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Task 3: Depressional wetland habitat development curve

Introduction

Early guidance by the US Environmental Protection Agency (USEPA) for wetland restoration planning recommends the use of Performance Curves (PCs) to forecast and evaluate project performance relative to desired or reference conditions. According to this early guidance, PCs should indicate the condition a project is likely to achieve at any future date after it is constructed. PCs are developed by assessing conditions of multiple wetland projects of different age and comparing them to natural wetlands that represent the intended endpoints of projects conditions. The PCs are based on the assumption that the developmental trajectory of any given project can be estimated by the developmental stages of other wetlands of the same kind but differing ages that in aggregate represent the entire developmental timeframe. The key element of a useful PC is a dataset that accurately represents temporal changes in wetland development.

In its review of CRAM as a tool for regulatory applications under Section 404 of the US Clean Water Act, the Engineer Research and Development Center (ERDC) of the US Army Corps of Engineers (USACE) recommended that PCs be developed based on CRAM for each of the wetland types covered by a separate CRAM Module. Since then, the interest in wetland PCs has grown.

The CRAM user community recognizes that PCs based on CRAM pertain to non-project wetlands as well as projects, and that they have utility beyond assessing project performance in a regulatory context. Because of this recognition, any Performance Curve based on CRAM is henceforth referred to more generally as a Habitat Development Curve (HDC).

Dataset

Overview

A major finding of the effort to develop the estuarine wetland HDC was that the supporting dataset must only include wetlands of known age that have been subject to natural developmental processes minimally perturbed by catastrophic natural events or by human intervention. Not knowing the age of wetlands can greatly decrease the precision of the HDC by artificially spreading data along the time axis. Major natural events such as wildfire and catastrophic flooding can also spread the data over time and thus reduce the precision of an HDC by resetting or retarding the developmental processes. Some wetland management practices, such as planting, weed control, irrigation, and other hydrological manipulations can retard or accelerate the processes. Some wetlands are managed for particular developmental stages and not allowed to fully develop. Thus, the inclusion of wetlands representing perturbed developmental processes can artificially increase the spread of the data along the condition axis as well as the time axis.

To create the most precise HDC possible, every assessment in the dataset, plus the wetland it represents, must be very well understood. Gaining the necessary understanding can involve reviewing case-specific reports, examination of aerial images and maps of different vintage, site visits, review of the CRAM data, and interviews with local experts and the CRAM assessment team. An initial dataset of

393 depressional wetland assessments dating from 2007 to 2015 was compiled from the statewide CRAM database (www.cramwetlands.org). These data represent assessments from depressional wetlands across California, and includes assessments from ambient surveys and wetland project evaluations.

Age Assignment

For the production of a wetland HDC, the most important characteristic of each wetland is its age. An effort was undertaken to assign an age to each depressional wetland represented by one or more of the 393 CRAM assessments in the refined HDC dataset. In general, the assigned age of a depressional wetland represents the year of its creation or the last date that the wetland age was effectively reset to zero by natural events or management practices.

To estimate the age of the depressional wetlands, current and historical aerial imagery, topographic maps, site-specific reports, and interviews with data collectors and project managers were utilized. Online sources of information are reported in Table 1.

Table 1. Online resources to estimate depressional wetland age.

Source Name	Web Address
Google Earth with historical imagery	https://www.google.com/earth/
USGS San Francisco Bay Area Regional Database (BARD)	http://bard.wr.usgs.gov/histMapIndex15.html
Nationwide Environmental Title Research, LLC (NETR) Online (aerial images & historical topographic maps)	http://www.historicaerials.com/
USGS Historical Topographic Map Collection	http://geonames.usgs.gov/pls/topomaps/f?p=262:1:1599334439898343
EcoAtlas - project information, maps and online reports	http://ecoatlas.org

Aerial imagery was the primary source of information used to assign ages to depressional wetlands dating since the early 1940s. Historical USGS topographic maps were useful for older wetlands, with the caveats that map scale varies with map vintage, and that many smaller wetlands are not recorded on small-scale maps. The use of multiple sources of information supported a weight-of-evidence approach to dating the wetlands.

