Review of Ten Years of Vernal Pool Restoration and Creation in Santa Barbara, California

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ABSTRACT. Vernal pools in the Santa Barbara area of southern California are restricted to narrow coastal terraces that occur south of the More Ranch Fault. To compensate partially for the historic loss of 90% of the vernal pools in this area, we implemented in 1986, in conjunction with the Isla Vista Recreation and Park District, an enhancement project at Del Sol Open Space and Vernal Pool Reserve in three phases involving 16 pools to: (1) enhance or restore existing degraded vernal pools; (2) re-create vernal pools where they occurred historically; and (3) create vernal pools from upland habitat. Manipulated sites were treated variously with or without vernal pool inoculum. Post-construction monitoring of 16 pools for plants, aquatic invertebrate fauna and amphibians, and/or avifauna occurred at different intervals; however, taken together the intervals reflect three post-construction monitoring phases including an early (year 1-3), mid (year 5-6), and late (year 10) phase. We hypothesized from the start of the manipulative projects that enhanced, restored, and created pools of the Santa Barbara area would eventually resemble natural vernal pools visually, possess an array of their known ecosystem functions, and be self-sustaining, as determined through comparative biological monitoring of natural reference pools. Six years after the manipulation of sites, vegetation and avifauna showed trends toward replication of natural pool characteristics. For aquatic invertebrates, however, we found distinct differences in the species diversity, taxonomic composition, and abundance among pool types. In 1996, we found that vegetation zonation, cover, and floristic composition and invertebrate faunas and tadpoles in the various pool treatments approached those of natural pools of the region, except for uninoculated created pools that continued to be different from natural pools and other manipulated pools.

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INTRODUCTION

Vernal pools of the Santa Barbara region occur on uplifted marine terrace deposits located south of the More Ranch Fault along approximately 5 miles (8 km) of coastline (Ferren and Pritchett, 1988). As much as 2000 feet (600 m) of vertical displacement has occurred on this major, east-west trending structural feature (Upson, 1951). However, only 30-100 feet (10- 30 m) of uplift is visible along the ocean bluffs on the southern side of the terraces. The present distribution of many vegetation types and habitats of the region is related directly to the topography that has formed as a result of the movement and subsequent erosion or deposition along the fault. Examples of these include coast live oak forest on north-facing fault escarpments, coastal bluff scrub on ocean cliffs, estuarine and various palustrine wetlands in down-faulted basins, and grasslands and vernal pools on uplifted, relatively flat "mesas."

Naturally occurring vernal pools of the South Coast of Santa Barbara County are restricted to these mesas, including More, Isla Vista, and Ellwood mesas, or in "sag pond" wetlands along the fault. The vernal pools are usually associated with seasonally wet "seeps" and subtle drainage troughs that have undulating surfaces with shallow depressions. These drainages are

perhaps also structurally controlled (surface topography may reflect faulting) and are upslope expressions of localized watersheds that drain into the adjacent estuaries or coastal ravines. The soils of the mesas generally belong to the Concepcion Series, a fine sandy loam with low permeability because of a dense subsoil clay layer that produces a seasonally-perched water table.

As a result of agricultural, military, university, and general urban development in the Santa Barbara area, at least 90 % of the vernal pools have been destroyed (Ferren and Pritchett, 1988; Ferren and Sawasaki, 1992). Most of the remaining pools have been disked for agriculture or fuel breaks, others have been drained periodically or treated chemically for mosquito abatement, and many of the vernal drainages have been truncated by roads, sidewalks, and residential development. These and other impacts, such as filling with construction debris, fragmentation by footpaths, and soil compaction from off-road vehicular activity, have obscured some aspects of the physical and biological attributes that may have characterized the pristine "natural" vernal pools of the Santa Barbara area. Thus our assumptions regarding the ecosystem functions of these pools must always be considered in the context of the extensive land use history and environmental impacts to the wetlands. Nonetheless, most vernal pools throughout the existing pool groupings support many native plant and animal species presumed to be restricted to or characteristic of these vernal pools (Smith, 1976; Forbes, 1988a; 1988b; Ferren and Pritchett, 1988; Ferren and Gevirtz, 1990; Soiseth, 1992; Soiseth et al., 1992; Haupt, 1992; O'Loghlen and Haupt, 1992a; 1992b).

Del Sol Open Space and Vernal Pool Reserve

Del Sol Open Space and Vernal Pool Reserve is one of the remaining mesa sites that contains vernal pool habitat in the Santa Barbara area. The Reserve is located in the urban setting of the community of Isla Vista approximately 10 miles (16 km) west of Santa Barbara, and covers 11.8 acres (5 hectares). It is owned and managed by the Isla Vista Recreation and Park District (IVRPD). The Del Sol site was purchased by IVRPD in 1978 and 1979 as three parcels of undeveloped land to be added to the District's "natural open space" parkland designation. Funds for the purchase resulted from passage of a bond initiative approved by local voters. With the Del Sol purchase, Isla Vista became one of the first communities in California to set aside property for the preservation of vernal pools (Ferren and Pritchett, 1988).

In 1986, the IVRPD and the UCSB Herbarium received funding from the State Coastal Conservancy (SCC) and assistance from the California Conservation Corps to implement the Del Sol Vernal Pools Enhancement Plan (SCC, 1986). Objectives of the first phase of the Enhancement Plan included: (1) removal of refuse; (2) installation of a barrier consisting of wooden posts to prevent vehicular access; (3) enhancement and restoration of three existing vernal pools and creation of six new pools; (4) public access and interpretive improvements; and (5) pre-project and post-construction monitoring of habitat manipulations (SCC, 1986). Results of the early years (yrs. 1-3) of post-construction monitoring of biological attributes (largely vegetation and flora) and physical attributes of the pools have been reported by Ferren and Pritchett (1988), Pritchett (1988a; 1988b; 1990), and Ferren and Gevirtz (1990).

