose (68 ml/ha) in March 1999 in six of the nine plots using hand-held sprayers. Because vegetation measurements in April 1999 showed incomplete control of exotic grasses, the treatment was repeated the next year. First, three of the previously-sprayed plots were dethatched using gasoline-driven, handheld weed trimmers in November 1999. The herbicide treatment was applied a second time in February 2000 to the same six plots as in 1999. Timing of herbicide application in both years coincided with emergence of the exotic grasses, but was done prior to seed set. Because the dominant grass was the small-statured and rapidly-maturing *Bromus madritensis* ssp. *rubens*, the window of time for effective herbicide application was only 20–25 days. Substantial rainfall was later in 1999 than 2000, accounting for the later herbicide application. No further herbicide treatments were done following the second treatment in 2000.

Percent cover data were collected in permanent 0.5 × 1.0 m quadrats, 20 per 1-ha plot in late April/early May of each year from 1999 to 2004. This gave a total of 60 sample quadrats per treatment for the three blocks. Vegetation cover was estimated to the nearest 1% by species in a gridded frame. Species were grouped as exotic grass, exotic forb, and native forb for statistical analyses using ANOVA to compare the treatments and controls within each year. The block effect was tested, and although some blocks had significantly lower total vegetation cover than others, there were no significant block-by-treatment interactions. Therefore, only treatment effects are shown. Sorenson's index ($2w/[a+b]$; a , n/b = richness in samples a and b , w = number of species in common) was calculated to compare species' similarity among treatments and years.

RESULTS

The grass-specific herbicide treatment reduced exotic grasses from 58% in the control plots to 41–44% in the treated plots in the first year of application, in 1999 (Fig. 2). In the second year of herbicide treatment, in 2000, grass cover was reduced from 53% to 28%, and had a further reduction to 19% with dethatching plus herbicide. The effect of herbicide treatments persisted through 2004, although there were no longer significant differences among the herbicide and dethatching plus herbicide treatments. By 2004 the grasses were recovering from the herbicide treatment, although their cover was still lower than the control.



The exotic grasses were dominated by *Bromus madritensis* ssp. *rubens* and *B. diandrus* in all years and treatments (Table 1). Values in Table 1 for each species group are shown for 2001, the year with the greatest cover of native forbs.

The exotic forbs were dominated by *Erodium brachycarpum* and *E. cicutarium*, with *Hypochaeris glabra* the next in dominance and 1–2% contribution by all other exotic forbs (Table 1). The grass herbicide treatment was most beneficial to the two *Erodium* species, promoting an increase in their cover of ca. 5–20% over controls in each year from 2000 to 2004 (Fig. 2). The dethatching treatment promoted an increase in cover of *Erodium* compared to the herbicide treatment only during 2002, but otherwise there were no significant differences among the two herbicide treatments.

The native forbs increased in cover in response to the reduction of exotic grasses in 2001 and 2003, with no difference in total cover in response to the herbicide or dethatching plus herbicide treatments in any year. Native forbs did not emerge during the extremely dry spring of 2002. Native forb cover was always lower than *Erodium* cover (Fig. 2). Among the native forbs there was only one clear dominant, *Amsinckia menziesii*, a few species with 2–3% cover, and of the other 21 to 41 species in any year each had <<1% cover (Table 1). The cover values for 2001 suggest that the dethatching treatment had a positive effect on several species of native forbs with 2–3% cover, although with many 0 values among the replicate quadrats these figures are not significant.

Not only cover, but also richness of native forb species was positively influenced by grass control treatments (Table 2). The number of species per 0.5 m² quadrat was significantly higher following grass control in 1999–2003 (with the exception of 2002, when there was virtually no emergence of native forbs). The lack of a significant difference in richness in 2004 may be due to the fact that the last substantial rain was in February, and many native forbs were already dry during the April sampling and may have been missed. The total number of species in the three 1-ha plots per treatment (sampled with 20 quadrats each) was higher in the treatments than controls in 2000 and 2003, although a significance

Fig. 2 (left). Responses of exotic grasses, exotic forbs, and native forbs to grass-specific herbicide and dethatching plus herbicide treatments during six years. Herbicide was applied in March 1999 and February 2000, and dethatching was done in November, 1999. Percent cover data were collected in April/May of each year. Bars with different superscript letters are significantly different from each other at $p = 0.05$. ns = not significant. Error bars are SE.

