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OPINION ARTICLE

Using performance standards to guide vernal pool restoration and adaptive management

Karen J. Schlatter[1], Akasha M. Faist[2], Sharon K. Collinge[3]

Although many restoration projects now include monitoring and evaluation in an adaptive management approach, a failure to employ distinct performance standards can lead to inconsistent and unclear results that may hinder learning from project outcomes and complicate large-scale assessments of restoration success. Such is the case with vernal pool restoration projects in California, where performance standard guidelines are vague and inconsistently applied across agencies implementing restoration projects. However, positive steps have been made in recent years to develop wetland functional assessments and monitoring protocols in California to reduce inconsistencies and promote ecologically meaningful restoration. Additional work is needed to develop specific guidelines for vernal pool restoration performance standards and define their role within an adaptive management framework. We provide a case study of a vernal pool restoration project in central California to illustrate some of the challenges in using currently available vernal pool performance standard guidelines and propose suggestions for increasing their ecological relevance and clarity.

Key words: California, evaluation, functional assessment, mitigation, monitoring, success criteria, wetland

Implications for Practice

- Current vernal pool restoration performance standards are often vague, challenging to access, inconsistent across agencies implementing projects, and lack ecological relevance.
- The absence of well-defined and ecologically meaningful performance standards is hindering adaptive management and large-scale assessments of restoration success.
- Regional performance standard guidelines should be developed that incorporate the following: assessments of performance variation (not just average performance); specific and repeatable measurement methods for performance standard metrics; at least a 5-year monitoring timeframe to assess performance; and greater emphasis on assessments of ecosystem function over form.

Introduction

A number of studies have illustrated the need to include measurements of "success" to evaluate if and to what extent objectives have been met in ecological restoration and habitat creation projects (Hobbs & Harris 2001; Palmer et al. 2005; Bernhardt et al. 2007; Suding 2011). Despite this observed need, the incorporation of empirical evaluations of restoration success into management plans has generally lagged behind the research (Wortley et al. 2013). Without well-defined and ecologically meaningful evaluation standards, a critical step is missing in the process of adaptive management to achieve high levels of restoration success (Palmer et al. 2005; Suding 2011). Although the number of academic publications demonstrating empirical evaluations of restoration projects has increased in recent years (Wortley et al. 2013), it is questionable how these evaluation methods are being incorporated into a majority of restoration projects with limited financial resources and focus on research.

Monitoring and adaptive management are often required for many government directed restoration and mitigation projects (USFWS 2005; USACOE & USEPA 2008; Williams 2011). The push for adaptive management suggests a trend toward using monitoring as a way to "learn by doing"—employing an experimental design to test management strategies and incorporating results into management decisions (Williams 2011). Critical to this process is the establishment of quantitative measurements of success, or performance standards, which are measureable metrics used to assess if the project meets its objectives (Harman et al. 2012). Performance standards provide a direct link between project goals and outcomes, enabling practitioners to determine the effectiveness of the project quantitatively and assess best practices and approaches. Performance standards are embedded in all steps of the adaptive management cycle; however, they are often unclear or deemphasized in the project planning process, with little guidance on how they should be

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[1]University of Colorado Environmental Studies Program, UCB 397, Boulder, CO 80309, U.S.A.
[2]Department of Ecology and Evolutionary Biology, University of Colorado, UCB 334, Boulder, CO 80309, U.S.A.
[3]Address correspondence to S. K. Collinge, email sharon.collinge@colorado.edu

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determined and the role they play in adaptive management (Bernhardt et al. 2007). Often, information gathered from ecological monitoring is not related to project outcomes, nor used to determine remedial actions (Palmer & Hondula 2014).

Defining objective and measurable performance standards can be challenging for restoration practitioners due to the lack of easily accessible scientific information and overarching regional management goals, differences in stakeholder values, and the uncertainty posed by rapidly shifting baseline conditions (Suding 2011). Yet, habitat restoration and mitigation projects are likely to be either misinformed or difficult to conduct in the absence of broadly accepted performance standards. Such is the case with vernal pool habitat creation and restoration in California. Millions of dollars are spent every year on wetland restoration projects in California alone (CWMW 2010); yet such expenditures can seem ineffective if the state cannot report on the success of such projects, provide a valid assessment of overall ecosystem health, or effectively adaptively manage systems using feedback from project evaluations.