A second phase of the plan included the re-creation (re-establishment) of three vernal pools within a drainage that previously contained vernal pools that apparently had been eliminated through disking for dryland agriculture. This project was funded by the County of Santa Barbara Wetland Mitigation Fund and included pre-project and post-construction biological monitoring of these wetlands and those previously manipulated at the Reserve. Results of the mid-years (yrs. 5-6) of monitoring have been reported by Callaway et al. (1992a; 1992b) and Walden et al. (1992) for vegetation and flora, Haupt (1992) and O'Loghlen and Haupt (1992a; 1992b) for avifauna, and Soiseth (1992) and Soiseth et al. (1992) for invertebrate fauna and amphibians. A third phase of the Plan will include the re-creation and enhancement of additional pools in 1996 and 1997. The pre-project monitoring of all pools at Del Sol for this phase constitutes a late-period (yr. 10) of Enhancement Plan monitoring. Management activities at Del Sol Reserve, including additional manipulations of vernal pool wetland, and upland grassland, have been proposed in a management plan prepared for the Reserve (Shadbourne, 1993).

The purpose of this paper is three-fold: (1) to provide a summary of the construction techniques and post-construction biological monitoring results of the first phase (early years) and second phase (mid-years) of the Del Sol Enhancement Plan; (2) to present the findings of the third or late phase (yr. 10) of biological monitoring; and (3) to assess the overall results of the ecological restoration efforts in the context of the project goals and success criteria now that a decade has passed since the first restorative actions were taken.

METHODS

Project Goals and Hypothesis Testing

Goals of the Del Sol enhancement project have changed somewhat over the past ten years with the preparation of a reserve management plan (Shadbourne, 1993) and implementation or design of additional project phases. However, the original plan's basic premise (SCC, 1986) remains true today: "The enhancement plan ...is aimed at preserving and expanding the Del Sol pools." To develop a methodology to measure how successful we would be in achieving this goal, Ferren and Pritchett (1988) proposed a hypothesis testing approach, followed and modified by Ferren and Gevirtz (1990), and now reworded by this

team, to assist with the interpretation of successful artificial manipulation of vernal pool habitat. The original intent of the hypothesis has not changed. As presented here in its modified form, a level of acceptable "proof " of the hypothesis would result in a conclusion that habitat had been modified successfully. In reality, however, the hypothesis provides a framework in which to evaluate success rather than a hypothesis to attempt to disprove.

Hypothesis: *Vernal pools at Santa Barbara can be enhanced, restored, re-created, and created (1) to provide a broad array of ecosystem functions that occur within the variability of naturally occurring vernal pools; and (2) to be self-sustaining and thus mature or decline in ecosystem functions in patterns resembling natural vernal pools.*

Ecosystem functions for the purpose of hypothesis testing can include (1) hydrology (e.g., ability to sustain inundation patterns consistent with vernal pool hydrology); (2) native plant associations (e.g., ability to support predominantly native species in zonation, cover, densities, and, richness consistent with donor or reference pools); (3) native faunal associations (e.g., ability to support predominantly native species associations consistent with donor or reference pools); (4) food chain support (e.g., presence of guilds of organisms that are found in presumed highly functional natural vernal pool ecosystems; and (5) habitat for sensitive groups of organisms such as rare, endemic, and/or endangered species (e.g., locally including *Hemizonia parryi* ssp. *australis* and *Pilularia americana*). Various biological monitoring approaches can be undertaken to obtain information that addresses the categories of information used to test this hypothesis. Although none of the ecosystem enhancements performed at Del Sol Reserve were mitigations for impacts to vernal pools that required agency-approved performance criteria, efforts were made to conduct monitoring of manipulated sites in comparison with "natural" pools that served as reference sites, most of which also were donor pools from which seed bank inoculum was obtained.

Project Construction

Phase I. In 1986, implementation of the "Del Sol Enhancement Plan" included: (1) the enhancement of one large pool (2699 m^2) by installation of a post barrier to prevent vehicular access and construction of a berm to reduce draining of the basin; (2) restoration of two large pools (1867 m^2 and 636 m^2) by removing fill and debris; and (3) creation of six small pools (59-94 m^2, three inoculated, three uninoculated) on upland sites (Ferren and Pritchett, 1988; Pritchett, 1988a; 1988b). Seed bank inoculum was removed from two natural pools on Ellwood Mesa, located approximately one mile (2 km) west of Del Sol Reserve, because all pools at the reserve were sufficiently physically degraded or dominated by non-native species such as *Lolium multiflorum* , which is favored by drought conditions, that we were concerned about contaminating the newly manipulated pools if we used seed bank inoculum from Del Sol Reserve. All plant species known from Ellwood Mesa pools currently occur or historically occurred at the Reserve.

Phase II. A suite of three pools (total area = 1011 m^2) was constructed in 1991 using a skip-loader and backhoe in a single long depression that was dominated by non-native plant species (Ferren and Sawasaki, 1992). This feature marked the site of a vernal pool drainage that occurred historically but apparently had been eliminated by dry-farming practices and urbanization. This process of re-establishing vernal pools where they had occurred previously we termed re-creation. It differs from restoration in that nothing remained of the historic habitat to restore, and it differs from creation of a new habitat from existing upland or another type of wetland because vernal pools presumably occurred at the re-creation site before the site had been altered. This can be an important distinction because there could be differences in soil types between previously occurring vernal pools and non-vernal pool sites that might affect the ultimate success of a habitat manipulation project. Thus we prefer to distinguish among these types of ecological restoration activities. Seed bank material was collected from 17 one square meter quadrats placed randomly within a previously enhanced pool at Del Sol Reserve, spread across the graded site, raked into the substrate, and compacted with a roller. Additional seeds and spores of various dominant vernal pool species, and some locally rare plants such as *Pilularia americana*, were added to the treated substrate before it was compacted.

Phase III. Vernal pool restoration activities in 1996 included: (1) re-creation of one large pool (459 m^2); (2) enlargement of three previously re-created pools from Phase II; (3) enlargement of one previously restored pool from Phase I; and (4) realignment of foot paths at the site. The newly re-created pool occupies a 500 m^2 basin excavated with a skiploader and hand tools. The pool was inoculated with seeds and seed bank material collected from 40 one-meter square quadrats in natural and re-created pools at the site, as described in Phase II. Three re-created pools and one restored pool were enlarged after the removal of path berms from wetland basins and realignment of paths. The trail system at the site was improved by moving paths from wetland areas to raised berms in upland habitat. The berms were constructed of packed subsoil with topsoil added to the side slopes to create a firm path base with vegetated sides.