Table 1

Percent cover of species and species groups in 2001 in control, herbicide, and dethatching plus herbicide treated plots. Values shown in bold are significantly different from other values in a row ($p < 0.05$). Data are shown for 2001, as this was the year with the highest native forb cover

% cover	control	S.E.	herbicide	S.E.	dethatch-herbicide	S.E.
Litter	50.3	3.6	39.3	3.0	38.5	2.6
Bare soil	8.0	2.0	7.2	1.5	18.0	2.3
Exotic annual forbs						
<i>Erodium brachycarpum</i>	23.7	3.2	39.0	3.7	39.2	3.3
<i>Erodium cicutarium</i>	1.8	0.7	6.2	2.2	0.2	0.2
<i>Hypochaeris glabra</i>	0.9	0.3	3.0	0.9	4.2	1.5
six other exotic forbs	1.3	0.9	1.5	0.7	0.7	0.3
Exotic annual grasses						
<i>Bromus madritensis</i>	24.0	3.1	5.0	1.5	5.1	1.3
<i>Bromus diandrus</i>	26.8	3.8	4.0	1.3	0.9	0.3
<i>Vulpia myuros</i>	0.4	0.3	1.1	0.4	6.8	1.4
four other exotic grasses	1.6	0.8	2.7	1.4	1.9	1.0
Native forbs						
<i>Amsinckia menziesii</i>	10.1	2.4	17.4	3.8	11.4	2.4
<i>Lotus hamatus</i>	1.8	0.6	1.3	0.5	2.3	0.7
<i>Plagiobothrys canescens</i>	0.0	0.0	2.1	1.0	3.2	1.7
<i>Calandrina ciliata</i>	0.2	0.1	1.3	0.4	3.3	1.1
<i>Lupinus bicolor</i>	1.0	0.3	0.4	0.2	3.1	1.0
31 other native forbs	3.1	1.9	6.9	4.2	5.4	3.1
Five native shrubs	2.5	1.8	2.1	1.5	2.0	1.9
One native perennial grass	0.0	0.0	0.1	0.1	0.0	0.0

Other exotic forbs: *Sisymbrium altissimum*, *Filago gallica*, *Sonchus asper*, *Silene gallica*, *Lactuca seriola*, *Brassica geniculata*.

Other exotic grasses: *Avena barbata*, *Bromus hordeaceus*, *Hordeum murinum*, *Schismus barbatus*.

Five native shrubs: *Artemisia californica*, *Eriogonum fasciculatum*, *Ericameria palmeri*, *Gutierrezia californica*, *Tetradymia comosa*.

Native grass: *Nassella pulchra*.

31 other native forbs: annuals--*Camissonia* species, *Camissonia bistorta*, *Castilleja exserta*, *Clarkia purpurea*, *Conyza Canadensis*, *Crassula conata*, *Eremocarpum setigerum*, *Erigeron foliosus*, *Eschscholzia californica*, *Euphorbia albomarginata*, *Hemizonia fasciculata*, *Hemizonia kelloggii*, *Lepidium nitidum*, *Linaria canadensis*, *Lotus strigosus*, *Microris lindleyi*, *Navarretia atractyloides*, *Pectocarya linearis*, *Plagiobothrys nothofolius*, *Plantago erecta*, *Plantago ovata*, *Stylocline gnaphaloides*, *Trifolium* spp., *Trifolium albopurpureum*, *Trichostemma lanceolatum*, *Tropidocarpum gracile*; perennials--*Daucus pusillus*, *Lessingia filaginifolia*, *Mimulus guttatus*, *Sanicula arguta*, *Stephanomeria exigua*.

Nomenclature follows Hickman (1993).

test cannot be done because these values represent an inventory of all of the species found. In addition to these native forbs, the plots contained nine exotic forbs, seven exotic grasses, and three native shrub species. The shrubs had less than 1% cover, indicating no native shrub recruitment even after exotic grass control.

The Sorensen's index analysis showed 31.6 to 88% native forbs species in common between the controls and herbicide, and herbicide-dethatching treatments in different years (Table 3). The dry year of 2002 is not

shown because of lack of native cover, and the similarity among treatments was lowest in 2004 with a dry spring and low native forb richness (Table 2). Similarity was highest among treatments for the wet spring of 2003. Overall the Sorensen's analysis shows there was a greater year than treatment effect on species similarity (Table 3).