Some depressional wetlands are older than can be determined from readily available information. These wetlands were assigned an age of 75 years, which is the vintage of the oldest information used in the age assignment process. This is assumed to be the minimum age for the oldest wetlands.

Dataset Refinement

The following criteria were developed to refine the depressional wetland HDC dataset. These criteria evolved through iterative explorations of the initial dataset to understand its sources of variability. Each analysis required investigations into the natural and human history of each case. The basic intent of the criteria was to only include cases from the dataset that represent mostly natural, uninterrupted or unconstrained processes of depressional wetland development.

- The assessment is accurately and completely recorded in the statewide CRAM database (www.cramwetlands.org), and has adequate assurances of scientific soundness based on the training and experience of the assessment team.

- If the wetland is not natural, then its intended purpose is to provide a diverse set of ecosystem services, especially general wildlife support, rather than a very restricted set of services or a single service, such as floodwater storage or wastewater treatment.
- If the wetland is natural, its age could be reasonably estimated using the resources listed in Table 1.
- The assessment area or its wetland is not subject to regular management actions such as grading, extensive water management for specific purposes (e.g., storage ponds, duck club ponds, or golf course water features), invasive plant species control, or other interventions that would affect the developmental trajectory of the wetland or its CRAM assessment.

Based on the above criteria, the initial 393 CRAM assessments were individually evaluated and grouped into four categories based on the management regime of their respective wetlands. The groupings represent different levels of wildlife support coupled with certainty of wetland age. The groups are described as follows:

- Group A (N=132). These cases are primarily project sites, including wetland creations, conversions, restorations, and enhancements done to provide a broad suite of ecological services, especially including habitat for diverse wildlife support. Each wetland in this group has a definite age (i.e., a definitive time zero).
- Group B (N=186). This is a diverse group of non-project wetlands. Many of these cases are managed for some level of wildlife support, however that level is variable and warrants further exploration. This group includes natural sites, naturalized sites, and unnatural sites managed for habitat, as well as unnatural sites that are primarily managed for other purposes. The wetlands in this group can at least be assigned an accurate minimum age.
- Group C (N=27). These wetlands are very clearly not created or managed for wildlife. They are subject to very restricted and intensive management to achieve specific purposes that are not generally consistent with wildlife support. Typical wetlands in this group include wastewater holding ponds and stock ponds in feed lots or barn yards. Most wetlands in this group have definitive ages.
- Group Z (N=48). This group consists of pre-construction wetland project assessments in wetlands of indeterminate age, or sites that have complex and unresolved histories of change in management regime.

Group Z was immediately excluded from the HDC dataset because it contributed substantial variability to the relationship between CRAM scores and wetland age, which could not be resolved. This reduced the size of the HDC dataset to 345 cases.

CRAM Index Scores were plotted against wetland age and color-coded by management group A-C to explore systematic differences among the management groups (Figure 1). CRAM scores have similar ranges for Groups A and B, but Group A consists of younger sites. This is because Group A consists primarily of projects resulting from environmental policies that have only existed for a few decades. Both Group A and Group B show some increase in condition over time, whereas Group C shows no increase in condition with time. Based upon this analysis, Group C was eliminated from the HDC dataset. This reduced the HDC dataset to 318 cases.

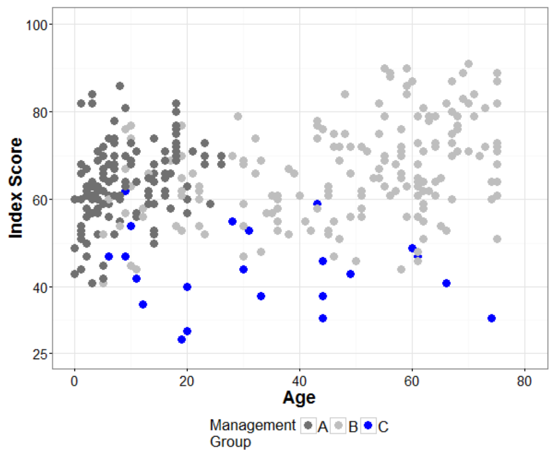

Figure 1. CRAM Index scores plotted against wetland age (years), with cases color-coded by their management regime (see text for description of the groups).