Restoration efforts on stream ecosystems have experienced similar growing pains in identifying meaningful measures of restoration success over the past 10 years (Palmer et al. 2005; Bernhardt et al. 2007; Woolsey et al. 2007; Doyle & Shields 2012; Palmer & Hondula 2014). Although we focus specifically on vernal pool systems in this article, we raise issues of performance standards that apply to a broad range of restoration projects in varying ecosystems and locations. We assess success of our vernal pool mitigation project in central California, synthesizing lessons learned from our long-term monitoring data set with additional research on performance standards to build upon recommendations for measuring success. The development of a revised list of vernal pool performance standards and measurement methods is outside the scope of this article; but, by drawing attention to the prevalent issues of inconsistency and ambiguity in existing vernal pool performance standards, we aim to stimulate discussion, research, and eventually progress toward the development of well-defined and ecologically relevant standards.

Vernal Pool Ecology and Restoration Efforts

Primarily distributed in regions with Mediterranean climates and some non-Mediterranean climates including temperate forest systems (Brooks & Hayashi 2002), vernal pools are ephemeral wetlands that experience inundation from winter rains and desiccation in the summer and fall (Keeley & Zedler 1998). Vernal pools are critical areas of floral and faunal diversity and typically support a high number of endemic species due to their unique and extreme seasonal conditions (Keeley & Zedler 1998). However, land-use change has resulted in the loss of 60–95% of vernal pool habitat in California alone (Barbour et al. 2005, 2007). Many vernal pool species are classified as endangered or threatened (USFWS 2005), which has prompted the establishment of vernal pool recovery programs and restoration efforts.

Vernal pool restoration was first attempted in the 1980s (Zedler 1987), and the number of projects has increased in the past 30 years. However, the unique hydrological regime of vernal pools can be difficult to reestablish, which often results in unsuccessful restoration attempts (De Weese 1998; Calhoun et al. 2014). The difficulty in creating and restoring vernal pool habitat is particularly an issue for mitigation projects that allow for the destruction of intact vernal pools on the premise that constructed vernal pools will replace natural pools' ecological function and structure (Black & Zedler 1998; Calhoun et al. 2014). A review of wetland construction projects in California found that constructed vernal pools received the lowest ratings for replacing lost habitat values (De Weese 1998). Calhoun et al. (2014) suggest that vernal pool construction projects should be used as a "last resort" only when attempts at protection have been exhausted.

In light of such challenges in vernal pool creation and restoration projects, well-defined measurements of success and repeatable evaluation methods would be valuable to managers in assessing why failures occur and how projects could be better implemented in the future. In particular, project performance standards developed from reference pool sites are critical in providing quantitative project goals that can stipulate further management actions if they are not met.

The Evolution of Performance Standards

Although significant progress has been made in attempts to establish meaningful ecological assessments, government initiatives outlining performance standard guidelines for wetland and stream restoration projects demonstrate that the evolution is not complete. The U.S. Army Corps of Engineers (USACOE) and U.S. Environmental Protection Agency (USEPA) provided guidance in establishing wetland systems performance standards in the 2008 Compensatory Mitigation for Losses of Aquatic Resources Rule (USACOE & USEPA 2008). The document's vague language, use of form-based performance standards over function-based standards, and lack of integration of standards into adaptive management have resulted in regional inconsistencies, unsuccessful restoration of ecosystem function, and project permits that lack any specified performance standards (Bronner et al. 2013). Similarly, the "Function-Based Framework for Stream Assessment and Restoration Projects" by the USEPA (Harman et al. 2012) attempted to provide guidance on defining performance standards and function-based assessments for stream restoration projects; however, the document lacks operationalization, and several suggested metrics do not actually measure ecosystem function (Palmer et al. 2014).

Looking more specifically at vernal pool performance standards, a review of California vernal pool mitigation projects in 1998 found that the standards in use were "insufficient to assure successful habitat replacement," with high variability in the types of parameters evaluated across agencies and projects (De Weese 1998:217). A more recent study on the classification of vernal pools in California determined that performance standards were lacking standardization as to what plant community attributes are measured, had variable lengths of monitoring time following project implementation, and metrics intended to evaluate ecological parameters were not ecologically relevant (Barbour et al. 2007). A 2014 review of vernal pool creation projects in the northeastern United States provides a similar critique of performance standards, noting that they are insufficient indicators of restored habitat function, particularly with regard to the maintenance of faunal communities (Calhoun et al. 2014).

