Validation of the California Rapid Assessment Method For Vernal Pool Systems: Final Report

Central Coast Wetlands Group at Moss Landing Marine Labs

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Executive Summary

Vernal pools are shallow ponds that fill during winter and spring, but are dry for the rest of the year. They support numerous endemic species, both plants and animals, including invertebrates such as fairy shrimp. Due to vernal pools unique ecological functions and their continued degradation and loss from urban development and agriculture, there is a need to chronicle the condition of these systems throughout California as well as document their presence and condition at regional and watershed scales. The use of rapid assessment methods to quantify condition, describe impacts, establish protection strategies, and initiate restoration efforts is well supported within California's wetland management strategies. The Wetland and Riparian Area Monitoring Plan (WRAMP) was created as a framework to inventory and monitor California wetlands. The California Rapid Assessment Method (CRAM) is part of this framework and is used to rapidly characterize the overall condition of individual wetlands and relate that condition to a larger population of systems throughout California.

The CRAM validation process for the Vernal Pool Systems is described in this report. The process ensures that the developed CRAM condition metrics correlate with more intensive assessment measures including plant and invertebrate abundance and diversity estimates. This study found that overall CRAM Index score and individual CRAM Attribute scores were significantly correlated with large branchiopod species richness as well as the plant diversity Shannon index. The Vernal Pool CRAM module can be found at www.cramwetlands.org.

With completion of this validation process, the development team is able to assure that the Vernal Pool Systems CRAM module (v6.2) provides a meaningful, repeatable, and accurate assessment of wetland condition across the state of California.

Introduction

Vernal Pools

Vernal pools are shallow ponds that fill during winter and spring in areas of California with Mediterranean climate patterns (Zedler 1987). They experience drastic shifts in inundation area, varying in size and depth seasonally and annually. These challenging conditions support high numbers of endemic plants and animals, species which exhibit specialization to the vernal pool habitat (King et al. 1996). Vernal pools have been lost or severely impacted by urban development and agricultural practices over the last century, resulting in many of the endemic flora and fauna becoming listed as endangered (Zedler 1987). Due to vernal pools unique ecological functions and their continued degradation, there is a need to chronicle the condition of these systems throughout California as well as document their presence and condition at regional and watershed scales (Jones 2009).

California Wetland Monitoring Workgroup

The California Water Quality Monitoring Council (Council) was established in 2007 under a mandate from legislation, CA Senate Bill 1070, to coordinate and integrate water quality and related ecosystem monitoring, assessment, and reporting (mywaterquality.ca.gov, 2017). The California Wetland Monitoring Workgroup (CWMW) was formed as a sub-group of the Council to build tools for wetland monitoring (CWMW 2013). The CWMW oversees the implementation of the Wetland and Riparian Area Monitoring Plan (WRAMP). The WRAMP is a coordinated monitoring and assessment strategy that is structured under the USEPA's three level framework for aquatic system assessments. The framework categorizes wetland monitoring under: Level 1, GIS mapping and inventory of aquatic resources; Level 2, field-based rapid assessments of wetland condition; and Level 3, more intensive measures of specific functions, including quantitative measures of water quality or species populations.

The California Rapid Assessment Method (CRAM) was developed to support these monitoring needs. CRAM provides an overall Index score (ranging from 25 to 100) that indicates the general health of a wetland and its capacity to perform important functions and services. The Index score is an average of four "Attributes" of condition. Each Attribute is composed of two to five metrics and submetrics (Table 1). The assessment of each metric or submetric is based on visual indicators surveyed during a field visit of less than half a day.

Table 1. CRAM Attributes and metrics with summaries of each metric

Attributes	Metrics/Submetrics	Metric Summary
Buffer and Landscape Context	Aquatic Area Abundance	Measures extent of wetlands within 500 m
	Percent with Buffer	Percent of area surrounded by at least 5 m of buffer land cover
	Buffer Width	Average of 8 buffer width measurements up to 250 m
	Buffer Condition	Vegetation quality (native vs. non-native), degree of soil disturbance, and impact of human visitation
Hydrology	Water Source	Anthropogenic influence on water sources (extractions or inputs) within local watershed up to 2 km
	Hydroperiod	Direct anthropogenic inputs or diversions
	Hydrologic Connectivity	Access to adjacent slopes without levees, road grades, or other obstructions
Physical Structure	Structural Patch Richness	Number of habitat structures present from a list of potential patch types for vernal pools
	Topographic Complexity	Complexity of micro- and macro-topographic features
Biotic Structure	Number of Co-dominant Species	Total number of living plant species that comprise at least 10% of any pool sampled
	Percent Non-native Species	The percent of the total number of co-dominant species that are not native according to Jepson 2012
	Endemic Species Richness	The total number of co-dominant species that are vernal pool endemics (listed in Appendix 1)
	Horizontal Interspersion	The complexity of plant zones (species assemblages or mono-specific stands)

CRAM Development Process

There are six steps to CRAM development, as described in Sutula et al. (2006) and outlined on the CRAM website (http://www.cramwetlands.org/about). These steps include:

1. Definition (describe the class of wetlands that the tool is built to evaluate)
2. Basic design (develop metrics and attributes that reflect unique condition characteristics of the wetland class)
3. Verification (partner with local wetland experts to test the draft method for utility, representativeness and clarity)
4. Validation (affirm that the tool generates a condition score reflective of California wetlands of that class and that correlates as expected with site specific data)
5. Module production (Complete method updates and post a CRAM Field Guide/Manual and online data upload system)
6. Ambient survey (Use the validated tool to document distributions of condition scores for California wetlands)

Previous work completed phases one through three of the CRAM development process. Vernal pool experts were convened to draft the vernal pool CRAM module and test the method in the field (i.e. verification). Until this current effort, the vernal pool CRAM module was not been validated; documenting relationships between CRAM results and independent measures of condition (level 3 data) in order to establish CRAM's defensibility as a meaningful and repeatable measure of wetland condition" (Stein et al. 2009). This project completed the validation process for the vernal pool CRAM module and established its scientific credibility for use in local, state, and federal programs.

