Vernal Pool Construction Monitoring Methods and Habitat Replacement Evaluation

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ABSTRACT. The Sacramento Field Office of the U.S. Fish and Wildlife Service evaluated 1,543 vernal pools constructed between 1988 and 1994. The pools were compensatory mitigation for 25 projects permitted by the U.S. Army Corps of Engineers, Sacramento District, in Placer, Sacramento, and Butte counties. The purpose of the evaluation was to determine if existing monitoring regimes were adequately assessing the target physical and biological properties of constructed vernal pools. Site specific monitoring methods and performance standards were compared with an interagency draft Vernal Pool Mitigation and Monitoring Guidelines and on-site evaluations were completed between March 29, 1994, and April 25, 1996. The element most frequently monitored (24 sites) was the number of vernal pool endemic plant species per pool. Each element monitored had a wide range of performance standards between sites, and the greatest range of standards (16) quantified vernal pool endemics. Hydrology standards were met by 96% of the pools and 69% met vegetation standards. Of the 25 sites, 83% met permit compliance. Federally-listed invertebrates were monitored at 16 sites and 12 sites reported their presence in constructed pools. A federally-listed plant and a state-listed plant were relocated with their vernal pool habitat. The listed plant species are being monitored at two sites. Although reference pools were monitored at 69% of the sites, direct correlation of target properties between reference and constructed pools was often difficult. In most cases, specific criteria were imposed by (pre-project) reference pools at the impact site that could not be replicated in pools constructed on a mitigation site at another location, because pools were not subject to the same conditions. Our study concluded that fewer variations in monitoring methods and performance standards should be allowed in evaluation of constructed pools for Corps permit compliance.

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INTRODUCTION

In their first mitigation follow-up study, the Sacramento Field Office of the U.S. Fish and Wildlife Service (Service) concluded that constructed wetlands which met performance standards and permit compliance often did not fully replace the habitat values lost (DeWeese, 1996). Constructed vernal pools received the lowest replacement value ratings in that study. The Service suspected that performance standards for vernal pools were insufficient to assure successful habitat replacement. However, we had not gathered enough information to substantiate our concerns.

In January 1994, an interagency team (Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (Corps), California Department of Fish and Game (CDFG), and the Service) was assembled at the request of the Corps and EPA to create Vernal Pool Mitigation and Monitoring Guidelines (Guidelines) (USFWS, 1994) which would assist permit applicants to establish a monitoring regime that would adequately assess target physical and biological properties of constructed vernal pools which are required to meet permit compliance. The Guidelines were peer reviewed by the academic and professional community and presented in public forum prior to distribution of the December 8, 1994, final draft. The interagency team was to re-evaluate the Guidelines after one-year of field testing.

To assist the interagency team in re-evaluation of the Guidelines, the Service completed a second mitigation follow-up study. The second study compares site specific monitoring regimes at 25 vernal pool mitigation sites with the Guidelines. The conclusions in this document reflect opinions of the Service and do not represent a consensus of the interagency team.

We found that no project was using the exact monitoring methods recommended in the Guidelines. However, many of the same elements are being monitored. Performance standards for permit compliance were the same at only three sites. In spite of numerous variations in the site specific performance standards, a certain percentage of pools had difficulty meeting performance standards each year. Often performance standards based upon conditions at the impact site could not be duplicated at the off-site mitigation area, because baseline surveys were completed in a single season and performance was based upon static criteria. Constructed pools which used performance standards based upon natural pools preserved on-site as reference pools received the highest performance ratings (resulting in permit compliance by year 5). However, the constructed pools at those same sites had harsh geometric shapes with steep, chronically unvegetated side slopes, and were excavated to great depths to reach a water restricting layer.

We concluded that there were too many variations in site-specific monitoring methods and performance standards for constructed vernal pools. There needs to be fewer variations in monitoring methods and performance standards to facilitate more accurate performance comparisons and assess common problems or improvements in habitat replacement.

Methods

The Service reviewed the site-specific monitoring methods (detailed in the annual monitoring reports submitted to the Corps) for 25 projects requiring mitigation and permit compliance, compared it with the Guidelines, and examined the relationship between elements monitored, performance standards and habitat replacement values.