Collaborative groups such as the California Wetland Monitoring Workgroup (CWMW) have recognized the issue of dispersed responsibility among agencies implementing wetland restoration projects in California (CWMW 2010) and developed the California Rapid Assessment Method (CRAM) in 2009 as a way to address the lack of standardized monitoring protocols (CWMW 2010). Although the use of CRAM is not currently mandated for agencies implementing wetland restoration projects, it is an accessible and useful resource for managers who wish to use it. CRAM is highly encouraged by regulatory agencies and is already being adopted in many projects (C. Schaefer 2014, Schaefer Ecological Solutions, personal communication).

Additionally, Bauder et al. (2009) provide useful guidelines for using a hydrogeomorphic (HGM) approach to assess wetland function of vernal pools in Southern California. Their approach includes four key components: "(a) the HGM classification, (b) identification of reference wetlands, (c) assessment models/functional indices and (d) assessment protocols" (Bauder et al. 2009:4). Particularly of use to vernal pool restoration practitioners, they provide rigorous scientific justification for parameters that should be used to indicate vernal pool function as well as detailed monitoring protocols for various metrics (Bauder et al. 2009). Bauder et al. (2009) proposed the following as critical functions specific to vernal pools in Southern California: (1) surface and sub-surface water storage, (2) hydrologic networks, (3) biogeochemical processes, (4) maintenance of characteristic plant community, and (5) maintenance of characteristic faunal community.

Bauder et al.'s (2009) approach represents an increasing emphasis on functional assessments and process-based restoration over form-based restoration and evaluation (see Doyle & Shields 2012; Bronner et al. 2013; Palmer et al. 2014). Evaluations of ecosystem function can include both assessments of dynamic processes and maintenance of structural components needed for ecosystem functioning, as is exemplified in Bauder et al.'s (2009) inventory of vernal pool functions. Functional assessments are becoming increasingly popular in the field of restoration ecology, as noted in the performance standard critiques listed above. While we should strive to incorporate such assessments into restoration projects, they typically require more time and money, and additional research is needed to determine their applicability in the field and their proven effectiveness in predicting ecosystem function (Palmer et al. 2014).

Although some agencies have incorporated various recommendations of the above sources as well as metrics from the HGM guidelines (Bauder et al. 2009) into restoration and habitat conservation plans (HCP) (see Solano County HCP and Draft San Diego Vernal Pool HCP, City of San Diego 2015), the majority of performance standards are still determined on a project-by-project basis, with little to no overarching guidelines or requirements as to what they should be. Ultimately, it is up to the agency and even the specific project manager to determine monitoring methods, performance standards, and any regulative actions if a project is deemed unsuccessful. Thus, while we recognize that the HGM and CRAM wetland assessment approaches as well as the extensive research supporting the proposed methods are critical and necessary steps in the development of appropriate performance standards, we believe that regional guidelines are specifically needed for the development of vernal pool performance standards, including guidelines on the integration of standards into adaptive management plans.

In the following section, we provide a case study in which we applied vernal pool performance standards using a long-term data set from our vernal pool flora mitigation project in central California. The purpose of the case study is to demonstrate issues we encountered in the application of performance standards to our project and provide fundamental insights based on our experience. We first assess our project results through performance standards defined by De Weese (1998), provide a comparison with more recent standards developed by Barbour et al. (2007), and finally, list recommendations for further improvements on these standards. While we focus primarily on vernal pool floral community assessments, our aim is that the observations can be applied more broadly to faunal community assessments and the development of performance standards in general. We do not provide detailed data analyses in the case study (see previous studies by Collinge) or focus on suggested detailed monitoring methods, as that is beyond the scope of this opinion piece.

Case Study

In 1999, we implemented a vernal pool creation project in a 15-ha study site that historically supported a vernal pool complex in Solano County, California, to mitigate for the endangered plant species, *Lasthenia conjugens* (Collinge et al. 2013). Eighty naturally occurring pools present at the site were used as references to guide construction of 256 pools and to measure success of constructed pools (Collinge et al. 2013).