Methods

Identify a gradient of stress

Vernal pools can be negatively impacted by adjacent land use, and landscape condition has been shown to be an effective predictor of wetland health (Roth et al. 1996, Micacchion and Gara 2008). Adjacent land cover affects wetland condition through many processes, including impacts of polluted runoff, loss of adjacent habitat area and condition, movement of invasive species, and alteration of hydrologic dynamics. Previous work demonstrates that wetlands surrounded by natural open space are more likely to support native flora, fauna, and important wetland functions (Solek et al. 2012). Conversely, when vernal pools are close to urban or agricultural land uses, they are more likely to have reduced function and species diversity. This study selected 29 sites along a gradient of development pressure, including some sites in open space preserves or parks, and others in cities and agricultural areas, to test the ability of the method to evaluate a broad range of vernal pool conditions.

Select Level 3 data

This study did not have the resources to collect new level 3 data, which would require knowledge of the individual systems and numerous years to collect species specific information. Fortunately, with gracious help from project partners, we were able to leverage previously collected Level 3 data for CRAM validation. The ideal validation dataset provides information indicative of wetland health for numerous vernal pool wetland systems, using a standardized collection method, collected concurrently with CRAM, and distributed along a condition gradient throughout the state. Such a robust data set was not available. Rather, due to limited time and resources, the development team used vegetation and invertebrate data made available by regional experts that used similar but varied protocols. Using the compiled data, we were able to extract abundance and diversity data necessary to create standard metrics for vegetation and invertebrate populations.

Identify metrics from Level 3 data

Standard Level 3 metrics were calculated using the data available. Although the collection protocols and level of effort varied, vegetation and/or invertebrate data were collected at most sites. The metrics generated from available data were:

- Invertebrate species richness
- Large branchiopod species richness
- Plant species richness

- Vernal pool endemic plant species richness
- Relative percent native plant cover
- Relative percent non-native plant cover
- Shannon index for plant species
- Shannon evenness for plant species

Where invertebrate data were available, methods and data varied, ranging from comprehensive counts of all species to presence/absence data for specific large branchiopods. Vernal pools can support special status branchiopods such as long horn fairy shrimp (*Branchinecta longiantenna),* and these threatened and endangered species are often the focus of vernal pool surveys. Many of the datasets were provided as a list of large branchiopods present rather than comprehensive macroinvertebrate counts. Some sites had complete samples of all invertebrates, and for those the total species richness of all invertebrates was tallied.

Vernal pools support many threatened and endangered plants, such as Contra Costa goldfields (*Lasthenia conjugens).* The relevé method is commonly used for plant surveys (Sawyer and Keeler-Wolf 1995). Many of the sites had intensive, but varying methods of plant surveys that enabled the calculation of several plant metrics. Metrics included total plant species richness, that is a tally of the number of all plant species present at a site, and the number of endemic species found at each site.

Raw data were not available at all sites. For some sites percent native cover data were available. For this analysis, species specific cover values were calculated relative to the total plant cover, excluding bare ground and litter. Relative percent cover of native and non-native plants were both calculated.

The Shannon Index was calculated to characterize the diversity of plant species. It combines the overall number of plant species and the number of individuals of each species (or in the case of vegetation data, the cover of each individual species) (Spellerberg and Fedor 2003). The Shannon Index is calculated by defining the cover class midpoint or absolute cover value for each plant species and dividing that value by the total cover to calculate the statistic designated "pi". The natural log (ln) of pi was calculated and then multiplied by pi. The sum of the products was calculated, and the absolute value of that summation is the Shannon Index, designated "H".

Shannon Evenness was calculated by dividing H by the natural log of species richness for the site. Low values of Shannon Evenness indicate that one or a few species dominate the vegetation community, while high values indicate that the cover of vegetation is more evenly split between species (Morris et al. 2014).

Conceptual models

The expected relationship between CRAM Index and Attribute scores and Level 3 data were predicted a priori for each Level 3 indicator (Table 2). As with other wetland classes, we associate high species richness of both flora and fauna with good wetland condition. Four metrics that reference species richness of various phyla were developed. Higher percent native plant cover is considered an indicator of better condition, and thus, expected to show a positive correlation with CRAM Index scores. Conversely, higher non-native cover is associated with disturbance and degraded conditions and expected to correlate negatively with CRAM Index scores. The Shannon diversity metrics generate higher values for sites with greater ecological diversity and should demonstrate a positive correlation with CRAM Index scores.

Table 2. Expected relationships between CRAM Index and Attribute scores and Level 3 data

	CRAM Index Score	Buffer and Landscape	Hydrology	Physical	Biotic
Invertebrate Species Richness	+	+	+	+	+
Branchiopod Species Richness	+	+	+	+	+
Plant Species Richness	+	+	+	+	+
Vernal Pool Endemic Plant Species Richness	+	+	+	+	+
Relative Percent Native Plant Cover	+	+	+	+	+
Relative Percent Non-native Plant Cover	-	-	-	-	-
Shannon Plant Index	+	+	+	+	+
Shannon Plant Evenness	+	+	+	+	+

Field site selection

Field sites were selected from California's population of vernal pools where species specific data (Level 3) were available. Sites were selected that had a range of ecological and adjacent land use condition,, and represented a broad geographic coverage across the state. Vernal pools are only found in areas with particular climatic and geologic conditions. Areas of California with abundant vernal pools include the Central Valley, the San Francisco Bay Area, inland regions of the Central Coast, Southern California from San Diego north to the Riverside area, and the Modoc plateau. We were able to identify sites throughout these areas, other than the Modoc region, for inclusion in our study. Project partners graciously aided site selection, gaining access to the properties, and providing Level 3 data. John Vollmar of Vollmar Natural Lands Consulting provided information on sites in the Central Valley and Bay Area. Larry Stromberg, wetlands consultant, provided information on sites in the North Bay Area and Santa

Rosa Plain. Jason Bachiero of the Center for Environmental Management of Military Lands and his colleagues at Fort Hunter Liggett in the Department of the Army allowed us to conduct CRAM assessments on vernal pools on the base. Ivette Laredo with the US Fish and Wildlife Service at Don Edwards National Wildlife Refuge coordinated access to the Warm Springs vernal pools near Fremont, CA. Lindsay Teunis of ICF International arranged access to Southern California vernal pools, including some on private lands and on Camp Pendleton (US Marine Corps) and the Marine Corps Air Station Miramar. A total of 29 vernal pool areas were sampled for the project (Figure 1).