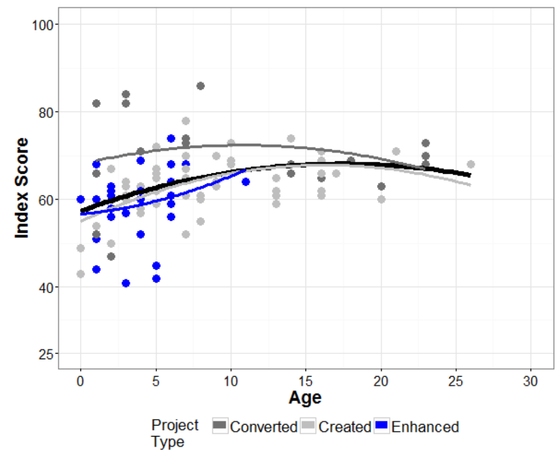

Figure 2. CRAM Index scores plotted against wetland age (years) for three project types within the Group A wetlands (converted, created, or enhanced), showing the regression line for each category and the overall nonlinear regression (black) for all of Group A.

The elimination of Group C improved the overall correlation between wetland condition and age. However, there remained substantial variability in the relationship that warranted efforts to further refine Groups A and B.

Group A includes both mitigation and restoration projects, which can be further classified as wetland creation, conversion, or enhancement efforts. Case-specific knowledge of these actions was needed to further classify each case as a conversion, creation, or enhancement project. Projects are classified as conversions when a depressional wetland replaces another wetland type. Projects are classified as creations when a depressional wetland is created where no wetland previously existed. Projects are classified as enhancements if actions are restricted to improving certain aspects of condition, such as planting native vegetation, mowing non-natives, or increasing physical structural complexity. Plotting condition against age for each of these project types within Group A revealed insignificant differences in their developmental rates (Figure 2). Based on this analysis, no further refinement of Group A was undertaken.

Next, because the condition scores of Groups A and B overlap, they were combined so that the data could be further explored by wetland category, or purpose of each wetland. These categories can be described as follows.

- Agricultural ponds: these are sites in agricultural settings used to store water for agricultural purposes (e.g., irrigation, frost control);
- Diked estuarine sites: these are sites typically in Southern California where an area of tidal estuarine marsh was historically diked and is now a depressional wetland, although it still retains much of its previous estuarine marsh character;

- Highway sites: these are sites immediately adjacent to a highway that typically hold stormwater, although they are not necessarily engineered stormwater basins;
- Stockponds: these are sites created to provide a water source for cattle or other livestock;
- Waterfowl ponds: these are typically very large depressional wetlands managed specifically for waterfowl support;
- Water management sites: this is a diverse set of sites that are all managed specifically for water retention or detention purposes, including stormwater basins, pump station ponds, small municipal reservoirs, detention basins, etc.;
- Other depressions: these are sites that did not obviously fit into any of the other categories of depressional wetlands, including reference sites (explained further below). Many of these wetlands are natural or naturalized, and provide a diverse set of ecological services, including wildlife support.