These 25 projects were selected from 50 records of vernal pool mitigation projects in our mitigation follow-up study database which tracks Corps permits that require compensatory mitigation for filling wetlands. The selection criteria included: 1) the project needed to be an in-kind replacement (not replacing vernal pools with some other type of wetland), 2) at least one annual monitoring report needed to be on file (70% of the 50 records had monitoring reports on file), and 3) the total number of sites selected needed to reflect a maximum range in constructed pool age. Twelve of the 25 projects impacted (permanently destroyed at the project site by filling, grading, etc.) more than one wetland type and required that we separate the information on constructed vernal pools from the total mitigation requirements. We reviewed all of the monitoring reports in the selected project files. To compile and compare the data, we created a form listing the thirteen Guidelines monitoring elements and recorded the site-specific monitoring methods and performance standards opposite each element on a separate form for each project. The elements were: site selection and construction techniques (1), reference pools (2), hydrology (3-5), vegetation (6-9), wildlife (10), invertebrates (including the presence or absence of federally listed species) (11), water quality (12) and site maintenance (13).

We conducted on-site evaluations between March 29, 1994, and April 25, 1996, to observe monitoring methods and compare performance standards with permit compliance and replacement values. We recorded the number of pools which met site-specific performance standards and, if problems were identified, which standard was not met. During our site visits, we also recorded the following information: 1) number of wetted acres constructed; 2) number of pools impacted versus number of pools constructed; 3) whether the mitigation site was in a preserve area created by setting aside a portion of the project site (referred to as “on-site”) or if an additional parcel was set aside for the purpose of creating a preserve (referred to as “off-site”); 4) gross acres of the preserve site; 5) wetland density (ratio of pool area to total area) at the preserve site after constructing pools; and 6) whether only vernal pools or multiple wetland types, including vernal pools, were constructed at the preserve.

Ten sites were evaluated twice to observe periods of inundation and desiccation (Zedler, 1987). During our evaluations, we discovered that two different consultants had constructed pools at two different sites, using two distinct monitoring regimes, which were mitigation components of the same project. Therefore, the results are based upon 26 mitigation sites, rather than 25 projects. Each site visit was conducted with the project consultant present to answer questions and provide us with additional specific information that may not have been discussed in the monitoring reports. The author of this study also observed construction activities and monitored pools at some sites to further evaluate specific methods.

Results

Seventeen sites (144.7 constructed vernal pool acres) were in Sacramento County, eight sites (49.3 constructed vernal pool acres) were in Placer County, and one site (6.0 constructed vernal pool acres) was in Butte County. Mitigation pools were constructed off-site for 64% (16) of the projects and on-site for 36% (9) of the projects. The combined projects constructed 1,543 vernal pools, totalling approximately 200 wetted acres. The greatest number of pools (472) were constructed in 1994. Only 5% of the projects we evaluated constructed pools during the same year as the impacts. Two years or more lapsed between project impacts and constructing pools for 44% of the projects.

Pool construction and subsequent monitoring reports were the product of 11 different consulting firms; however, one of the consulting firms monitored 11 of the 26 sites. The element most frequently monitored (24 sites) was the number of Vernal Pool Endemic (VPE) plant species per pool (Stone, 1990). Site maintenance (routine monitoring of the preserve area for adverse conditions, such as off-road vehicle use, trash dumping, arson and vandalism) was not established at any of the sites. Additional monitoring requirements for the federally-listed Butte County Meadowfoam (*Limnanthes floccosa* ssp. *californica*) and the state-listed Boggs Lake Hedge-hyssop (*Gratiola heterosepala*) were implemented at two sites.

To facilitate comparison of specific monitoring elements, the following results are introduced by paraphrased recommendations from the Guidelines (USFWS, 1994) in italics.

Site Selection

Give priority to sites that historically supported vernal pools or have appropriate soil type (preferably same series as impact site) and will be adequately buffered (Castelle, 1994). Preserve sizes ranged between 4.5 gross acres and 520 gross acres, with the mode (6 sites) between 25 and 50 gross acres and 8 sites greater than 100 gross acres. On 19 sites, more than one type of wetland had been constructed and restoration measures were included for existing wetlands at many of the mitigation sites. An intermittent stream traversed the mitigation parcel at five sites. Vernal pools were the only wetlands constructed at seven sites. Compensatory wetlands were constructed within shared off-site mitigation areas for 13 (of the 25) projects; however, none of these areas were an official mitigation bank. Only one of the sites we evaluated was an established, interagency approved, mitigation bank. Vernal pools were constructed within existing vernal pool complexes at eight sites, converting a low density complex into a high density complex. Three mitigation sites were on parcels which were formerly used as rice farms. Twelve of the mitigation sites were established in locations considered undesirable for non-vernal pool wildlife habitat. For example, two sites were within utility easements with pools constructed underneath high voltage power lines; five sites were adjacent to freeways; and, five sites were created on parcels that are less than 13 gross acres, surrounded by development, and not adequately buffered (less than 50- to 250-foot width perimeter of uplands between the constructed or preserved habitat and the preserve boundary).