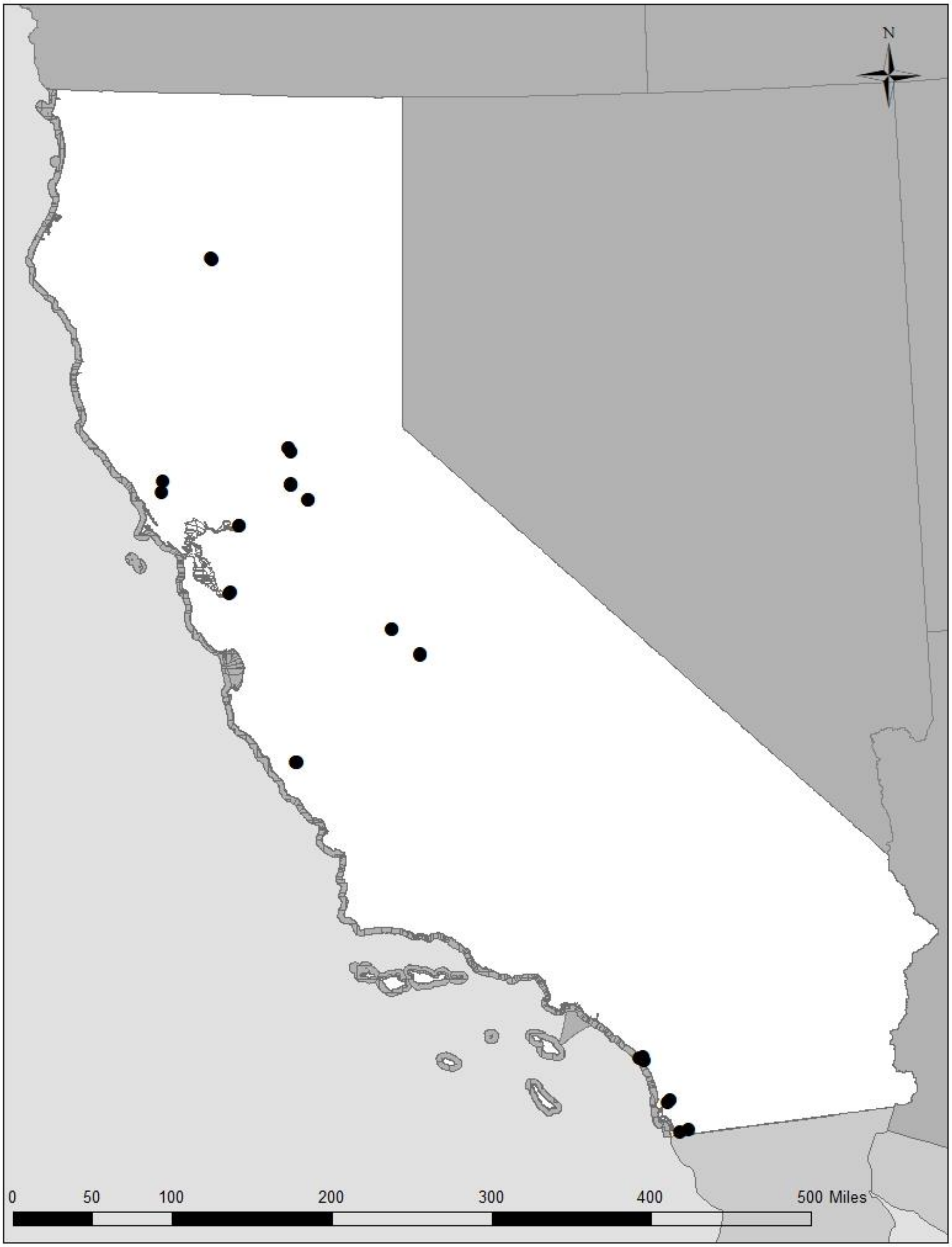


Figure 1. Map of vernal pool validation sites (N=29)