We used performance standards outlined in De Weese (1998), which were based on USFWS 1994 draft vernal pool mitigation and monitoring guidelines, to inform our monitoring efforts and determine the metrics used to evaluate project success, as this was one of the few resources available on performance standards at the time the pools were constructed. We monitored hydrological and vegetation parameters of constructed pools and a subset of reference pools beginning in 1999 (see Collinge et al. 2013 for detailed monitoring methods) and conducted a project evaluation in 2011 based on De Weese (1998) (see Table 1).

Hydrological Monitoring

Hydrology performance standards (De Weese 1998) specify that: (1) the depth of inundation of constructed pools should

Table 1. Comparison of published vernal pool performance standards. (VPE stands for vernal pool endemic.)

Performance Standard	*Source*		
Hydrology	De Weese 1998	Barbour et al. 2007	Solano County HCP 2012
Pool depth	Maximum depth of inundation is within range of reference pools.	Depth and/or duration of ponded water in created pools should not differ statistically ($p = 0.05$) from those in nearby natural pools.	No hydrology performance criteria in vernal pool section. Hydrology and water quality monitoring to be determined/conducted by individual reserves according to resource management plan.
Duration of inundation	Longest period of inundation not greater than 125% of reference pools.		
Vegetation			
Absolute and relative cover	Absolute and relative cover by VPEs in constructed pool should be no less than the minimum recorded in reference pools.	Absolute and relative cover by vernal pool endemics in constructed pools should not be statistically different ($p = 0.05$) from the average values in ref pools.	Absolute and relative cover of each vernal pool endemic in restored pools shall be statistically similar to the range of values of each species found in reference pools.
Species richness	Each constructed pool must support no fewer than the lowest number of VPEs recorded in reference pools.	The number of vernal pool endemics in constructed pools should not be statistically lower ($p = 0.05$) than the average number of those taxa among reference pools.	The number of vernal pool endemics in restored pools shall be statistically similar to the average number of those taxa among reference pools.
Reproductive vigor	VPEs shared by both the impact and reference pools shall be as vigorous and reproductively active in the constructed pools as the reference pools.	The vigor (biomass accumulation) and reproductive activity (seed production) of VPEs in constructed pools should not be statistically lower ($p = 0.05$) than those of the same species in reference pools.	Criterion deleted.
Dominant species	By last year of monitoring, any VPEs that are dominant (relative cover of at least 20%) in at least 30% of reference pools shall be present as a dominant species in all constructed pools.	Recommend deletion.	Criterion deleted.
Community types	None	The identity of community types in created pools and the mixture in which they occur should match that of reference pools (using a Sorensen Similarity Index formula where "matching" means an SSI > 50%). Reference pools should be chosen subjectively so that collectively they represent the diversity of species and communities that exist in the pools to be taken.	There shall be no significant difference in the ratio of restored and reference plots observed versus the ratio of restored and reference plots expected between the first three groups formed in the cluster analysis corresponding to deep, shallow, and edge community types.
Nonnative species	None	The number and cover of exotic species in any constructed pool should not be significantly higher than the average among reference pools.	The number and cover of nonnative species in any restored pool shall be statistically similar to or lower than the average among reference pools.

be within the range of that observed in reference pools, and (2) that the longest period of inundation in constructed pools should not be greater than 125% of that found in reference pools. We found that one fourth to one third of our constructed pools did not meet the "depth of inundation" hydrological performance standard. Most constructed pools that did not fall within the range of reference pools were too shallow. Although the majority of pools met the second hydrology standard, 18–50% of constructed pools (depending on the monitoring year) did not meet the *minimum* period of inundation in reference pools, an important variable for vernal pool invertebrate species reproduction (Philippi et al. 2001). In addition, the "period of inundation" can be interpreted differently by the practitioner, that is, by including only the period of continuous inundation or by including any date on which a point in the pool was inundated, again highlighting issues of ambiguity that can lead to inconsistency in project evaluations. Although we used the second definition, continuity of inundation may be important for determining the success of native (especially vs. exotic) vernal pool species (Gerhardt & Collinge 2003; 2007).

While Barbour et al. (2007) attempt to provide some clarifications and improvements to the De Weese (1998) vernal pool hydrology performance standards (see Table 1), definitions and suggested metrics are still somewhat vague. They suggest that the "depth and/or duration of ponded water in created pools should not differ statistically ($p = 0.05$) from those in nearby natural pools" (Barbour et al. 2007:108). Although not specified, presumably it is the *average* depth and/or duration of ponded water of the constructed pools that should not statistically differ from the *average* of reference pools for a given year. The use of averages in constructed and reference pool comparisons can be misleading in evaluations of success, as we discuss in greater detail in the "principles" section below. In addition, it would be helpful to describe specifically how depth and duration should be measured. Similarly, the standard for ponded water duration is vague, leaving the practitioner to define duration as continuous or the total sum of days inundated.