The annual variation in cover of vegetation was related to precipitation, and timing of precipitation (data not shown) was as important as annual total precipita-

Table 2

Count of native forbs in 0.5 m² sample quadrats: # species per quadrat, total in all 60 quadrats per treatment, and total number of native forbs found in all treatments. Numbers in bold show control quadrats that have significantly lower species richness than treated quadrats

Year	# native forb species/quadrat			total # native forbs in all treatments
	control	herbicide	dethatch- herb	
1999	0.78	1.00	1.00	22
2000	1.91	3.71	3.30	42
2001	3.02	3.97	4.97	36
2003	2.90	3.31	3.87	33
2004	0.93	1.07	0.82	28
Year	# native forb species/60 quadrats			total # native forbs in all treatments
	control	herbicide	dethatch- herb	
1999	12	16	11	22
2000	19	28	29	42
2001	28	30	31	36
2003	22	31	28	33
2004	8	24	11	28

Table 3

Sorenson's index comparing native forb species presence among treatments. C = control, H = herbicide, TH = de-thatched plus herbicide

	C vs. H	C vs. TH	H vs. TH
1999	0.500	0.696	0.590
2000	0.638	0.583	0.596
2001	0.793	0.847	0.754
2003	0.830	0.880	0.813
2004	0.438	0.316	0.400

tion. Southern California received the lowest amount of precipitation during the 2001/02 growing season since records began in California (1849), and virtually no native forbs germinated or emerged (Fig. 2). Exotic forbs (mainly *Erodium*) were also less than 10% in cover, and the most abundant grass in this year was the desert grass *Schismus barbatus*. *Erodium* and native forbs both had relatively high cover in 02/03, perhaps in part because the exotic grass seed bank was depleted from the poor grass production in 01/02, but also because rains were late and heavy, beginning in February of 2003. By contrast, 03/04 was a good year for grasses, as rains were early, with major rainfall beginning in November. In years of early rain when grasses had early productivity, native as well as exotic forbs had lower cover in the subsequent April/May (especially 98/99 and 03/04).

DISCUSSION

The grass-specific herbicide controlled exotic annual grasses for four seasons following application, but by the fifth year, grass in the treated plots was recovering, although still 20% lower than the controls. This shows that exotic grass dominance is the most stable state for this landscape, and restoration to native vegetation will require continual control of exotic grasses at approximately five-year intervals. Furthermore, exotic forbs were best able to take advantage of the space made available by the decrease in grasses, although native forbs increased in two of the six years when precipitation conditions promoted relatively high cover. The removal of exotic grasses was also shown in prior experiments to promote a competitive release of exotic forbs more than of native species (Brooks, 2000; Gillespie and Allen, 2004), but native forb establishment was higher in a matrix of exotic forbs than grasses. This suggests there is a competitive hierarchy, with *Bromus* spp. being most competitive and *Erodium* spp. less competitive against the native forbs.

Native shrubs showed virtually no colonization into the herbicide-treated plots, as expected, even though the valley bottoms were surrounded by hills covered with CSS vegetation as a potential seed source. We examined sample quadrats that were in the proximity of shrubs, but these also did not have higher shrub colonization. We observed stands of *Ericameria palmeri* and *Tetrad-*

ymia comosa that were expanding during the six-year study, but both were limited to a few square meters. Coastal sage scrub is a fire-driven vegetation type, but shrub recruitment can occur between fires (DeSimone and Zedler, 1999). These shrub species can in fact disperse into native perennial grassland, and are part of a dynamic of shifting native shrub-grass ecotones (DeSimone and Zedler, 1999).

The lack of shrub recruitment in the former agricultural lands may have several explanations. The first may be that these valley bottoms have always been forblands rather than shrublands, and shrubs are not suited to the site. Another hypothesis is that shrubs are not suited to the new soil conditions caused by plowing. However, CSS shrubs established from seed in frequently disked soil that was cleared of all vegetation in another farmland site (Padgett et al., 2000). The latter site was less than 60 km distant and of the same granitic parent material. A third hypothesis is that the high dominance of exotic grasses and forbs excludes shrub seedlings, and greater effort must be used to reestablish shrubs in these valleys. For instance, establishment of the native shrub *Artemisia californica* from seed was greatly reduced at all grass densities greater than 25 grass plants/m², although, unlike our study, a few individual shrubs were able to establish even in high grass densities (Eliason and Allen, 1997). Similarly, *Erodium botrys* reduced oak seedling establishment from seed in northern California (Gordon and Rice, 1993).