Construction Techniques

Excavate side slopes and pool bottoms that mimic impact site pools, in order to duplicate hydrologic depth, surface area, and inundation period. The pools constructed prior to 1994 generally used slope ratios of 3:1 and 4:1 and were excavated to a maximum depth of 13 to 18 inches. Recently constructed pools have slope ratios between 7:1 and 10:1, with maximum depths as shallow as 4 to 6 inches. Constructed pools at several sites were inundated for longer periods than natural pools, especially during the first two years after construction when soils may remain densely compacted.

Final mitigation site density should not exceed 30% of pool acres to gross site acres. The sites we evaluated had densities which ranged from 3 to 26%, without consideration of other wetland types on-site. When all on-site wetland types were considered, the highest density was 44% wetlands after construction.

Inoculum should not be stored for more than one year, to avoid adverse effects to the establishment of vegetation (Leck, 1989). Inoculum refers to the topsoil and organic seed-bearing material removed from impact site vernal pools and placed in constructed pools at the mitigation site. Only 5% of the projects we evaluated used the inoculum within the same year it was collected. Often the inoculum was collected for both vernal pools and seasonal swales and the resulting mixture stored together. Inoculum from pools on a volcanic substrate was collected at one project site and the rocky soils were installed over claypan at the mitigation site. In one project, half of the pools were constructed one year and the remaining pools constructed a year later; hence, half of the inoculum was stored for an additional year. The differences in plant vigor and absolute cover between pools inoculated the first year and pools inoculated the second year were readily apparent. The flora in the pools inoculated with the longer stored soil performed poorly during the first three years of monitoring (Sugnet & Associates, 1992).

Excavation spoils should be hauled off-site. Eight sites had not hauled off the spoils from excavating to construct the compensation pools.

Reference Pools

The establishment of biological viability can only be verified by comparing constructed pools with natural vernal pools from the same immediate area. Preserved natural vernal pools were concurrently monitored as reference pools for 18 projects. Natural pools preserved at the impact site were monitored as reference pools for five projects. Natural pools preserved at the mitigation site were monitored as reference pools for nine projects. Natural pools somewhere within the immediate area of the mitigation site were monitored as reference pools for four projects. No reference pools were selected and monitored for seven projects.

Hydrology

Install two hydrology staff gauges (one deep, one shallow, where 70% pool bottom is lower) in all constructed and reference pools, monitor weekly during the wet season. Document depth, area, and duration of inundation results with hydrographs, on-site photographs, and aerial photography. Two gauges per pool were installed at one site. Single staff gauges were placed in the deepest part of the reference and constructed pools at seven sites. Aerial photographs were included in the monitoring reports of three sites and photo-documentation of hydrology in sample pools was included in the monitoring reports of two sites. Hydrographs were included in the monitoring reports of five sites. At three sites, the mitigation plans required that hydrology in all constructed pools be monitored for one year prior to installing the inoculum.

Vegetation

Measure absolute cover and relative cover of vegetation (Barbour et al., 1987) using transects with point intercept, square meter quadrats, photo documentation and graphing; identify species with 20% relative cover or greater; indicate status and relative cover of hydrophytics (Reed, 1988); and determine the number of vernal pool endemic (VPEs) species present per pool (Guidelines, Table 1 lists 69 vernal pool species which are either vernal pool endemic obligates or, at least when found in the Central Valley, are native species which more frequently occur in vernal pools than in other habitats). Absolute cover was monitored at 21 sites, relative cover was monitored at 12 sites, number of VPEs were monitored at 24 sites, and dominance of hydrophytic species was monitored at 13 sites. Absolute and relative covers were measured by visual estimates at most sites. Permanent transects were used at four sites with point intercept and at two sites with square meter quadrats. Graphs depicting relative and absolute cover for each pool were included in the monitoring reports for 11 sites. Photodocumen-tation of vegetative cover in sampled pools was included in the monitoring reports for four sites. The number of VPEs per pool were measured from the total plant species composition per pool. Identifying plant species composition was accomplished by tallying from a list compiled of species most frequently encountered in or near vernal pools, including native, non-native, wetland, upland, and VPEs. A specific number of VPEs present per pool were needed to meet permit compliance at 15 sites. This number was based upon the average number of VPEs per pool at the project site prior to impacts (and later transported in inoculum to the mitigation site). VPEs had to be a specific percentage of the reference pool species to meet permit compliance at five sites. VPEs were measured with a database derived index, the Vernal Pool Floristic Index (Sugnet & Associates, 1992), at five sites.