The combined Group A and B data in Figure 1 show that many of these wetlands receive low CRAM scores, regardless of age. This finding requires additional exploration of the data to understand the cause of these low scores. Many of these wetlands exist only for a specific purpose, and are not necessarily created or managed to support a diverse set of habitat functions. For example, agricultural ponds, highway sites, intensively used stockponds, and water management sites are not usually allowed to develop conditions generally indicative of a healthy wildlife habitat. If the combined data are categorized, different relationships between condition and age are evident among these wetland categories (Figure 3). There is no clear relationship between age and condition for agricultural ponds, highway sites, or water management sites. None of these categories have high condition scores, and in fact, most have uniformly low scores. Additionally, scores for diked estuarine sites and waterfowl sites also do not show a strong positive relationship over time, despite some of these sites having moderately high scores for condition (Figure 4). However, there is a weak positive relationship between age and the condition of stockponds (Figure 3). This is because many of the older ponds have been abandoned, and thus have become naturalized, and now have higher condition scores as compared to the still active, intensively used ponds that have lower condition scores. Despite the higher scores of the naturalized ponds, the category as a whole is difficult to include within the HDC dataset because often the data do not exist to determine the timing of abandonment or other changes in management. In addition, although sites may naturalize, they still retain their history of previously being a stockpond, always affecting some aspects of the CRAM score (e.g. setting, hydrology, topographic complexity), and thus not providing a good model of diverse wetland habitat development. There is also a positive relationship between condition and age for the Other Depressions category. This is not surprising, since many of the wetlands in this category exhibit complex biological and physical structure due to either no management or relaxed management regimes. Based on these findings, agricultural ponds, highway sites, stockponds, water management sites, diked estuarine sites, and waterfowl sites were removed from the HDC dataset, reducing it to 212 cases.

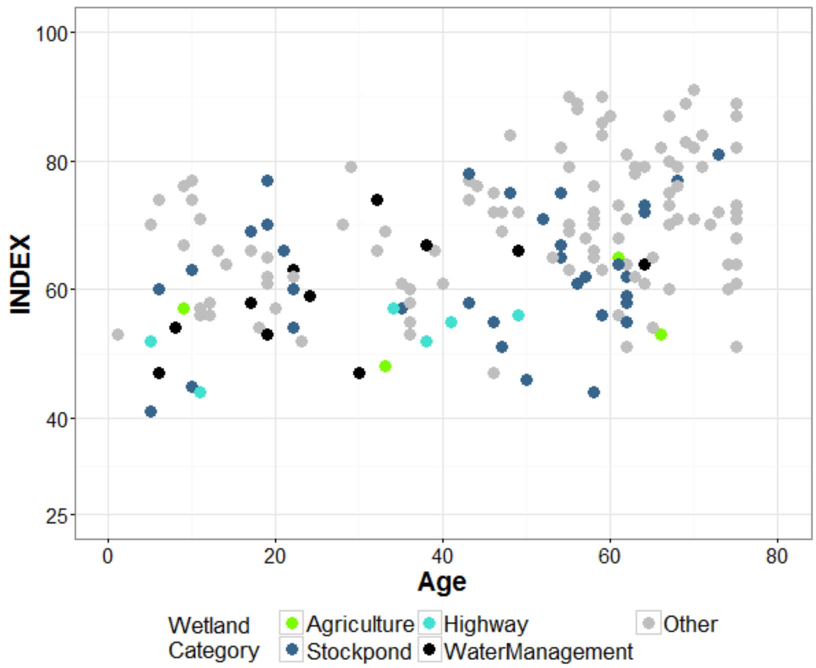

Figure 3. CRAM Index scores from Groups A and B plotted against wetland age (years) highlighting four categories of wetlands: Agriculture, Highway, Stockpond, and Water Management categories.