Vegetation Monitoring

Vegetation performance standards state that absolute cover, species richness, vigor and reproductive activity, and dominance by vernal pool endemics (VPEs) shall be similar in constructed and reference pools (see Table 1) (De Weese 1998). *On average*, many of our constructed pools did meet at least one of the vegetation performance standards on a yearly basis. In 2003, the average abundance of our target plant species, *L. conjugens* was not significantly different in constructed pools and reference pools (Collinge 2003). However, by 2009, one third of constructed pools contained little to no VPE species despite employing the same management regime for constructed and reference pools over the duration of the project (Collinge et al. 2013). This suggests that although initial restoration efforts may have been considered successful according to mitigation project performance standards, the long-term restoration outcomes were notably less positive.

We also found the De Weese (1998) standard of vigor and reproductive activity to be vague and difficult to determine. We compared the number of viable seeds from the VPE *L. conjugens* (Contra Costa goldfields) in constructed and reference pools as a measure of plant vigor, and also noted that the increased abundance of vernal pool plant species in constructed pools during the first few years of the experiment suggested seed viability.

Barbour et al. (2007) provide a series of useful suggestions for clarifying and improving the De Weese (1998) vegetation performance standards including measurable definitions of vigor (biomass accumulation) and reproductive activity (seed production), criterion to address exotic species, and several new criteria that are community oriented rather than species oriented. Similarly, Calhoun et al. (2014) do not recommend the use of species richness as a performance standard because richness may reflect a high number of exotic species, and does not necessarily relate to vernal pool health. Rather, community composition is a suggested standard that can provide a more ecologically relevant measure of success (Calhoun et al. 2014). Lastly, Barbour et al. (2007) suggest deleting the De Weese (1998) criterion of VPE species dominance, as they contend it does not promote heterogeneity of constructed pools.

Principles for Improved Performance Standards

Our case study demonstrates the following issues with vernal pool performance standards (see Table 2): (1) using averages to evaluate performance can be misleading of true project outcomes; (2) performance standards can be vague and lack specific measurement methods; (3) metrics used may not be ecologically relevant or measure ecosystem function (e.g. species richness vs. community composition); (4) short-term monitoring may not indicate long-term success and/or sustainability of restoration goals. While there may be revised and more recent vernal pool performance standards that address some of these issues, they are not easily accessible as our research efforts on this topic proved. It was exceedingly difficult to find information on vernal pool performance standards currently in use in mitigation and restoration projects in California, even when contacting the agencies overseeing ongoing projects. Some recently developed HCPs do list specific performance standards, but they similarly embody some of the issues we outline above.

Synthesizing lessons learned from our experience and research conducted by others, we developed the following key principles for improving vernal pool performance standards (see Table 2). We consider this a preliminary set of principles which researchers, agencies, and practitioners can debate and build upon to encourage the development of ecologically relevant, clear, consistent, and accessible performance standards. First, an assessment of performance variation can provide a critical and more complete evaluation of project success in the case where "failed" constructed vernal pools are balanced out by successful constructed pools in the calculation of the average performance. Variance can also be used as an indicator of ecosystem regime shifts (Scheffer 2009), which could

Table 2. Issues encountered in our vernal pool restoration project evaluation and suggested actions for improving performance standards.

Issues Encountered	*Suggested Actions*
Inconsistent use of performance standards across agencies and projects	Standardize performance standards on a regional scale by creating standards based on comparisons of restored pools to regionally relevant, naturally occurring pools
Terms used in performance standards can be vague and lack specific measurement methods	Clear definitions and specific and repeatable methods for measuring metrics described in standards should be provided in performance standards guidelines
Using averages to evaluate performance can be misleading of true project outcomes	Assess variation in performance (potential use of a predetermined failure rate metric)
Metrics used may not be ecologically relevant or measure ecosystem function	Performance standard metrics should ideally measure ecosystem function rather than form
Short-term monitoring may not indicate long-term success and/or sustainability of restoration goals	Five-year minimum length of monitoring time, but a longer timeframe is preferred
Lack of easily accessible information on vernal pool performance standards	Make standardized set of suggested regional performance standards available on agency and practitioner websites
Monitoring results often not used in an adaptive management process	HCPs and recovery plans should outline adaptive management steps including the use of monitoring data to reevaluate project goals and restoration practices and provide suggested actions if performance standards are not met