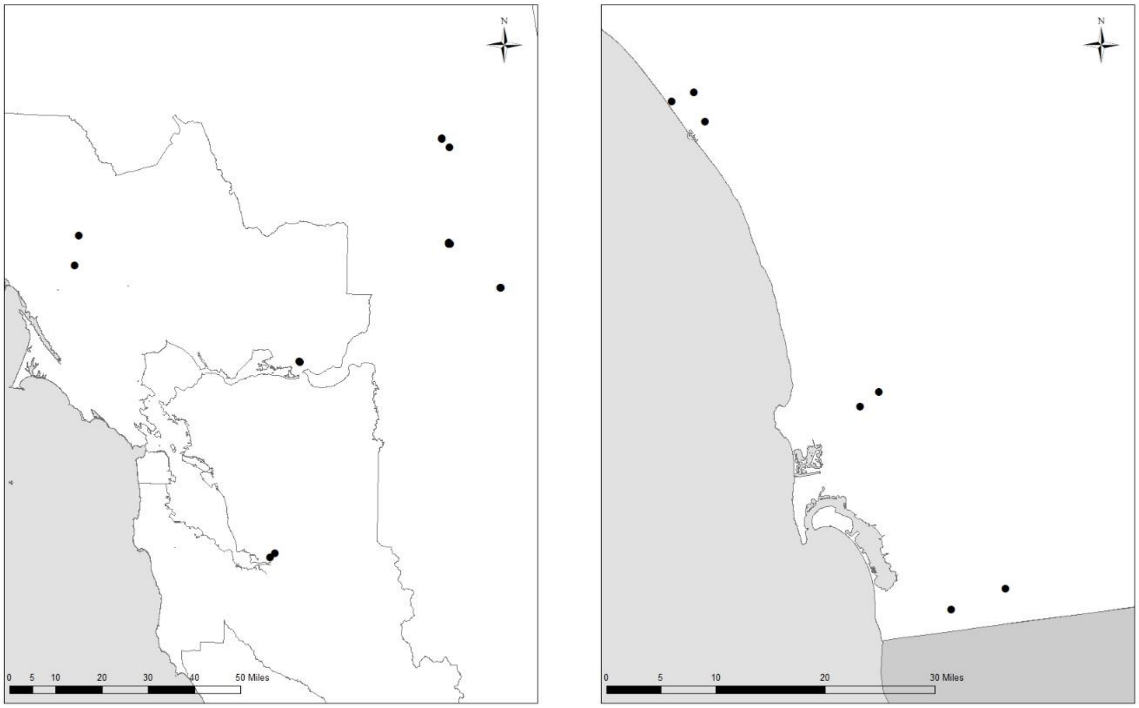


Figure 2. Detailed maps of vernal pool validation sites in the San Francisco Bay Area and San Diego

Field assessments

Field assessments were conducted using the CRAM Vernal Pool Systems module (version 6.1) at 29 sites during spring 2016. All assessments followed the quality assurance procedures outlined in the CRAM QA Plan (CWMW 2016) and the QAPP for this project (CCWG 2014).

Compile Level 3 data

Site specific Level 3 data for vernal pools selected for this validation effort were graciously shared by local colleagues. John Vollmar provided data for all of the Central Valley sites and some of the Bay Area sites. The regional contacts who arranged access to the remaining sites also provided Level 3 data for those sites. The collection methods varied among wetland scientists and research efforts around the state. Comparable data were compiled into one master list and standardized when possible.

For sites with invertebrate data, the total number of species was tallied to calculate a species richness metric. The number of large branchiopods, such as fairy shrimp and clam shrimp, was extracted for each site where those data were available. Of the 29 study sites, data documenting multiple classes of invertebrates were available at 19 sites, and data on large branchipods populations were available for another 12.

Vegetation data were available for 20 sites. Raw data on vegetation species cover, available at 18 of those sites, were used to calculate the Shannon diversity and evenness indices. The remaining two sites did not include specific vegetation species data.

Analyze correlations between CRAM and Level 3 data

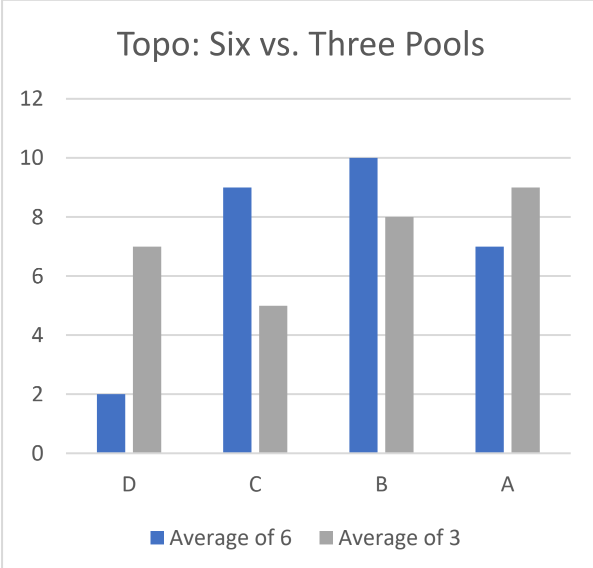
Each CRAM attribute was tested for normality using the Shapiro-Wilk test, and transformed if necessary to conform to a normal distribution. The Buffer and Landscape Context and Hydrology Attributes data were skewed. Normalization calculations were attempted (square root and log transformations) but did not result in normal distributions, so the non-transformed data were analyzed. The invertebrate species richness metric was skewed and was successfully log transformed. The CRAM Index score and all four Attribute scores were tested for correlation with all Level 3 metrics. The Pearson correlation test was used for the CRAM Index score and the Physical and Biotic Structure Attributes, and the Kendall's tau b test was used to test the Buffer and Landscape Context and Hydrology Attributes for correlation with all Level 3 metrics. Kendall's tau b correlation is a non-parametric statistical test for correlation of ranked data that produces more accurate p-values with smaller sample sizes than Spearman's ranked correlation.