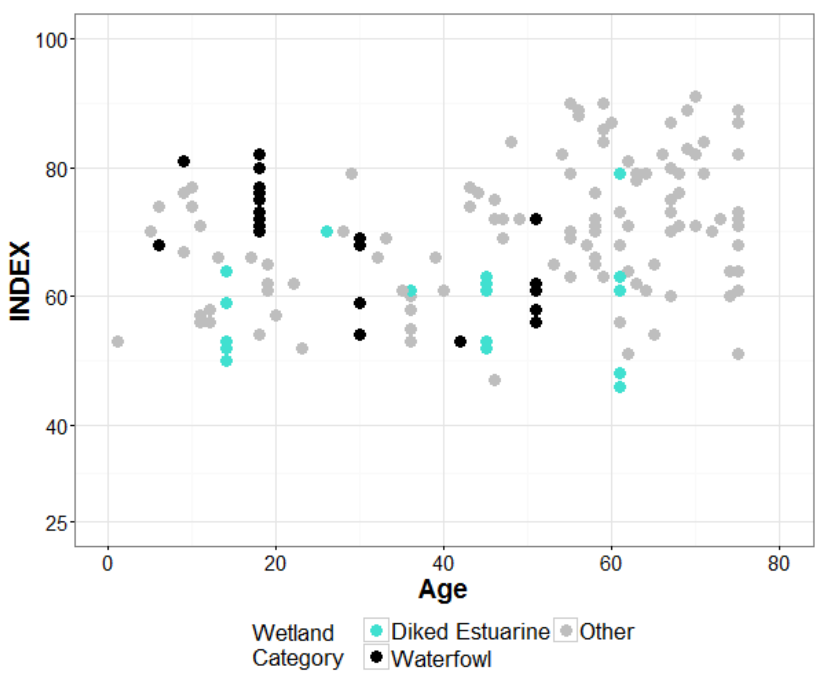

Figure 4. CRAM Index scores from Groups A and B plotted against wetland age (years) highlighting the Diked Estuarine and Waterfowl Pond categories.

Further investigations into the cases comprising the Other Depressions category revealed 15 sites that were subsequently removed from the HDC dataset for specific reasons (Figure 5). First, the complex management history of some of the sites confounded our ability to accurately determine their ages. Second, some sites proved to have intensive use and management activities than previously understood based on the initial review and cases - closer inspection of these sites revealed that they are not managed to support diverse wildlife habitat. This reduced to final HDC dataset to 197 cases.

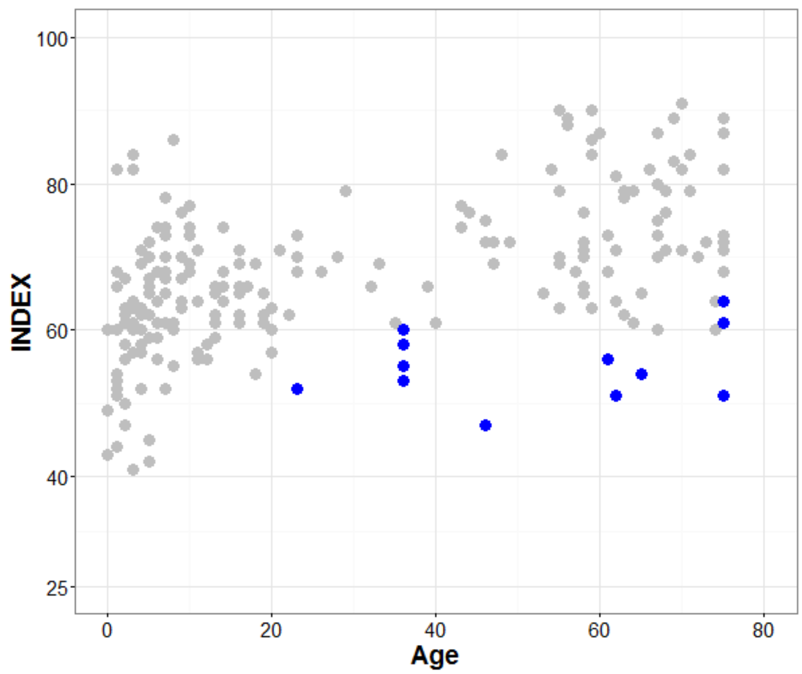

Figure 5. CRAM Index scores plotted against wetland age (years) for the HDC dataset, highlighting the eliminated 15 sites of the Other Depressions category (blue dots).