Abandoned croplands in northern California were dominated by exotic annuals after 50 years (Stromberg and Griffen, 1996), and small-scale disturbance by gophers may exclude colonizing native perennial grasses in this former native grassland. Kangaroo rat activity also favored exotic over native forbs in a central California forbland (Schiffman, 1994). Gophers and kangaroo rats occur in Crown Valley, where they may also have impacts on native species colonization. Thus our restoration experiment has given no definitive answer whether this has always been a forbland, or whether shrub colonization is inhibited by current conditions. It was most likely not a perennial grassland, as remnant perennial grasslands in California only occur in coastal prairies, coastal mountains, and Sierra Nevada foothills (Dremann, 1988) that have higher precipitation than our study area. Burned shrublands on the hills surrounding these valleys were colonized by shrubs following the fire of 1993, but not the formerly plowed valleys. Shrub seeding experiments are underway, but these have also resulted in very little shrub recruitment (Cox, unpublished data), suggesting that seed limitation is not the reason for the absence of shrubs. The seedbanks of Mediterranean shrublands tend to be diverse and long-

lived (Sternberg et al., 2004). Shrub seedlings could be planted and observed over the long term to determine whether new seedlings emerge from beneath parent plants, or are also reduced by exotic grass and forb competition.

In spite of the absence of shrubs, the abandoned croplands had a relatively high richness of native forb species. The highest number of 42 forb species (the total in 9 ha) occurred in 2000, a year with average rainfall for this study. By contrast, in 2003 we found 67 native forb species with 20% cover in only 3 ha in nearby hills with CSS vegetation. This site also had about 20% shrub cover but only 16% exotic grass plus forb cover (Allen et al., unpublished). Although this is a small survey, farming has apparently reduced the native forb diversity in these valleys, and the forbs have not been able to recolonize to the extent that they occur in the surrounding hills that have a prior grazing and fire history. Since remnant forblands no longer occur in this area because all valley bottoms were intensively used for agriculture, there is no reference area to assess the pre-disturbance richness.

While the control of exotic grasses did not promote as high a richness of native forbs as was hoped for this study, the reduction of fine grass fuel for fire was in itself an important accomplishment. The invasion of exotic grasses has caused more fine fuel and more frequent fires in many semiarid shrub- and grasslands (Brooks et al., 2004). In CSS grass invasion has caused an increase in fire frequency from every 25–30 years (Keeley and Keeley, 1984) to every 1–5 years (Cione et al., 2002). By contrast, the residual *Erodium* litter does not burn because, unlike dried grasses, the litter disarticulates when it senesces, falling to the ground and leaving no standing litter to burn. Thus the management technique used here has the important outcome of reducing the flammability of the landscape by reducing fine grass fuel.

The short duration of effectiveness, five growing seasons, indicates the system has stabilized to an exotic annual grassland, and periodic grass control must be undertaken to maintain increased cover and richness of forbs, and to reduce flammable grass fuels. Several additional treatments need to be undertaken at this site to improve native species diversity. The low diversity of native forbs suggests that additional forb species should be seeded, specifically those that still occur in hillsides and either did not disperse or could not establish even after treatment. Finally, other exotic grass control measures besides herbicides need to be considered. Dethatching apparently had little effect in this study beyond the herbicide impact, as was also shown in another study on mulch control (Meyer and Schiffman, 1999). Grazing has had variable results in annual

forblands, with increased native forbs following early season grass consumption in one site (Weiss, 1999) and decreased native forbs because of forb consumption in another (Meyer and Schiffman, 1999). Timed, short-duration grazing is under trial at this site to determine its effectivity. Fire is another management tool for this fire-adapted vegetation, which has been used successfully to control the exotic seedbank in spring or summer burns, but not fall burns (DiTomaso et al., 1999; Meyer and Schiffman, 1999). Spring fire to reduce the exotic grass seedbank was effective in controlling grasses but also caused a dominance of exotic *Erodium* spp. (Gillespie and Allen, 2004). However, fire often has limited application on public lands because of regulatory restrictions. Herbicides are objectionable to some members of the public, and our research shows herbicides, or other grass control measures, would need to be undertaken approximately every five years. Where herbicides are chosen as a management tool, they would likely only receive limited use in areas where exotic grass competition limits survival of sensitive native species of concern, or possibly to reduce the probability of wildfire. As discussed by Naveh (1998, 2005), restoration ecology is transdisciplinary, and requires interactions among scientists and managers. The resultant compromises will determine the future diversity of our landscapes.