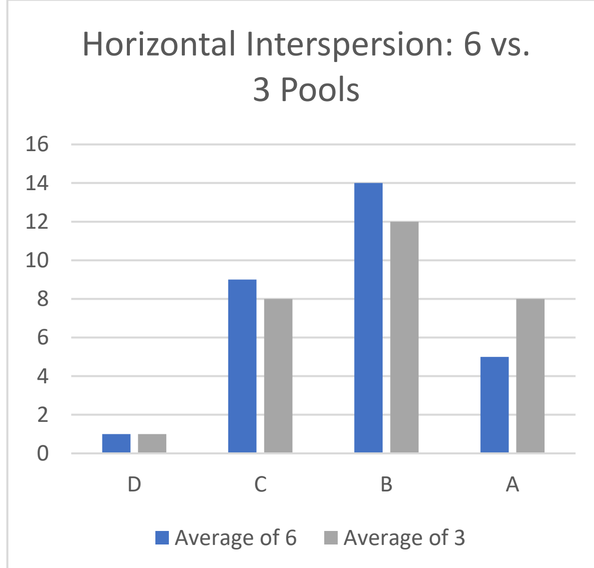
Results

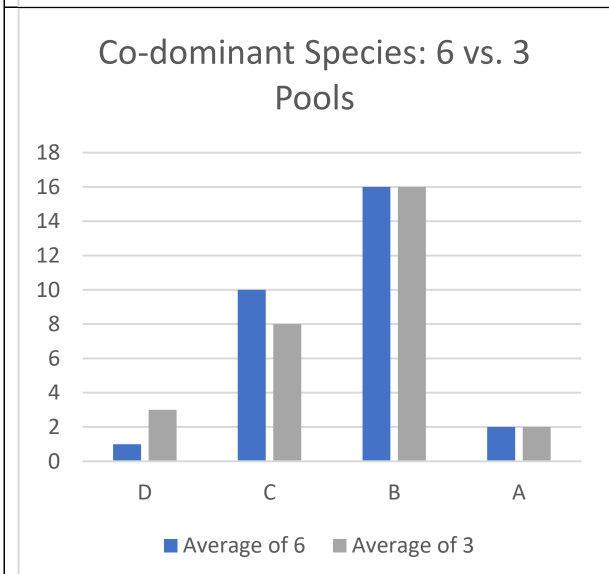
Module Revisions

The vernal pool CRAM field book released in 2013 (version 6.1) was drafted based on knowledge input of vernal pool specialists and structured to replicate the basic framework of other CRAM modules. Practitioners began to use the module before validation was complete, and users of the draft method noted several problems with the functionality of some metrics. Based on this feedback, several revisions were proposed and tested during field visits and through desktop analyses.

The new version (CRAM Vernal Pool Systems Field Book Version 6.2) compiled recommended changes including the reduction in the number of replicate pools sampled for each assessment area (AA). Previously (version 6.1), up to six individual pools within a larger vernal pool matrix were sampled individually to generate Topographic Complexity, Plant Community, and Horizontal Interspersion scores. The individual scores from each pool were combined to generate an overall metric score for the AA. This was an exhaustive process that took significant time to complete and resulted in redundant information. The CRAM development team proposed to reduce the replication to three pools. The implications of this method alteration were tested, comparing the CRAM metric and Attribute score results derived from three pools and six pools at all sites visited for this project (Figure 3).







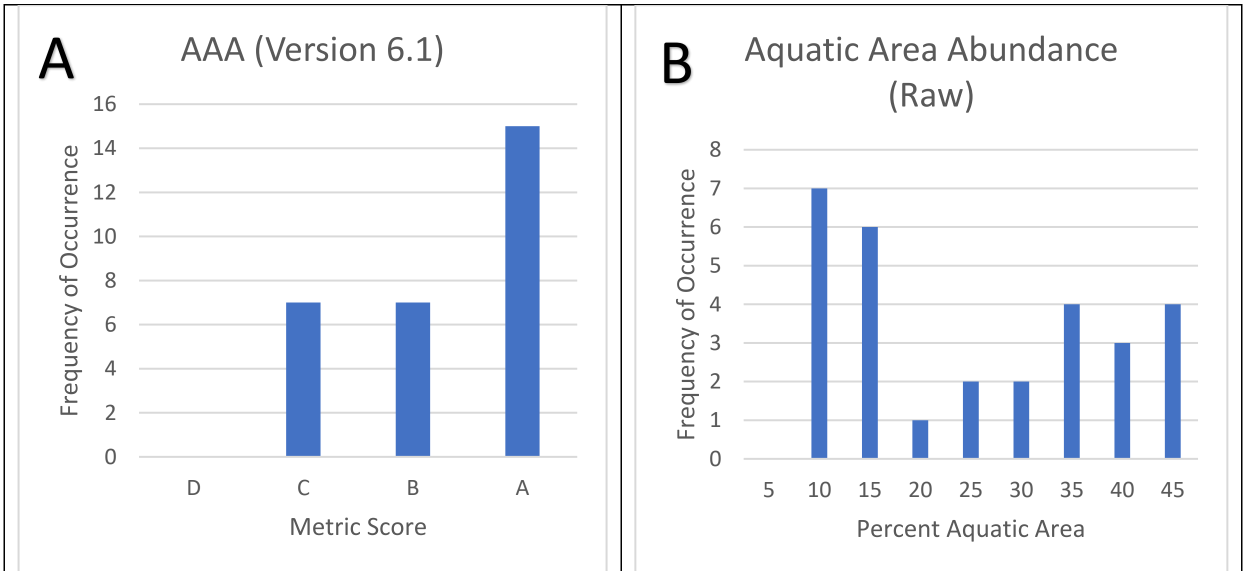
	Topo	Horizontal Interspersion	Co-dominants
t-stat	0.79	-0.64	0.36
p-val	0.43	0.52	0.72

Figure 3. Comparison of metric results for six pools versus 3 pools

Most other method changes focused on adjusting scoring bins to ensure a more even distribution of condition scores. Although the sites sampled for this project were not probabilistically sampled, as in an ambient survey, the sites were selected to represent a broad range of vernal pool condition. Because the validation effort needed site specific Level 3 data for each site, many vernal pools within the sample set were located in preserves or other open space areas and likely over represent higher condition systems. This factor was considered when adjusting scoring bins.

Aquatic Area Abundance

The Aquatic Area Abundance metric in v6.1 field book was found to generate skewed results (Figure 4A). The CRAM development team used field data and GIS/Google Earth interpretation to estimate percent aquatic area to improve metric scoring bin distribution (Figure 4B). Based on the distribution of raw data for Aquatic Area, new scoring bins for the metric were proposed (Figure 4C), resulting in a more even distribution of scores (Figure 4D), as represented by the raw data.



C

Rating	Old Bins	New Bins
A	21-100%	31-100%
B	11-20%	21-30%
C	6-10%	11-20%
D	0-5%	0-10%