Monitoring and Analysis

Phase I. The pre-construction monitoring program for Phase I focused largely on developing a description of the study area, including the environmental setting, origin of the vernal pools, land use history, construction of a pre-project topographic and wetland boundary map, soil analysis, and description of the vegetation and inventory of the flora (Ferren and Pritchett, 1988).

To help evaluate the construction and revegetation portions of the Del Sol Vernal Pools Enhancement Plan, a two-year post-construction monitoring program was implemented that included studies of the physical environment, flora, and vegetation. Post-construction activities included construction of a topographic map, recording of the extent and duration of flooding patterns, inventory of the flora, recording of plant cover, determination of plant species abundance indices, and a qualitative assessment of invertebrate and vertebrate animal use of the wetlands (Ferren and Pritchett, 1988). A natural vernal pool at Del Sol Reserve and two donor pools from Ellwood Mesa were used as reference pools to compare flooding and vegetation trends with the manipulated pools. A third year of post-construction monitoring was undertaken to examine the vegetation zonation among the natural and manipulated vernal pools (Ferren and Gevirtz, 1990).

Phase II. Phase II monitoring included year-five and year-six post-construction monitoring for Phase I of the Del Sol project and, simultaneously with the latter, year-one of the post-construction monitoring for Phase-II vernal pool re-creation. Monitoring activities included an evaluation of plant zonation, relative cover, and richness (Callaway et al., 1992a; 1992b; Ferren and Sawasaki, 1992; Walden et al., 1992), invertebrate and amphibian richness and densities (Soiseth, 1992, Soiseth et al., 1992), and bird species richness, densities, and resource utilization (Haupt, 1992; O'Loghlen and Haupt, 1992a; 1992b).

Phase III. Pre-project monitoring in 1996 included vegetation and invertebrate studies at the Del Sol and Del Playa Road sites on Isla Vista Mesa and at Ellwood Mesa. Plant monitoring was designed to allow comparisons of zonation and plant cover distributions in natural and manipulated pools. In May 1996, transects for monitoring vegetation and topography were established crossing each vernal pool in directions corresponding to transects originally used in 1987. Transect end points were located in upland areas approximately 2 m from pools when distinct boundaries were present. A tape measure was stretched between the transect end points. Topography was determined by measuring elevations along the tape using a level and stadia rod. The line intercept method was used to record cover of each plant species under the tape. Mean plant cover was calculated from transect data for each species in each pool type: (1) natural, (2) restored/enhanced, (3) re-created, (4) created inoculated, and (5) created uninoculated. In addition to the transect data, the vernal pools were surveyed in detail to compile a plant species list. Percent cover values were estimated for each species in the pools using cover classes corresponding to the Braun-Blanquet scale.

Two methods were used to compare plant community structure in manipulated and natural pools. Four parametric and non-parametric measures of correlation (Pearson untransformed data, Pearson natural log transformed data, Spearman, and Kendall) were computed to test for significant associations between plant cover in natural pools and that of each of the other pool types (restored/enhanced pools; re-created pools; created inoculated pools; and created uninoculated pools). From both types of species cover data, similarity matrices were created by calculating Euclidean distances between each pair of vernal pools. The distance matrices were computed using total absolute percent cover for each species from transects, and using the midpoints of cover class estimates for each species. To confirm consistency among results, a variety of different distance measures were applied. Nonmetric multidimensional scaling, a technique that arranges objects spatially based on their pairwise similarities, was used to portray graphically the similarity relationships among the vernal pools. Pools closer together on the graphs are more similar to each other with respect to species cover than those that are spaced further apart.

Aquatic fauna were sampled to examine seasonal patterns of occurrence, and to compare invertebrate and tadpole (*Pseudacris regilla*) abundance and species richness in natural, manipulated, and created vernal pools at Del Sol, Del Playa Road and at Ellwood Mesa sites (Wiseman and Cooper, 1997). Samples were collected on 5 dates between 10 February and 12 April, 1996 using standard sweeps of 1 mm mesh D-frame net. Invertebrates were preserved in 70% ethanol, and later enumerated and identified under a dissecting microscope. On each sampling date, the following physical properties of the pools were measured: pool area, pool volume, maximum depth, temperature, dissolved oxygen, and conductivity.

Post-construction monitoring in late 1996 and early 1997 (project year eleven) included rain season data collection on precipitation, pool sizes, temperature, pH, salinity, filterable solids, and bird use at Del Sol (Malisch, 1997; Hubbard, unpublished). After the pools dried, Malisch (1997) analyzed soil organic content and experimentally compared seed banks of natural, ten year old re-created and first season re-created vernal pools. Post-construction monitoring results for Phase III are not reported herein.

RESULTS AND DISCUSSION

Phase I. Monitoring results from post-construction years 1-3 at Del Sol Reserve are summarized as follows:

(1) enhanced and restored pools exhibited hydrology similar to natural vernal pools;
(2) drought conditions apparently affected Phase I results, including less extent and shorter duration of flooding than predicted;
(3) created pools can fail to exhibit vernal pool hydrology, particularly in small basins;
(4) plant richness and zonation of manipulated pools resembled those of natural pools;

(5) annual vernal pool plants dominated cover in restored and created pools;
(6) restored and created pools did not resemble natural pools in plant species cover and abundance during the short-term (Phase I) analysis;
(7) inoculum from natural vernal pools produced vernal pool plants and planktonic invertebrate animals in restored and created pools;
(8) inoculum produced greater numbers of ostracods in created pools than those without inoculum;
(9) loss of turbidity in created pools was correlated with the presence of inoculum;
(10) observations of native plant and animal (invertebrate, bird, and amphibian) use of the pools support the view that ecosystem functions such as food chain support and ecosystem role of the vernal pools in a grassland setting are probably similar among natural, restored, and inoculated- created pools; and
(11) enhanced, restored, and created-inoculated pools were self-sustaining during the first three years (Ferren and Pritchett, 1988; Pritchett, 1988a; 1988b; Ferren and Gevirtz, 1990).

Ferren and Gevirtz (1990) determined, however, that, *there is presently no conclusive evidence to suggest that [the success] hypothesis, or some variation, has been proven.* Poor performance on the part of invertebrates in particular and the dominance of plant cover by annual species rather than perennials supported their determination.