ACKNOWLEDGMENTS

I (E.B.A.) wish to acknowledge my friend and colleague, Zev Naveh, for his interest in my research and for many conversations that helped me to learn the importance of thinking about the Total Human Ecosystem and the transdisciplinary nature of restoration research. I also thank the many students and laboratory assistants who helped with field work and data analysis over the six years, and the land managers at the Western Riverside County MultiSpecies Habitat Reserve who assisted with logistics of the research. David Cudney gave advice on choice of herbicide. I am especially indebted to Jud Monroe, who had the vision for large-scale management of invasive species and encouraged me to undertake this research project. The research was funded by the WRCMSHR Management Committee, and by grants through the Shipley-Skinner Fund to the University of California, Riverside.

REFERENCES

Allen, E.B. 2004. Restoration of *Artemisia* shrublands invaded by exotic annual *Bromus*: a comparison between southern California and the intermountain region. In: Hild, A.L., Shaw, N.L., Meyer, S.E., Schupp, E.W., Booth, T., eds. Seed and soil dynamics in shrubland ecosystems. Proceed-

- ings, August 12–16, 2002. U.S. Forest Service, Rocky Mountain Research Station, Ogden, Utah, Proceedings RMRS-P-31, pp. 9–17.
- Allen, E.B., Eliason, S.A., Marquez, V.J., Schultz, G.P., Storms, N.K., Stylinski, C.D., Zink, T.A., Allen, M.F. 2000. What are the limits of coastal sage scrub restoration in southern California? In: Keeley, J.E., Keeley, M.B., Fotheringham, C.J., eds. 2nd Interface between ecology and land development in California. U.S. Geological Survey Open-File Report 00-62, pp. 253–262.
- Bar (Kutiel), P., Cohen, O., Shoshany, M. 2004. Invasion rate of the alien species *Acacia saligna* within coastal sand dune habitats in Israel. *Isr. J. Plant Sci.* 52: 115–124.
- Bell, S.S., Fonseca, M.S., Motten, L.B. 1997. Linking restoration and landscape ecology. *Restor. Ecol.* 5: 318–323.
- Brooks, M.L. 2000. Competition between alien annual grasses and native annual plants in the Mojave Desert. *Am. Midl. Nat.* 144: 92–108.
- Brooks, M.L., D'Antonio, C.M., Richardson, D.M., Grace, J.B., Keeley, J.E., DiTomaso, J.M., Hobbs, R.J., Pellant, M., Pyke, D. 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54: 677–688.
- Carlsen, T.M., Menke, J.W., Pavlik, B.M. 2000. Reducing competitive suppression of a rare annual forb by restoring native California perennial grasslands. *Restor. Ecol.* 8: 18–29.
- Cione, N.K., Padgett, P.E., Allen, E.B. 2002. Restoration of a native shrubland impacted by exotic grasses, frequent fire, and nitrogen deposition in southern California. *Restor. Ecol.* 10: 376–384.
- Corbin, J.D., D'Antonio, C.M., Bainbridge, S. 2004. Tipping the balance in the restoration of native plants: experimental approaches to changing the exotic:native ratio in California grassland. In: Gordon, M.S., Bartol, S.M., eds. Experimental approaches to conservation biology. University of California Press, Berkeley, pp. 154–179.
- D'Antonio, C.M., Vitousek, P.M. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annu. Rev. Ecol. Syst.* 23: 63–87.
- DeSimone, S.A., Zedler, P.H. 1999. Shrub seedling recruitment in unburned Californian coastal sage scrub and adjacent grassland. *Ecology* 80: 2018–2032.
- DiTomaso, J.M., Kyser, G.B., Hastings, M.S. 1999. Prescribed burning for control of yellow starthistle (*Centaurea solstitialis*) and enhanced native plant diversity. *Weed Sci.* 47: 233–242.
- Dremann, C.C. 1988. *Prairie relics of California: a guidebook based on Dr. James Barry's 1971 survey and maps.* Redwood City Seed Company, Redwood City, California.
- Eliason, S.A., Allen, E.B. 1997. Exotic grass competition in suppressing native shrubland re-establishment. *Restor. Ecol.* 5: 245–255.
- Gillespie, I.G., Allen, E.B. 2004. Fire and competition in a southern California grassland: impacts on the rare forb *Erodium macrophyllum*. *J. Appl. Ecol.* 41: 643–652.
- Gordon, D.R., Rice, K.J. 1993. Competitive effects of grassland annuals on soil-water and blue oak (*Quercus douglasii*) seedlings. *Ecology* 74: 68–82.