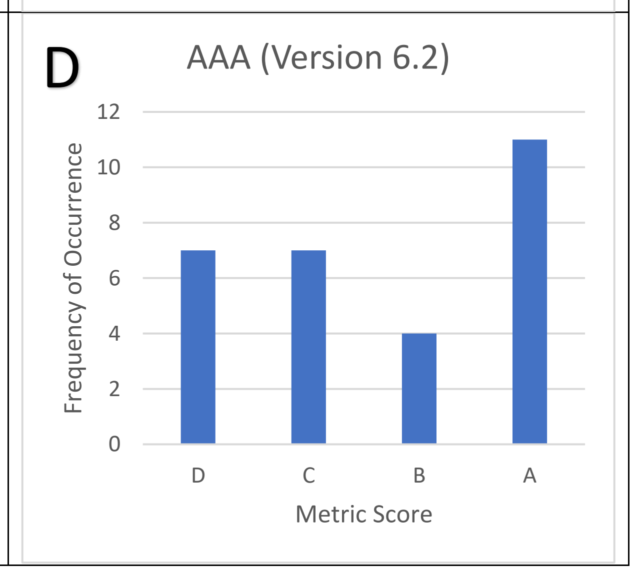
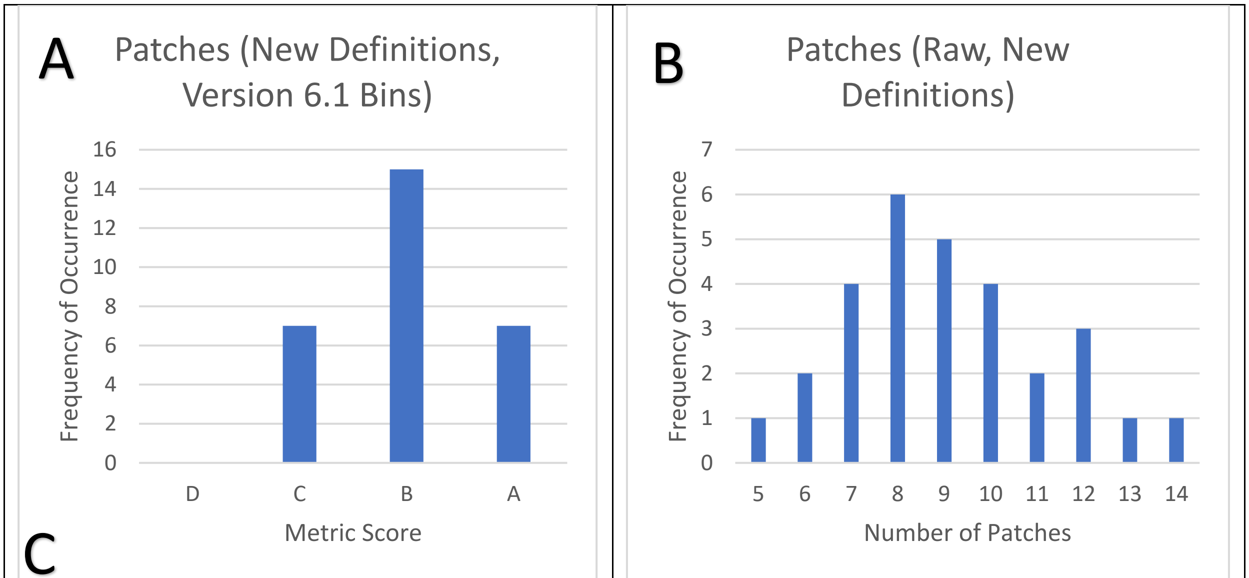


Figure 4. A) Score distribution for Aquatic Area Abundance under version 6.1 B) Aquatic Area Abundance raw data C) Scoring bins for Aquatic Area Abundance D) Score distribution for Aquatic Area Abundance under version 6.2

Structural Patch Richness

The Structural Patch Richness metric narrative was improved and additional clarification was included for the patch type definitions. Revised definitions helped users better distinguish among patch alternatives which resulted in fewer patches being miss scored (compared with version 6.1), often reducing the metric score (appropriately) for that site. Even after patch types were combined and clarified, no assessment area received a D score for patch types, and most received a score of B (Figure 5A). To rectify the imbalance in scoring for patch types, we calculated the number of patches for each site (Figure 5B) to establish more appropriate bins. The new scoring bins (Figure 5C) resulted in a more even distribution of metric scores among the sites sampled (Figure 5D).



C

Rating	Old Bins	New Bins
A	≥ 11	≥ 12
B	8-10	9-11
C	5-7	7-8
D	≤ 4	≤ 6

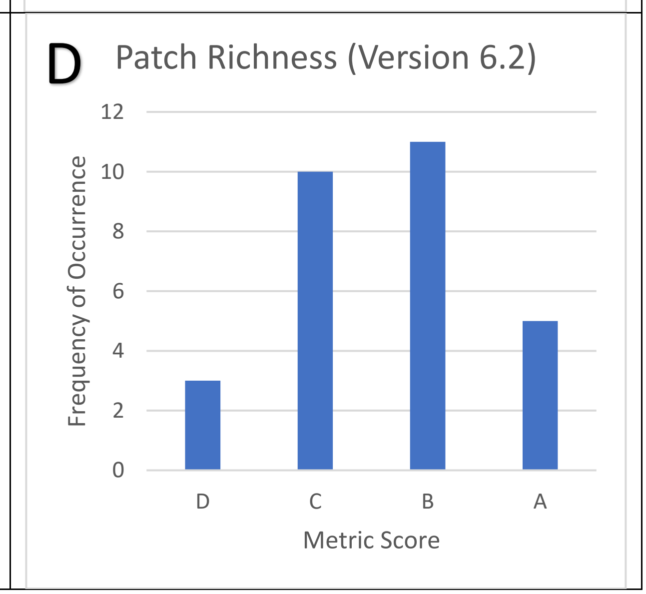


Figure 5. A) Score distribution for Structural Patch Richness under version 6.1 B) Structural Patch Richness raw data C) Scoring bins for Structural Patch Richness D) Score distribution for Structural Patch Richness under version 6.2

Pool and Swale Density

The Pool and Swale Density metric measures the distribution of aquatic feature within the AA. While testing the previous version of the method, practitioners noted that measuring the pools and swales along north and south axes often fails to capture the full arrangement of features in the AA. For example, if the AA is oriented northeast to southwest, the transects in the cardinal directions will be short compared to the overall AA length, and may not capture the presence of pools in the system. Therefore, the method was altered so that the first transect is drawn along the long axis of the overall orientation, and the second transect is oriented perpendicular to the first (Figure 6).

In Version 6.1 the percentage of pools and swales along each of the four transects originating at the center was measured separately and then averaged for the overall pool and swale density, which resulted in unequal weighting of the shorter transects. To correct for this bias, the total length of all pools and swales along the transects was divided by the total length of both transects, so that no particular segment is weighted more heavily.