Phase II. Monitoring results for plant associations (Callaway et al., 1992a; 1992b; Ferren and Sawasaki, 1992; Walden et al., 1992), invertebrate and amphibian associations (Soiseth, 1992; Soiseth et al., 1992), and avifauna associations (Haupt, 1992; O'Loghlen and Haupt, 1992a; 1992b) are summarized as follows:

(1) enhanced, restored, and created-inoculated pools continued to support native plants in years five and six;
(2) annual plants dominated the plant cover during year-one of re-created pools;
(3) perennial plants increased in dominance as compared with annual plants in five and six year restored and inoculated-created pools;
(4) inoculated pools had higher species richness and cover than uninoculated pools;
(5) abundance and distribution of plants in created pools differed from natural pools;
(6) copepods occurred in all pools sampled;
(7) cladocera occurred in all pools except uninoculated pools;
(8) aquatic insects and amphibians were less abundant than zooplanton
(9) sampling methods were not adequate for benthic or epibenthic taxa such as ostracods, turbellaria, and oligochaetes;
(10) use of vernal pool habitats by birds is highest during wet months;
(11) large pools supported the greatest numbers and highest species richness of birds;
(12) restored pools had open water and muddy margins, and attracted the greatest number and diversity of birds;
(13) enhanced and natural pools had more submergent and emergent vegetation and were favored more ducks and dowitchers;
(14) by May 12 all standing water in the pools had disappeared and the composition of the avian community switched from predominantly water associated species to those using other habitats on the Reserve;
(15) the difference in results between years of avian studies probably related to the timing and amount of rainfall (more water birds occurring at the Reserve during years of less rainfall may have been related to the rarer nature of the freshwater habitat elsewhere in the region in drier years;
(16) Del Sol Reserve was visited by an impressive number (highest count 160 birds) and richness (33 spp.) of birds which used the resources in a variety of ways.

Phase III. Pre-project monitoring at the Del Sol Reserve, Del Playa Road (Phase II and III reference area), and Ellwood Mesa (Phase I donor pool and reference areas) sites included invertebrate sampling from February to April 1996 and vegetation surveys in May 1996. Vegetation transects in natural, restored/enhanced, created uninoculated, created inoculated, and re-created vernal pools and adjacent upland habitat included plants of 61 taxa (Table 1). Plant distributions were associated with pool topography (Figure 1, 2). Native plants (e.g., *Eleocharis macrostachya, E. acicularis, Eryngium vaseyi,* and *Plagiobothrys undulatus*) occupied large proportions of pool bottoms. Pool slopes generally supported narrow bands of native and introduced plants. Introduced plants (especially *Lolium multiflorum*) were dominant on the outer margins of vernal pools. The zonation of plants in manipulated pools was similar to that of natural pools (Figure 1, 2). The distributions of plant cover by species in all manipulated pools except created-uninoculated pools were similar to the cover patterns of natural vernal pools. Mean cover values for plants on transects in restored/enhanced, re-created, and created-inoculated pools were correlated with mean cover of those species in natural pools (Pearson raw data, Pearson natural log transformed data, Spearman, and Kendall; Table 2). The mean cover of plant species in created-uninoculated pools was not significantly correlated with mean cover of the same species in natural pools. Analysis of estimated plant cover data gave similar results (Table 2). Analysis of plant cover patterns using nonmetric multidimensional scaling supported the results of correlation analysis (Figure 3). In general, the similarities between manipulated and natural pool types are of approximately the same scale of those within the natural pool type. This analysis of plant distributions suggests that the vegetation of manipulated pools, with the exception of created-uninoculated pools, is within the range of variation found in natural pools in the area.

TABLE 1. Flora of Isla Vista area vernal pools and adjacent uplands, May 1996.

Species Name	Plant Life Cycle	Origin	Pool Type/Treatment				
			Natural Pool	Restored/ Enhanced	Created Uninoculated	Created Inoculated	Re-created Pool
Alopecurus saccatus	A	N	x	x			x
Ambrosia psilostachya	P	N	x	x	x	x	
Anagallis arvensis	A	I	x	x	x	x	x
Asclepias fascicularis	P	N				x	
Atriplex semibaccata	P	I	x				
Atriplex triangularis	A	N	x				
Avena barbata	A	I	x				
Avena fatua	A	I	x	x	x	x	x
Baccharis pilularis	S	N	x	x	x	x	
Brassica nigra	A	I		x			
Bromus diandrus	A	I	x	x	x	x	x
Bromus hordeaceus	A	I	x	x	x	x	
Centunculus minimus	A	N				x	
Convolvulus arvensis	P	I	x	x	x	x	
Cortaderia sp.	P	I			x		
Cotula coronopifolia	P	I	x	x		x	x
Crassula aquatica	A	N	x	x	x	x	x
Cynodon dactylon	P	I	x				
Cyperus eragrostis	P	N	x	x			x
Distichlis spicata	P	N	x	x	x	x	
Elatine brachysperma	A	N	x	x	x		x
Eleocharis acicularis	P	N	x	x	x	x	x
Eleocharis macrostachya	P	N	x	x	x	x	x
Epilobium pygmaeum	A	N	x				
Erodium botrys	A	I	x	x	x	x	x
Eryngium vaseyi	P	N	x	x	x	x	x
Gastridium ventricosum	A	I	x		x	x	
Geranium dissectum	A	I	x				
Gnaphalium palustre	A	N	x				x
Grindelia camporum ssp. *bracteosum*	P	N		x	x	x	x
Hemizonia parryi ssp. *australis*	A	N	x	x	x	x	x
Hordeum brachyantherum ssp. *brachyantherum*	P	N	x	x		x	
Hordeum brachyantherum ssp. *californicum*	P	N		x			
Hordeum marinum ssp. gussoneanum	A	I	x	x	x	x	x
Hypochaeris glabra	A	I				x	
Isocoma menziesii	S	N	x				
Juncus bufonius var. *bufonius*	A	N	x	x	x	x	x
Juncus occidentalis	P	N	x	x	x	x	x
Juncus phaeocephalus var. *phaeocephalus*	P	N		x			
Lactuca serriola	A	I		x			x
Lolium multiflorum	A	I	x	x	x	x	x
Lythrum hyssopifolium	A	I	x	x	x	x	x
Medicago polymorpha	A	I		x			x
Nassella pulchra	P	N	x	x	x	x	
Phalaris aquatica	P	I			x		
Phalaris lemmonii	A	N	x	x			x
Plagiobothrys undulatus	A	N	x	x	x	x	x
Plantago lanceolata	P	I	x	x	x	x	
Polygonum arenastrum	A	I	x	x			
Polypogon monspeliensis	A	I	x	x	x	x	x
Psilocarphus brevissimus var. *brevissimus*	A	N	x	x	x	x	
Raphanus sativus	A	I	x	x	x	x	x
Rumex acetosella	P	I	x	x	x	x	x
Rumex crispus	P	I	x	x	x		x
Sisyrinchium bellum	P	N	x		x		
Sonchus oleraceus	A	I		x	x	x	x
Spergularia villosa	P	I			x	x	
Tragopogon porrifolius	B	I		x			
Vicia benghalensis	A	I	x	x	x	x	x
Vicia sativa	A	I	x	x	x	x	x
Vulpia bromoides	A	I	x	x	x	x	x