Defining the Range of Reference Condition

Reference wetlands exhibit the potential to sustain high levels of their intrinsic ecosystem services. They are typically mature sites subject to continuous evolutionary processes and not subject to major changes in water supply (either natural or anthropogenic) or other stressors. In addition, for the purposes of developing the depressional wetland HDC, the following criteria were used to select the set of reference sites used to develop that reference envelope:

- The CRAM Index score is > 82. This threshold score was determined by the following steps:
  - Subdivide the full range of possible CRAM scores (25-100) into tertiles (25-49, 50-74, and 75-100), and
  - Add 7 points to the bottom score defining the third tertile (75). The value of 7 CRAM points represents the 95% confidence interval of the CRAM Condition Index. Assuming that the tertiles represent “poor,” ”fair,” and “good” conditions, the threshold value of 82 assures that all reference sites represent “good” conditions.

- The wetland is on protected land such as wildlife refuges, national or state parks, reservations, military bases, protected watershed lands, etc.
- The wetland has not been significantly modified by unnatural causes in the last 50 years.

Based on these criteria, a reference site does not have to have high or "good" scores for each CRAM Attribute. Lower scores for one Attribute can be offset or mitigated by higher scores for another Attribute. Reference wetlands are therefore not ideal or perfect wetlands (Table 2). In aggregate, the reference sites comprise a reference envelope of patently desirable wetland conditions. The reference envelope is defined as one standard deviation above and below the average CRAM Score.

A total of 15 reference sites were identified and selected (Tables 2 and 3). They include depressions in four ecoregions (Bay/Delta, Sierra, Klamath/North Coast, San Joaquin Valley), and eight counties (Marin, San Mateo, Sacramento, Tuolumne, Humboldt, Del Norte, El Dorado, and Merced). All sites are located in State or National Parks, on refuges, preserves, protected watershed lands, or protected tribal lands. Their ages range from 54 years to the minimum age of 75 years at the time of their assessments. As noted earlier, these sites may be older than 75 years. That is their minimum age based on all available information. In other words, based on these reference sites, reference conditions can be achieved within 75 yrs. The set of reference sites represents a range in seasonality and climatic regime; both perennial and seasonal wetlands with short hydroperiods are represented. The final HDC dataset includes these 15 reference sites.

Table 2. Summary of Reference Site CRAM Scores.

	INDEX	**Landscape and Buffer**	**Hydrology**	**Physical Structure**	**Biotic Structure**
Average	85	83	97	78	84
Standard Deviation	3	11	7	10	12
Min	82	63	75	63	69
Max	90	100	100	100	100

Table 3. List of Reference Sites:

AArowID	AA name	Age	Annual Rainfall 30 Yr.Av. (in)	Perennial / Seasonal	INDEX	Buffer	Hydrology	Physical	Biotic
411	Drake's Estero Pond	54	31	Seasonal	82	85	100	75	69
2026	Ano Nuevo Pond	69	34	Perennial	83	88	92	63	89
2028	Whitehouse Canyon Pond	56	32	Perennial	89	75	100	88	94
3094	Stone Lakes Natural Wetland	59	18	Seasonal	84	81	75	88	92
1755	Hidden Lake	70	49	Perennial	82	63	100	75	92
1849	Frog Pond/ Mud Lake	71	40	Perennial	84	63	100	75	97
1894	Tioga Pass Pond 1	55	39	Perennial	90	88	100	88	86
1923	NWCA 1150	69	43	Seasonal	89	88	100	75	92
2088	Espa Lagoon Depressional	66	63	Perennial	82	75	92	63	100
2921	Turup Klamath Floodplain	67	78	Seasonal	87	93	100	75	78
3050	Sugar Pine Point State Park Pond	59	30	Seasonal	86	81	100	75	89
3056	Tioga Rd 2 Lost Pond	56	45	Perennial	88	75	100	100	75
3061	Tuolomne Meadows Oxbow Pond	60	37	Seasonal	87	100	100	75	72
3071	Cosumnes River Preserve depression	75	18	Perennial	87	93	100	75	78
3083	San Luis NWR- Oxbow Pond	75	12	Seasonal	82	93	100	75	58

Results and Discussion

The purpose of these intensive individual wetland investigations was to develop a HDC for depressional wetlands. The analyses focused on building a final HDC dataset by assigning ages to wetlands and eliminating cases that did not contribute to a reasonably precise empirical model of natural developmental processes for depressional wetlands through time. Building the necessary HDC dataset required investigating every case to understand the relative influences of natural processes and management on condition, as indicated by the CRAM Condition Index.