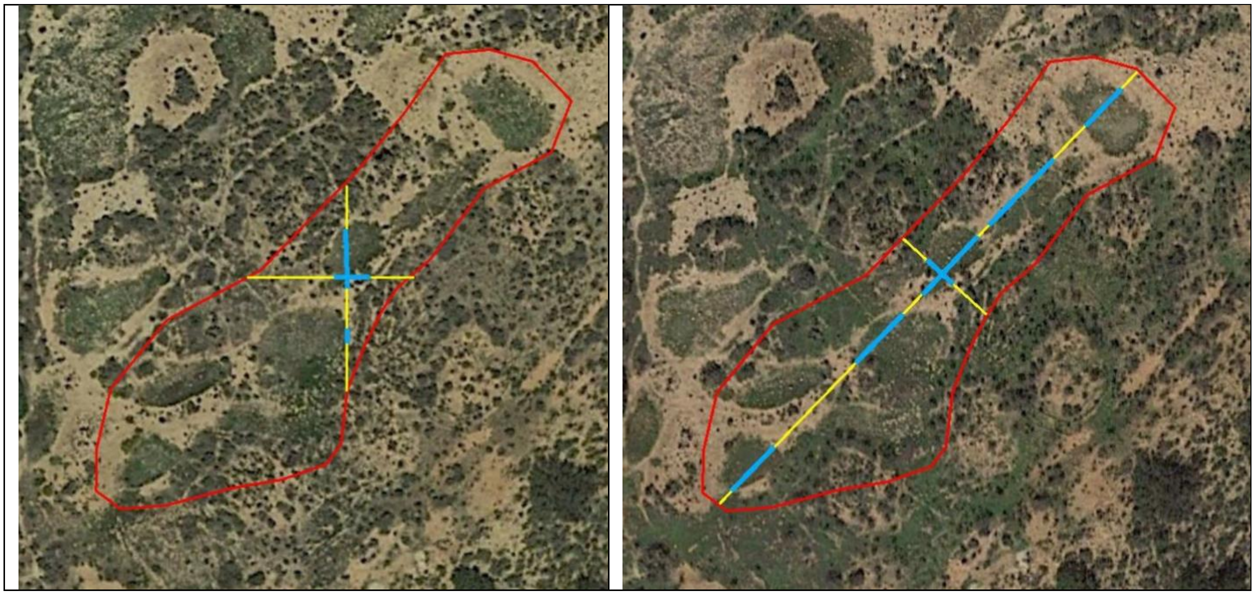
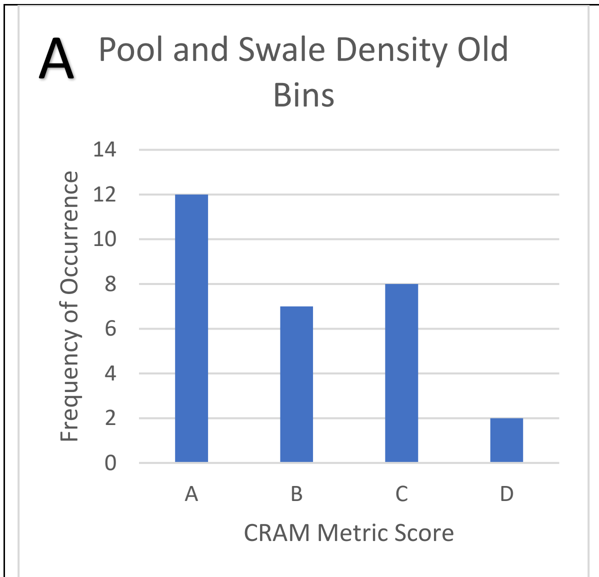
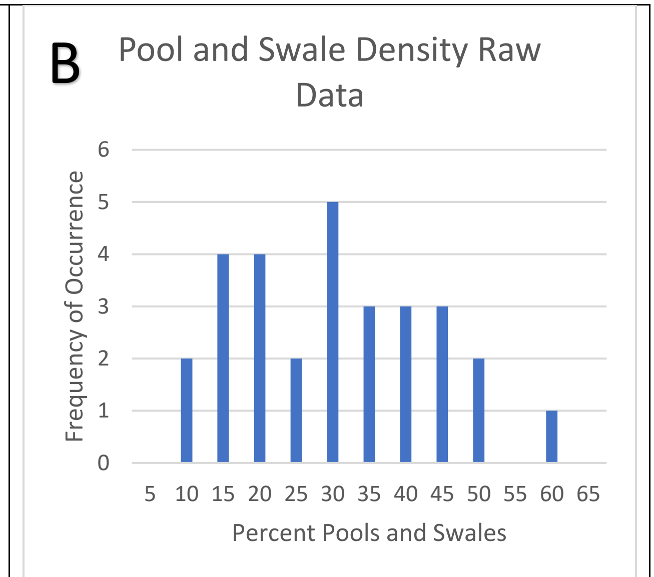


Figure 6. Transects for Pool and Swale Density as measured in v6.1 (left) and in the version 6.2 (right)

The revised method (v6.2) altered the method for measuring pool and swale density to reflect the dominant shape of the assessment area. The distribution of pool/swale density data (Figure 7) were scored using bins from Version 6.1 (Figure 10), and found to be skewed toward the upper quartiles, with many sites scoring A's and very few D's. The bins were adjusted to better represent the full range of condition (Figure 7).