Plant Life Cycle: A = annual, B = biennial, S = shrub, P= perennial; Origin: I = introduced, N = native

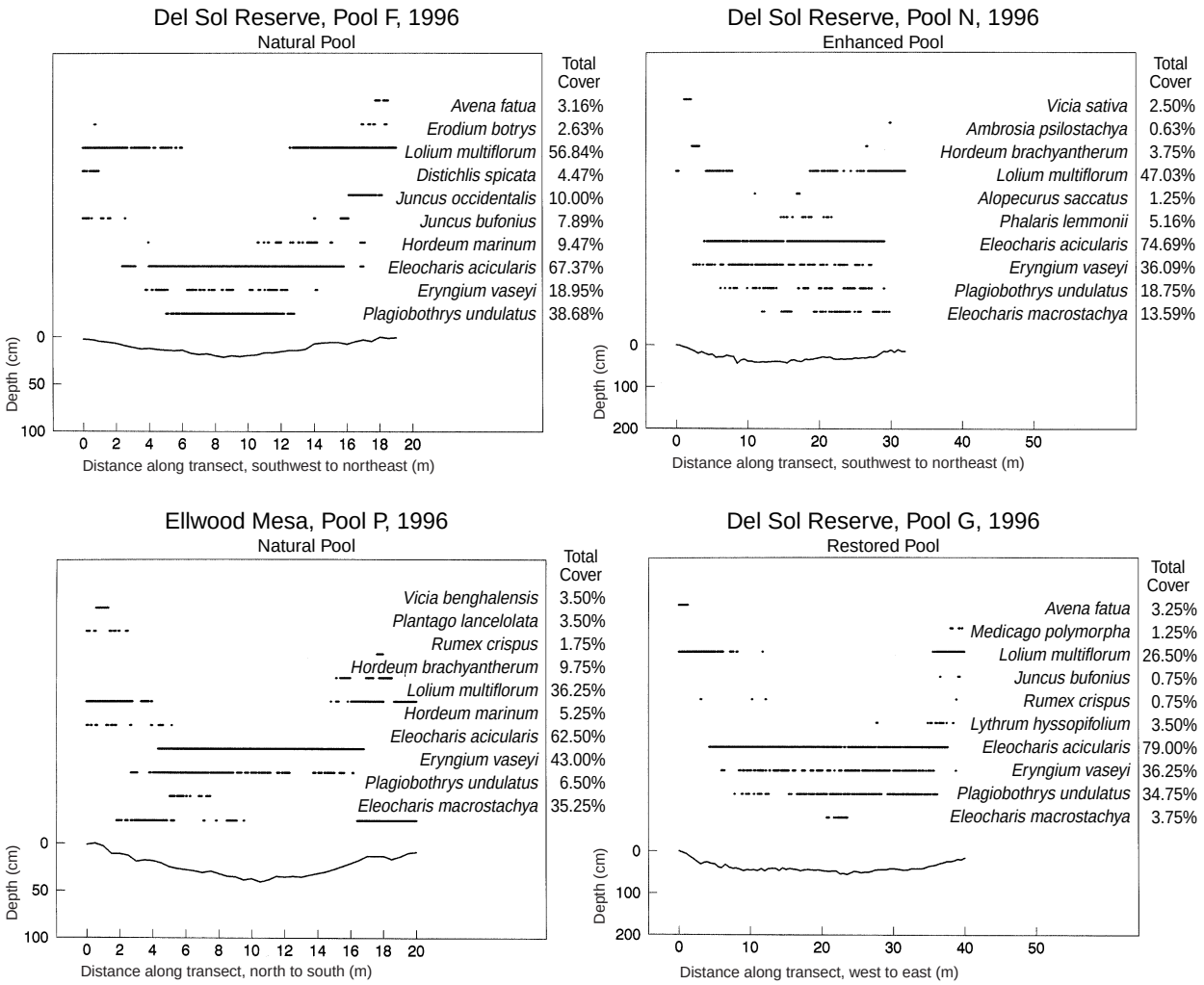

FIGURE 1. Distribution and total cover of the ten most common plant species along example transects from natural, enhanced, and restored vernal pools in the Santa Barbara area. Refer to Table 1 for a complete checklist of native and introduced plants recorded for the vernal pools and adjacent uplands in 1996.

TABLE 2. Correlations in plant species cover between natural vernal pools and other vernal pool categories at Del Sol Reserve in Isla Vista, California. Pearson, Spearman, and Kendall are types of statistical evaluations. Categories = enhanced/restored inoculated, created uninoculated, created inoculated, and re-created inoculated.

Natural Pools vs.	Restored/ Enhanced	Created Uninoculated	Created Inoculated	Re-created
Transect Data				
Pearson raw data	0.95	0.39*	0.73	0.95
Pearson natural log data	0.76	0.20*	0.52	0.71
Spearman	0.65	0.18*	0.44	0.68
Kendall	0.52	0.13*	0.28*	0.52
Estimated Cover Data				
Pearson raw data	0.93	0.15*	0.66	0.87
Pearson natural log data	0.86	0.48	0.62	0.84
Spearman	0.82	0.45*	0.70	0.80
Kendell	0.68	0.31*	0.59	0.66

* Correlations not significant at $p < 0.05$, all other correlations significant.