be helpful in evaluating both constructed and reference pool functional health and determining management strategies. A useful metric related to variance could be the number (and percentage) of constructed pools that had zero frequency of native species (i.e. all cover was by exotics). This statistic would show that although the *average* abundance of VPEs did not differ significantly between constructed and reference pools, there were some "failed" constructed pools that did not meet the performance standard. A predetermined "failure rate" could provide a threshold to determine if additional restoration actions are needed to achieve a higher level of vernal pool creation success. In addition, a similarity index at the community level could be an informative metric to assess how similar restored vernal pool communities are to reference pools.

Second, our case study illustrates the potential gap in the adaptive management cycle in which monitoring results should be used to inform and revise management goals and practices. Our monitoring data suggested that one third of the constructed pools "failed" due to shallow pool depth and accumulation of invasive plant species litter. A subset of failed pools were manually re-excavated and seeded to promote the establishment of our target plant species, although this was not mandated nor funded by the managing agency. HCPs and other recovery plans should outline steps in the adaptive management process including the use of monitoring data to reevaluate project goals and restoration practices and require additional management actions if performance standards are not met.

In addition, it is assumed but worthy to note that performance standard guidelines should be based on a comparison of restored pools to appropriate, naturally occurring reference pools that are regionally relevant (both within and outside of the site if possible) (Barbour et al. 2007; Bauder et al. 2009). To create appropriate performance standards, data collection from reference pools should take place over time rather than in one season to account for system dynamics (which are highly variable for vernal pools) and similarly, restored pool monitoring should take place over a different seasons (De Weese 1998; Bauder et al. 2009; Calhoun et al. 2014).

We propose that through the use of site-appropriate reference pool comparisons, performance standards could be standardized on a regional or statewide scale; for example, the identity of community types in created pools and the mixture in which they occur should match that of reference pools (taken from Barbour et al. 2007, see Table 1). While vernal pools distributed across the region will obviously vary in species composition, size, hydrology, and other variables, using reference pools to define performance standards essentially standardizes the assessment through the comparison of site-specific variables. In this manner, success can be measured even as overall conditions are changing, as opposed to assessing success based on a fixed idea of general vernal pool attributes. While we acknowledge that not all projects will have the same goals and thus the same standards, making such regional performance standard guidelines widely available (but not obligatory) to practitioners would greatly help to reduce inconsistencies across agencies and would enable assessments of restoration success and vernal pool health on a broader ecological scale.

Our case study highlights the focus on form versus function-based restoration and monitoring; the mitigation project was designed to establish a specific plant species, and monitoring was focused on components that would indicate success of that goal. As a result of our project's narrow focus on flora, the vernal pool faunal community was entirely ignored, even though the recovery of endemic vernal pool faunal populations is a goal for other restoration projects in the region and nation-wide. The plant community is not indicative of faunal community health, nor is it an accurate reflection of the physical, chemical, and biological processes that shape ecosystem function (Cole 2002). As the development of function-based assessments evolves, performance standard metrics should ideally measure ecosystem function rather than form; Bauder et al.'s (2009) HGM framework is an essential building block for this development in vernal pool restoration performance standards. In addition, to facilitate conformity of performance standard measurements, specific and repeatable methods for measuring metrics described in standards should be provided. Lastly, we and others (Barbour et al. 2007; Solano HCP 2012; Calhoun et al. 2014) recommend a 5-year minimum for the length of monitoring, but long-term data collection is preferred as the system can change trajectory over time, as demonstrated by our study (Collinge & Ray 2009; Collinge et al. 2013).

Although we have framed the above principles largely in terms of vernal pool systems, they can be applied more broadly to restoration efforts in other ecosystems with varying restoration goals. We believe that poor performance standard guidelines are in part causing the current gap in the adaptive management cycle. By clarifying performance standards and related metrics and measurement methods, practitioners can more effectively use meaningful empirical project evaluation to inform next steps in management and improve long-term performance of restoration projects.

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