Wildlife and Listed Invertebrates

Monitor wildlife and invertebrates on a case by case basis. Annual avian surveys at the mitigation site were required of 11 projects. Birds were monitored at 13 sites and all (vertebrate) wildlife were noted at three of these sites. Invertebrates were monitored at 16 sites and federally-listed species, either Vernal Pool Tadpole Shrimp (*Lepidurus packardi*) or Vernal Pool Fairy Shrimp (*Branchinecta lynchi*) were present in constructed pools at 12 of the 16 sites. In the third year monitoring report for one site, listed species were reported in 23 (of 25) constructed pools. At one five-year old site, Vernal Pool Tadpole Shrimp have been found in some of the constructed pools every year.

Water Quality

Monitor water quality on a case by case basis. Temperature, turbidity, and conductivity were monitored at eight sites. The data was included in the monitoring reports for permit compliance with no discussion or conclusions.

Table 1. Performance standard most frequently required for each element monitored and number of alternatives.

Guidelines Element	# Sites Monitoring Element	Performance Standard Most Frequently Stated for Element	# Sites Using Stated Standard	# Alternate Standards
Depth of Inundation	16	Comparable to reference pools	7	4
Period(s) of Inundation	16	Vegetation as surrogate for hydrology	5	4
Area of Inundation	9	Aerials required	6	2
Absolute Cover	21	80% cover	6	10
Relative Cover	12	>50% cover VPEs*	7	4
Number of VPEs*	24	7 species/pool, 12 species/pool (tied)	3	14
Dominance of Hydrophytics	13	>50% species hydrophytic	7	3
Reference Pools	18	At mitigation site	9	2
Wildlife	13	Annual surveys for avian use	11	2
Invertebrates	16	Voluntary surveys	8	5
Water Quality	8		8	0
Site Maintenance	0		0	0

* vernal pool endemic plant species.

Site Maintenance

Monitor for uncontrolled human disturbance, i.e., all terrain vehicles (ATVs), trash, and other unexpected conditions, i.e., soil piping, erosion, water run-off pollutants, wildlife mortality. Routine inspections of the overall mitigation site, to maintain suitable conditions, were not discussed in any of the monitoring reports reviewed. Specific impacts were mentioned in three reports (arson reported at one site, ATV damaged pools photodocumented at two sites).

Performance Standards

The Guidelines' performance standards are based upon establishing a reference site and primarily compare the hydrology and vegetation of constructed pools to natural pools to evaluate performance. The performance standards for hydrology are: *maximum depth of inundation within range of reference pools and longest period of inundation not greater than 125% of reference pools.* The performance standards for vegetation are: *absolute cover and relative cover by VPEs in each constructed pool shall be no less than the minimum recorded in the reference pools; each constructed pool must support no fewer than the lowest number of VPEs recorded in reference pools; VPEs shared by both the impact and reference pools shall be as vigorous and reproductively active in the constructed pools as the reference pools; and, by the last year of monitoring, any VPEs that are dominant (relative cover of a least 20%) in at least 30% of the reference pools shall be present as a dominant species in all of the constructed pools.* Only three sites used the same performance standards for permit compliance. Each element monitored had a wide range of performance standards with the greatest number of alternatives (16) relating to species richness (VPEs). The most frequently stated performance standard was annual completion of avian surveys (11 sites). Table 1 lists each element with its most frequently used site-specific performance standard and the number of alternative standards being used at other sites.

The most frequently monitored elements and the percentages of sites that met the performance standard for that element were as follows: 1) Hydrology–depth of inundation (96%), period of inundation (91%), and area of inundation (94%); 2) Vegetation –absolute cover (66%), relative cover (78%), species diversity (89%), and dominance of hydrophytics (77%); and 3) Invertebrates–species diversity (50%).