The comparison of vernal pool plant cover estimates from 1996 with data from 1987 and 1992 reveals two important trends: (1) increasing cover of native plants over time and (2) increasing cover of perennial plants (Figure 4). Cover of several vernal pool plants (e.g., *Eleocharis macrostachya*, *E. acicularis*, and *Eryngium vaseyi*) increased in both the created-inoculated and re-created pools.

The composition and abundance of vernal pool invertebrates and tadpoles showed rapid changes in 1996 (Wiseman and Cooper, 1997). Dominant types included ostracods, tadpoles (*Pseudacris regilla*), mosquito larvae, beetles (Dytiscidae and Hydrophilidae), and waterboatmen (Corixidae). Biweekly estimates of insect abundance increased between February and April. Richness of taxa in standard sweeps increased from February to March (Figure 5, 6) . Fauna present in early samples include animals that had emerged from resting stages, adult insects that had immigrated from other habitats, and tadpoles

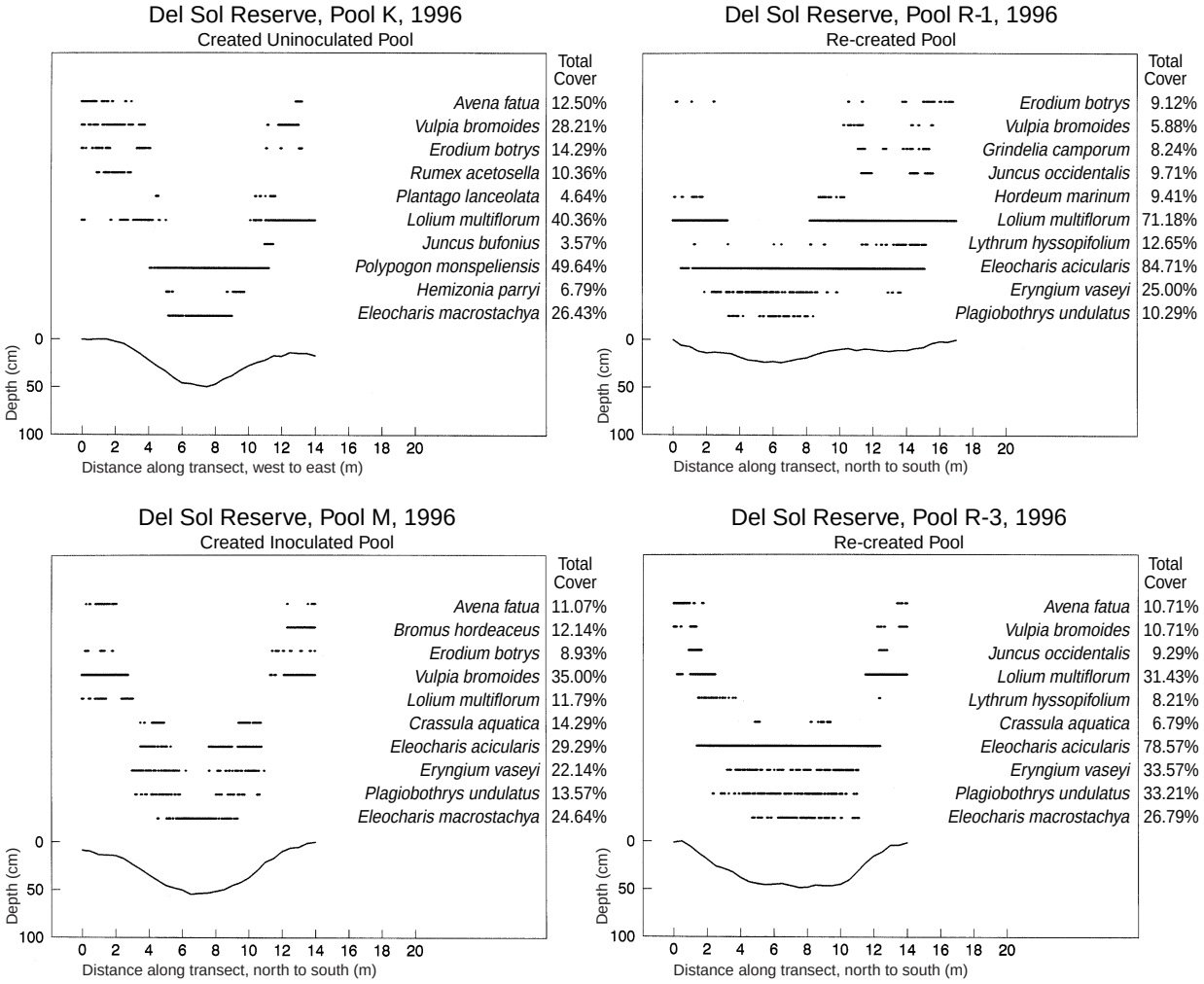

FIGURE 2. Distribution and total cover of the ten most common plant species along example transects from created uninoculated, created inoculated, and re-created vernal pools in the Santa Barbara area. Refer to Table 1 for a complete checklist of native and introduced plants recorded for the vernal pools and adjacent uplands in 1996.

(Table 3). Larval forms were found in subsequent samples. Standard sweeps from large pools had higher invertebrate richness than those from smaller pools. The abundance of beetles in the family Hydrophilidae differed between pool types with more occurring in the largest pools. Invertebrate fauna of modified and created pools was similar to that of natural pools except for created-uninoculated pools, which had lower densities of aquatic fauna.

CONCLUSIONS

We conclude that a decade of pre- and post-construction habitat monitoring data suggest there is no evidence, for all but one type of the types of manipulations, inconsistent with the hypothesis we have used to provide the framework for evaluating the success of vernal pool manipulations at Del Sol Reserve in Santa Barbara County. Numerous studies by different individuals or groups using different approaches have demonstrated that enhanced, restored, re-created, and created-inoculated vernal pools are self-sustaining and provide a broad array of ecosystem functions similar to those of naturally occurring vernal pools. These functions include, for example, the establishment of wetland hydrology, habitat for native plants and animals, habitat for sensitive species, food chain support, and the roles of vernal pools in grassland ecosystems. Within the limits of the hypothesis framework and the various criteria we have used to evaluate it, we conclude we have successfully enhanced, restored, re-created, and created vernal pools at Del Sol Reserve.