The resulting HDC for depressional wetlands has a variety of important characteristics (Figure 6). These characteristics are outlined below.

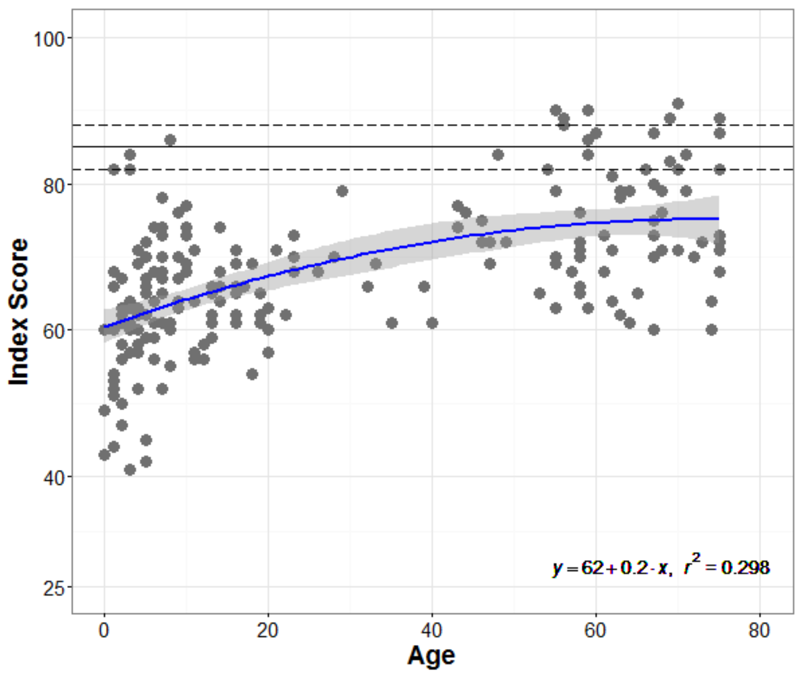

Figure 6. Depressional wetland Habitat Development Curve (HDC). The curve includes project sites, natural and naturalized sites, and sites that are created or managed to support a diverse set of habitat functions and services. The solid horizontal line is the average reference CRAM Condition Index score (85). The average is bounded by dashed lines representing +/- one standard deviation delimiting the reference envelope.

Despite being based on a large statewide dataset of carefully dated wetlands subject to strict inclusion criteria, the resulting HDC is less precise than desired. The model only explains about 30% of the substantial variability in the relationship between wetland age and condition. There are a variety of possible explanations.

- The analysis of contributing factors suggests that the depressional wetland type, as defined for CRAM, includes an especially broad range of natural conditions that are reflected by a broad range of CRAM Condition Index scores for every wetland age. The criteria used to refine the dataset prudently disregarded the broad natural range in hydroperiod for depressional wetlands throughout California. However, this natural variability in hydrology translates into a broad range in condition as assessed using CRAM.

- It is likely that the condition of natural depressional wetlands is especially sensitive to temporal climatic variability. For example, biological structural complexity could be markedly different between wet and dry years. The HDC dataset spans years of drought and deluge.
- This observed variability in condition is also due to wetland management. It can ameliorate the natural variability of individual sites but contribute additional variability across a population of sites subject to different management regimes.

Based on these three considerations, a much more precise HDC may not be possible for the very broad range of wetland conditions comprising the depressional wetland type as defined for CRAM.