Discussion

Performance Standards

Two important trends were discovered when the number of constructed pools meeting site-specific performance standards were compared with the total number of pools constructed per year: 1) pools constructed between 1988 and 1990 had the highest performance ratings and 2) in spite of numerous variations, a certain percentage of pools each year had difficulty meeting their performance standards. Six projects were constructed between 1988 and 1990. All the projects were five or more years old and were expected to fully meet performance standards on the fifth monitoring year. Reference pools were monitored at five of these six sites and performance standards were based on the constructed pools replicating the reference pools. The hydrology performance standard was stated in four monitoring reports as "within range of the reference pools." The vegetation performance standards did not appear to be as dependent upon the reference pools. For example, two monitoring reports stated 7 VPE species/pool and one monitoring report stated 12 VPE species/pool, but did not state whether these numbers were an average, the minimum, or based upon a single year at the reference site. In any case, there should be no absolute or static numbers if monitoring at the comparison reference site is concurrently conducted each year. One monitoring report stated that constructed pools should have 75% VPE relative cover, however, average reference pool absolute cover was not stated and no absolute cover was required for constructed pools. Therefore, if a pool with 80% bare ground had 75% VPE relative cover, it would pass the performance standard. A specific percentage of absolute cover was required at four sites, presumably based upon reference pool data, but variations over time were not documented.

In some cases, specific criteria were imposed by impact site conditions that could not be replicated at the mitigation site. Reference pools were monitored at on-site preserves to compare with constructed pools off-site at four of the six projects implemented between 1988 and 1990. The worst performance rating (50% pools not meeting performance standards) of mitigation sites was for a project with standards based upon information gathered at the impact site over a single season. The project's vegetation standards were based upon each pool achieving 80% of the hydrophytic species found in the inoculum-source pools. Baseline surveys completed at the project site found numbers as high as 46 hydrophytic species per pool, because source pools had been grazed solely by horses, resulting in much richer flora than pools grazed by cattle (Balance Hydrologics, 1994). The constructed pools easily met the standards of the Guidelines and had a higher species diversity than existing pools at the mitigation site, yet, were not meeting site-specific permit compliance.

The earliest constructed pools in our study (1987) had poor performance in hydrology. The crucial element for vernal pool construction is the presence of a vernal pool forming soil, which includes the presence of a water restrictive layer (L. Stromberg, pers. comm.). The Guidelines recommend that site selection include historic vernal pool soils to ensure success. Vernal pools constructed on historic vernal pool soils are considered by some

TABLE 2. Number of constructed vernal pools meeting permit compliance or failing hydrology and/or vegetation standards per year.

Year	Total Sites	Total Pools	Hydrology Problem	Vegetation Problem	Total Pools Meeting Compliance
1987	1	97	47	72	25
1988	1	31	4	6	25
1989	2	77	0	0	77
1990	3	238	1	5	233
1991	5	328	7	101	227
1992	5	213	0	55	158
1993	2	87	0	67	20
1994	7	472	0	280	192
TOTALS	26	1543	59	586	957

to be restoration. Table 2 lists the total number of pools constructed and how many failed (either or both) the hydrology or vegetation standards each year. The data show that no pools have failed the hydrology standards since 1991. This clearly indicates that more pools are being constructed on the proper soils. Since November 13, 1992, it has been the policy of the Sacramento Corps District not to authorize the use of bentonite linings to create wetlands, including vernal pools, because subsequent impacts (i.e., cattle, ATVs) could cause the bentonite to suspend in the water column (K. Norton, pers. comm.) and damage to the liner would drain the pool and prevent further inundation.

Pools constructed in 1994 had the lowest performance ratings (60% pools failing a performance standard). Further examination revealed that 125 pools at one site required hydrology monitoring for one year prior to inoculation, and therefore, were not yet meeting the vegetation standard. At another site, 155 pools were not meeting a vegetation standard of 80% absolute cover per pool because the site was only one year old. Neither site needed remediation, because both were on track to meet performance standards by year five. The average percent of pools constructed between 1987 and 1994 that needed remediation was 35%.

Habitat Replacement Evaluation

Vernal pool mitigation sites are selected and constructed based on economy of scale and density to get the greatest wetland acreage within the smallest land area. The impact site typically consists of uplands, seasonal wetlands, vernal pools, interconnecting swales, and perhaps an ephemeral stream. The average vernal pool compensation is a fragmented replacement, resulting in a potential loss of wetland functions and habitat values. Compensation vernal pools are often separated from other wetland mitigation components and combined with additional compensation vernal pool projects. Then additional isolated depressions are excavated at the preserve site to construct seasonal wetlands, as compensation for any seasonal wetlands lost, and also as compensation for interconnecting swales, because swales are not easily re-created. The results are a homogeneous wetland preserve with very different wetland functions and habitat values from what was lost.