After a decade of hydrologic function, only the created-uninoculated pools fail to demonstrate the establishment of various biological functions, particularly for native vernal pool plants, of naturally occurring reference pools in the region. Thus, in the situation where a habitat manipulation such as habitat re-

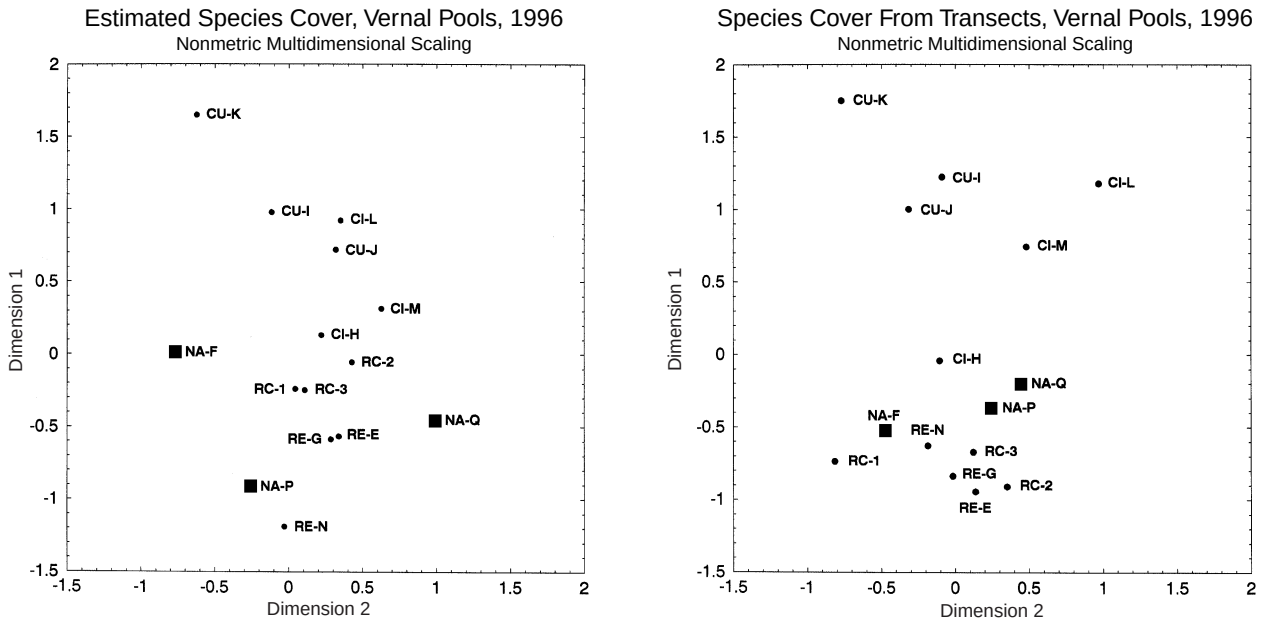

FIGURE 3. Nonmetric multidimensional scaling of plant species cover in vernal pools of the Santa Barbara area. NA = natural pools (F, P, Q); RE = restored enhanced pools (E, G, N); CU = created uninoculated pools (I, J, K); CI = created inoculated pools (H, L, M); RC = recreated pools (1, 2, 3).

creation or creation results in a substrate with no naturally-occurring seed bank material, the addition of inoculum is apparently essential to establish vernal pool functions within the variability of natural vernal pools, at least within the first decade of construction. This is true for habitat manipulations at Del Sol Reserve even though newly created pools are in proximity to vernal pools with many ecosystem functions. Native vernal pool plants may require inoculation to achieve cover, density, zonation, and richness similar to natural vernal pools. Failure of uninoculated pools to establish plant cover in early post-construction years provides opportunities for invasive exotic species such as *Polypogon monspeliensis* or pioneering native species such as the sensitive plant *Hemizonia parryi* ssp. *australis* to establish in great numbers and minimize or perhaps prevent the future establishment of native vernal pool dominants potentially dispersed to created pools by physical vectors (e.g., wind) or biological vectors (e.g., birds), from occurring in patterns similar to natural pools after they reach the new pools.

In the end, the usefulness of the hypothesis testing approach to evaluate the degree of success to which artificial habitat has been established depends on the rigor of the performance criteria that have been used to assess the functions of the manipulated habitats as compared with the natural or reference habitats. We in Santa Barbara have had the luxury of using experimentation as our methodology, with the overall goal to re-establish historic vernal pool losses. We propose the question, however, should these same manipulated vernal pools established successfully at the level we have tested them, or similar artificial pools elsewhere with the established functions described herein, serve as mitigation for intentional new losses of California's vernal pool natural heritage? Although we do not support the

TABLE 3. Presence of invertebrate groups and amphibians in vernal pools of the Santa Barbara area. Early groups (10 Feb 96) apparently fly or hop into pools or come from resting stages. In later sampling dates, larvae appear from various invertebrate groups. All groups persisted through subsequent sampling dates. Rapid changes are noted in the composition of aquatic fauna in these vernal pools.