- There is a paucity of data for depressional wetlands aged 30-50 years. Wetlands younger than 30 years are primarily various kinds of projects resulting from environmental policies in effect 30 years or less. This suggests that the number of wetlands aged 30-50 years will increase as the current cohort of projects age. The HDC indicates that, as these projects age, their overall condition will tend to improve.
- Based on the HDC, depressional wetland projects are likely to mature over a period of 50 to 60 years. The developmental process slows over time. The length of time to mature reflects the slow development of both physical and biological structure. The physical structure may develop slowly because of the general lack of kinetic energy in lentic versus lotic systems. However, an examination of the curves for the CRAM Condition Attributes suggests that biological structure develops more slowly than physical structure. This probably reflects the rate of plant community development through natural species recruitment. Depressional wetlands in California tend to be small and isolated from each other, due to the arid climate of most of the state. This may contribute to a slow recruitment rate. However, an analysis of maturation rate for wetlands with and without woody vegetation shows that the length of time required for a depressional wetland to mature is not affected by the type of vegetation present.
- Based on the HDC, depressional wetland projects are unlikely to achieve reference conditions. There are a variety of possible explanations.
    - The reference conditions defined for the HDC may not commonly be the target conditions of the projects.
    - Many of the projects have design objectives that are a subset of the ecological services provided by the reference sites.
    - The initial condition of projects (condition at time zero of the HDC) is highly variable, as assessed using CRAM (Figure 2). Some of the projects with the lowest CRAM scores at time zero are wetland creations. In these cases time zero represents the start of primary ecological succession. However, the cluster of projects with the highest CRAM scores just a few years older than time zero represents wetland conversions. In these cases time zero represents an advanced stage of secondary succession because wetland conditions already exist. In addition, the time zero scores also represent a range in project design and management efficacy.

If appropriate, CRAM can be used as a design template for future projects. In time this will align the project objectives with the reference envelope and increase the rate of wetland development as measured by sequential increases in CRAM Condition Index scores.

Conclusions

This effort to produce a Habitat Development Curve (HDC) for depressional wetlands supports the following conclusions.

- There is a strong, positive, curve-linear correlation between depressional wetland condition, as assessed using CRAM, and wetland age.
- The rate of natural development of depressional wetlands decreases over time, due mainly to the relatively slow maturation of the plant community.
- In general, disregarding the specific objectives, designs, and management regimes of depressional wetland projects, they are likely to require, on average, 50 to 60 years to mature.
- Enhancements and restoration projects that mostly involve secondary ecological succession tend to develop more rapidly than creations or conversion projects that involve primary succession.
- Project design, management, and the starting conditions of project sites are likely to strongly affect project developmental rates.

Recommendations

The following recommendations are provided to the Level 2 Committee of the California Wetlands Monitoring Workgroup (CWMW) for its consideration.

1. Promote CRAM as a set of design guidelines for depressional wetlands. This will improve the consistency and comparability of projects. Assuming that CRAM provides meaningful assessments of depressional wetland condition, using CRAM to guide wetland design will increase the rate of wetland development and align it with CRAM reference conditions.

2. Consider developing a CRAM sub-module for depressional wetlands that focuses on managed wetlands. Most of depressional wetlands in California are not natural and are managed for particular sets of ecosystem services. As a service to the wetland management community, one or more versions of the CRAM module for depressional wetlands should be developed that adopt the common management objectives as desired endpoints rather than the full suite of intrinsic ecosystem services. The intent of the sub-module(s) would be to assess project condition relative to the common management objectives.

3. Promote the use of the HDC for depressional wetlands as a project performance curve. Projects could aim to achieve conditions that are on or above the curve at any given time. In combination with the first recommendation above, this recommendation would help standardize performance criteria and assessments. For example, compensatory mitigation projects might be required to have CRAM scores on or above the HDC by year 5 after project construction.

4. Develop HDCs for all wetland types for which there is a CRAM module.