Constructing fewer and larger pools is more cost effective than a direct replication of the impact site (R. Francisco, pers. comm.); hence, most of the projects impacted a greater number of pools than were constructed at the mitigation site. In addition, we did not observe any concerted effort to create variable microtopographic pool bottoms to enhance plant distribution and invertebrate habitat in the constructed pools. The resulting change in hydrologic regime on the transplanted species is readily apparent when compared over a five-year period. During the first two years, there is comparable diversity and most of the plant species captured in the inoculum appear. Starting in the third year and sometimes sooner, it appears that a shift in species cover class (Barbour et al., 1987) occurs, with species that prefer longer inundation (i.e., *Eleocharis macrostachya)* beginning to dominate. These conclusions are based upon our observations of the same mitigation sites over time and comparing five years of cover class data detailed in the monitoring reports. However, to fully determine what plant species become significantly reduced in number due to lack of appropriate microhabitat variability in the re-created habitat, would require additional research.

One consultant stated that the 2:1 mitigation ratio (the Service recommendation to replace twice the acres of pools impacted) reduced available inoculum by one-half and resulted in sparse cover during the first three years (K. Whitney, pers. comm.). However, the sites we evaluated had a variable replacement ratio, usually lower than 2:1. For projects implemented after September 1, 1995, the Service added a preservation ratio of 2:1 (the preservation of existing vernal pool habitat at twice the amount impacted) and reduced the compensation ratio to 1:1, if the impacted vernal pools also are habitat for listed species. We expect to see a more rapid establishment of vegetation with this reduced ratio, and will be tracking the results.

The steep slopes of early constructed pools were the subject of vigorous criticism, because of their unnatural appearance, and the resulting barren “bathtub ring” due to lack of vegetation on the slopes. The steep slopes also did not provide optimum habitats for shorebirds and migratory waterfowl (Recher, 1966). More recently constructed pools have gentle slopes that are not only more aesthetically pleasing, but also are less likely to have unvegetated slopes. To further prevent bare slopes, many of the consultants "double seed" slopes by raking some upland topsoils downward toward pool bottoms and some inoculum upward, overlapping the soils on pool slopes. Over time, pool shapes have changed from harsh geometrics to randomly delineated shapes which more accurately mimic nature.

Routine site maintenance needs to have a higher priority and to be discussed in monitoring reports. The adverse impacts most frequently observed were trash dumping, ATV ruts, and no control for invasive non-native plant species. Often invasive non-native plant species readily occupy the recently disturbed sites and contribute to increased fire hazards. Some of the consultants have attempted control of these species by hydroseeding pool perimeters immediately after construction. Routine maintenance, such as mowing or hand weeding, is labor intensive and often ignored. Most mitigation sites are too close to urban development for controlled burns and generally we do not recommend the use of herbicides (or pesticides) within vernal pools. At one site, the consultant requested managed grazing to keep invasives under control and recently received approval from the Corps and the Service.

Numerous passerine birds, shorebirds, waterfowl, and jackrabbits were attracted to the compensatory wetlands we evaluated, regardless of whether they exactly replicate vernal pools. At one of the mitigation sites, we observed 15 fauna of the vernal pool/grasslands food chain (insects, birds, mammals and reptiles), including a coyote. One of the potential problems we have observed is that constructed pools often do not have small mammal burrows or deep hydric cracks in pool bottoms the first and second years, presumably because the soil remains densely compacted. These conditions could potentially delay establishment of species that utilize burrows and cracks for aestivation, such as Tiger Salamanders and Spadefoot Toads. Small mammal burrowing also creates additional microtopographic variations which enhance the pool habitat for plants and invertebrates and increases species diversity.

The art and science of constructing vernal pools have greatly improved over the past eight years. The technology for constructing wetlands that will provide viable habitats for rare plant species, federally listed invertebrates, migratory waterfowl, and other wildlife will continue to improve if we can specifically document which practices have been successful and which have failed. Our study concluded that if we are to validate performance comparisons over time, fewer variations in monitoring methods and performance standards should be accepted for permit compliance.

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