10 February 96	24 February 96	10 March 96	27 March 96	12 April 96
Ostracods Tadpoles Hydrophilidae adults Corixidae	Culicidae larvae Tipulidae larvae Dixidae larvae Chironomidae larvae Dytiscidae larvae	Odonate nymphs Chaoboridae	Baetidae larvae Hydrophilidae larvae Notonectidae larvae	Gerridae

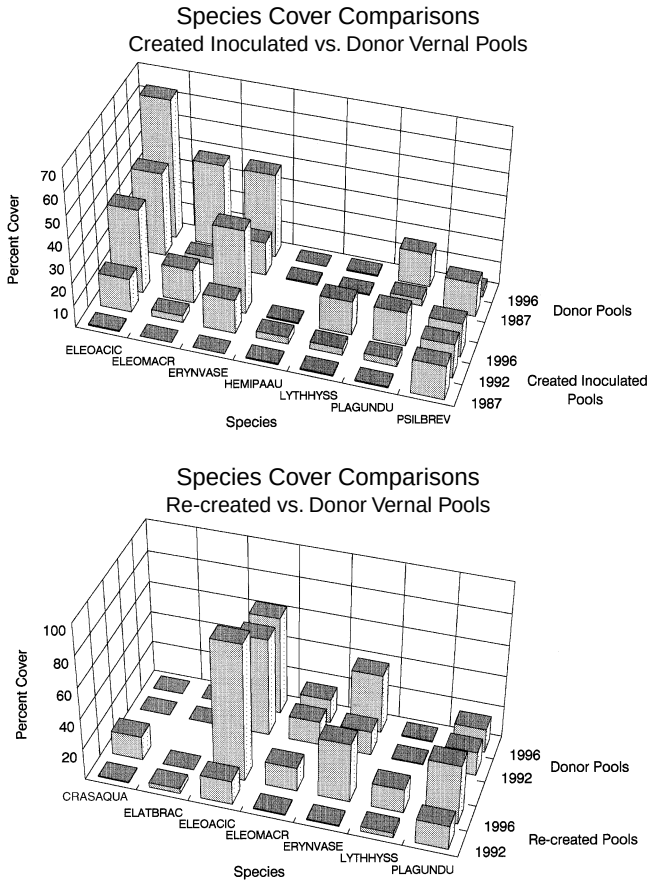

FIGURE 4. Vernal pool species cover comparisons in the Santa Barbara area. TOP: Created inoculated pools (years 1, 6 and 10) at Del Sol Reserve versus donor pools (years 1 and 10) at Ellwood Mesa. BOTTOM: Re-created inoculated pools at Del Sol Reserve (years 1 and 5) versus donor pools (years 1 and 5) Del Sol Reserve. CRASAQUA = *Crassula aquatica*; ELATBRAC = *Elatine brachysperma*; ELEOACIC = *Eleocharis acicularis*; ELEOMACR = *Eleocharis macrostachya*; ERYNVASE = *Eryngium vaseyi*; HEMIPAAU = *Hemizonia parryi* ssp. *australis*; LYTHHYSS = *Lythrum hyssopifolia*; PLAGUNDU = *Plagiobothrys undulatus*; PSILBREV = *Psilocarphus brevissimus.*

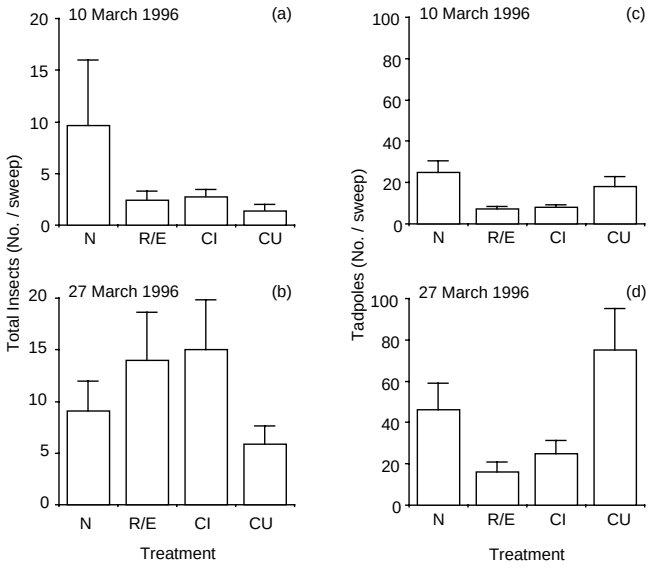

FIGURE 5. Total insect and tadpole results from vernal pools of the Santa Barbara area. (a-b). Insect numbers can be very different from one sampling time to the next. Thus results can be difficult to use for comparison purposes. However, all pool types support insects in increasing numbers during sampling periods. (c-d). Tadpoles also increased in numbers, further demonstrating the need for multiple sample dates to get an accurate picture of the aquatic animals in natural and manipulated vernal pools. N (n=5) = natural pools; R/E (n=4) restored, enhanced, and re-created pools; CI (n=3) = created inoculated pools; CU (n=3) = created uninoculated pools.

loss of additional natural vernal pools and compensation through mitigation, we do support the use of habitat manipulations as a methodology to gain new or enhanced and restored habitat where losses have been substantial and regional vernal pool functions are threatened with additional losses or with decline because of fragmentation or other impacts that have minimized their role in the ecosystem contexts in which they occur.

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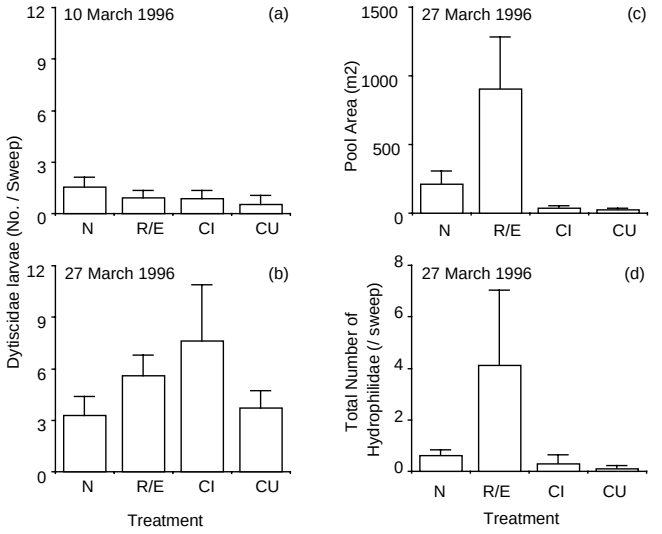

FIGURE 6. (a-b). Dytiscidae larvae in vernal pools of the Santa Barbara area. Larvae occur in all pool types and increased between sample dates. (c-d). Hydrophilidae in vernal pools. Hydrophilidae numbers are quite different among pool types, perhaps suggesting they key in on larger bodies as they fly around looking for places to lay their eggs. N (n=5) =natural pools; R/E (n=4) = restored, enhanced and re-created pools; CI (n=3) = created inoculated pools; CU (n=3) = created uninoculated pools.

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