- Hamilton, J.G. 1997. Changing perceptions of pre-European grasslands in California. *Madroño* 44: 311–333.
- Hickman, J.C., ed. 1993. *The Jepson manual. Higher plants of California*. University of California Press, Berkeley.
- Keeley, J.E., Keeley, S.C. 1984. Postfire recovery of California coastal sage scrub. *Am. Midl. Nat.* 111: 105–117.
- Kimball, S., Schiffman, P.M. 2003. Differing effects of cattle grazing on native and alien plants. *Conserv. Biol.* 17: 1681–1693.
- Meyer, M.D., Schiffman, P.M. 1999. Fire season and mulch reduction in a California grassland: a comparison of restoration strategies. *Madroño* 46: 25–37.
- Minnich, R.A., Dezzani, R.J. 1998. Historical decline of coastal sage scrub in the Riverside-Perris Plain, California. *West. Birds* 29: 366–391.
- Naveh, Z. 1998. Ecological and cultural landscape restoration and the cultural evolution towards a post-industrial symbiosis between human and society and nature. *Restor. Ecol.* 6: 135–143.
- Naveh, Z. 2005. Epilogue: Toward a transdisciplinary science of ecological and cultural landscape restoration. *Restor. Ecol.* 13: 228–234.
- Nelson, L.L., Allen, E.B. 1993. Restoration of *Stipa pulchra* grasslands: effects of mycorrhizae and competition from *Avena barbata*. *Restor. Ecol.* 1: 40–50.
- Padgett, P.E., Kee, S.N., Allen, E.B. 2000. The effects of irrigation on revegetation of semiarid coastal sage scrub in southern California. *Environ. Manage.* 26: 427–435.
- Palmer, M.A., Ambrose, R.F., Poff, N.L. 1997. Ecological theory and community restoration ecology. *Restor. Ecol.* 5: 291–300.
- Pavlik, B.M., Nickrent, D.L., Howald, A.M. 1993. The recovery of an endangered plant. I. Creating a new population of *Amsinckia grandiflora*. *Conserv. Biol.* 7: 510–526.
- Pysek, P., Prach, K., Rejmanek, M., Wade, M. 1995. *Plant invasions: general aspects and special problems*. SPB Academic Publishing, Amsterdam.
- Rejmanek, M., Thomsen, C., Peters, I. 1991. Invasive vascular plants of California. In: Groves, R.H., Di Castri, F., eds. *Biogeography of Mediterranean invasions*. Cambridge University Press, New York, pp. 81–102.
- Schiffman, P.M. 1994. Promotion of exotic weed establishment by endangered giant kangaroo rats (*Dipodomys ingens*) in a California grassland. *Biodivers. Conserv.* 3: 524–537.
- Schiffman, P.M. 2000. Mammal burrowing, erratic rainfall, and the annual lifestyle in the California prairie: is it time for a paradigm shift? In: Keeley, J., Baer-Keeley, M., Fotheringham, C.J., eds. *2nd Interface between ecology and land development in California*. US Geological Survey Open-File Report 00–62, pp. 153–160.
- Shipley, B., Keddy, P.A. 1994. Evaluating the evidence for competitive hierarchies in plant communities. *Oikos* 69: 340–345.
- Sternberg, M., Yu, S.L., Bar (Kutiel), P. 2004. Soil seed banks, habitat heterogeneity, and regeneration strategies in a Mediterranean coastal sand dune. *Isr. J. Plant Sci.* 52: 213–221.
- Stromberg, M.R., Griffin, J.R. 1996. Long-term patterns in coastal California grasslands in relation to cultivation, gophers, and grazing. *Ecol. Appl.* 6: 1189–1211.
- Stylinski, C.D., Allen, E.B. 1999. Lack of native species recovery following severe exotic disturbance in southern Californian shrublands. *J. Appl. Ecol.* 36: 544–554.
- Weiss, S.B. 1999. Cars, cows, and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a threatened species. *Conserv. Biol.* 13: 1476–1486.
- Zaady, E., Boeken, B., Ariza, C., Gutterman, Y. 2003. Light, temperature, and substrate effects on the germination of three *Bromus* species in comparison with their abundance in the field. *Isr. J. Plant Sci.* 51: 267–273.
- Zink, T.A., Allen, M.F., Heindl-Tenhunen, B., Allen, E.B. 1995. The effect of a disturbance corridor on an ecological reserve. *Restor. Ecol.* 3: 304–310.