C

Rating	Old Bins	New Bins
A	31-100%	36-100%
B	21-30%	26-35%
C	11-20%	16-25%
D	0-10%	0-15%

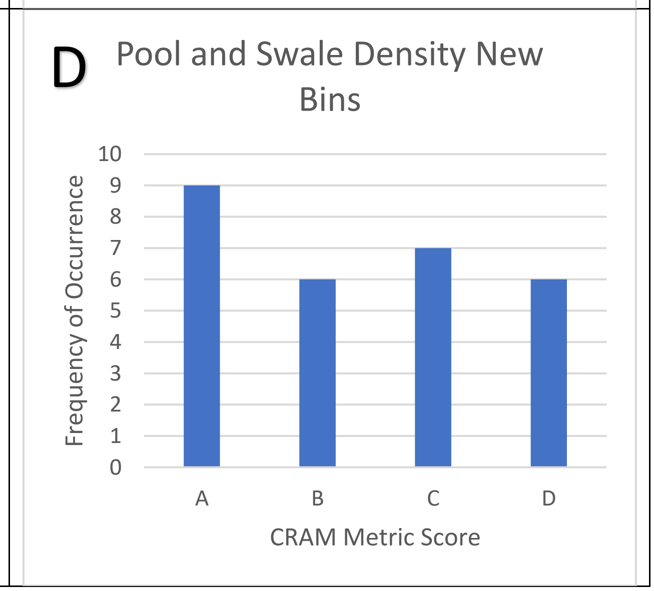
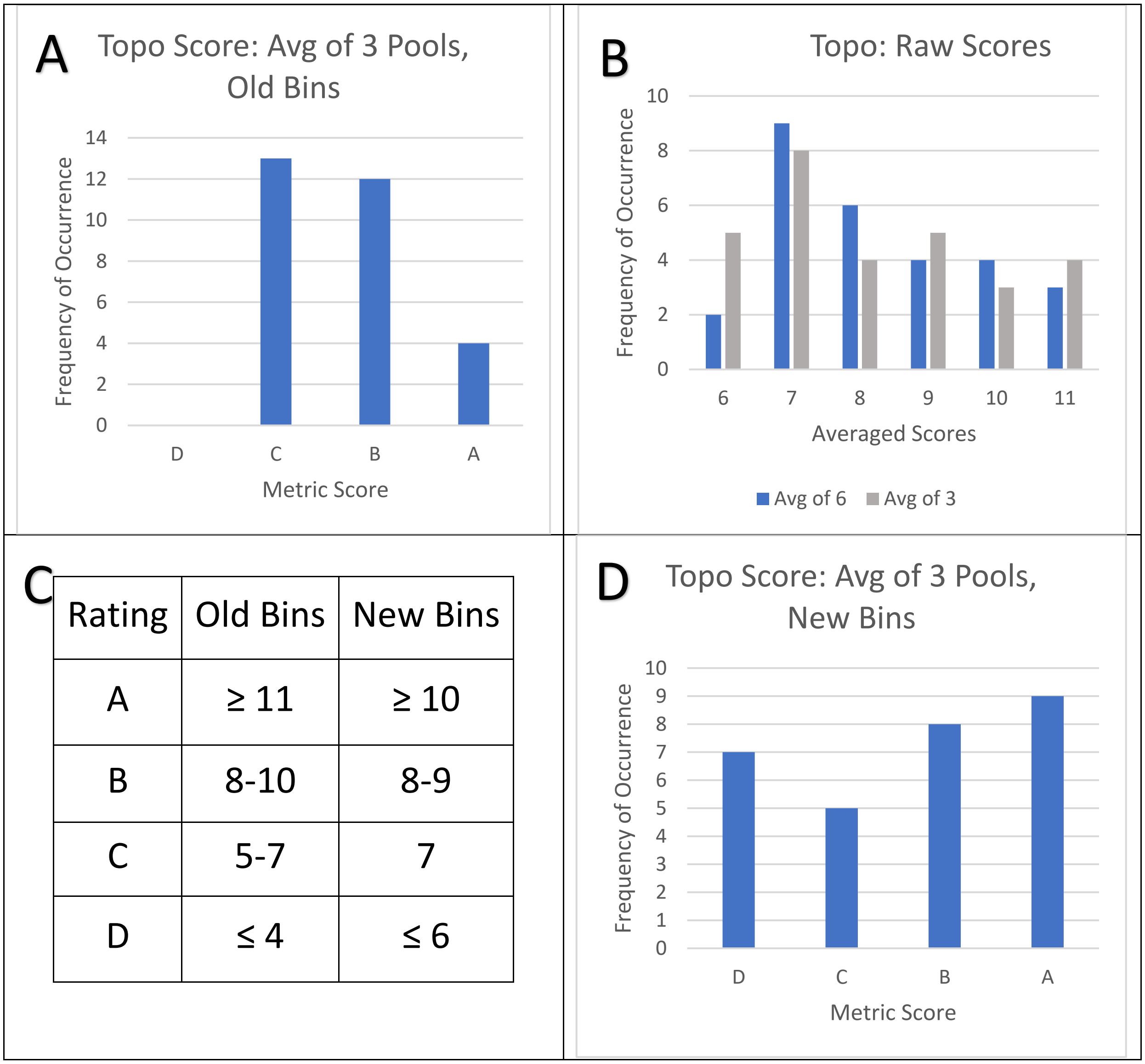


Figure 7. A) Score distribution for Pool and Swale Density under version 6.1 B) Pool and Swale Density raw data C) Scoring bins for Pool and Swale Density D) Score distribution for Pool and Swale Density under version 6.2

Several metrics are scored by compiling information from multiple pools within the AA. A challenge with scoring metrics that have multiple replicate evaluations is that averaging of replicate scores leads to a convergence of values. As a result, most sites received intermediate scores of B or C for these metrics even when lower or higher scores were noted within individual pools. Averaging 3 pools, rather than the previous 6 pools, reduced but did not eliminate the effects of averaging scores. Therefore the bins were adjusted for these metrics to reflect the true range of the averaged raw scores.

Topographic Complexity

The original Topographic Complexity method required 6 pools to be scored separately and the results averaged to determine the overall metric score for the AA. Based on recommendations from the Vernal Pool technical team, we compared metric scores from averaging multiple scores for six pools and for three pools. The metric scores were not significantly different between methods according to a two-sample t-test, where t(9) = -0.13, P = 0.89 (Figure 8B).



Rating	Old Bins	New Bins
A	≥ 11	≥ 10
B	8-10	8-9
C	5-7	7
D	≤ 4	≤ 6

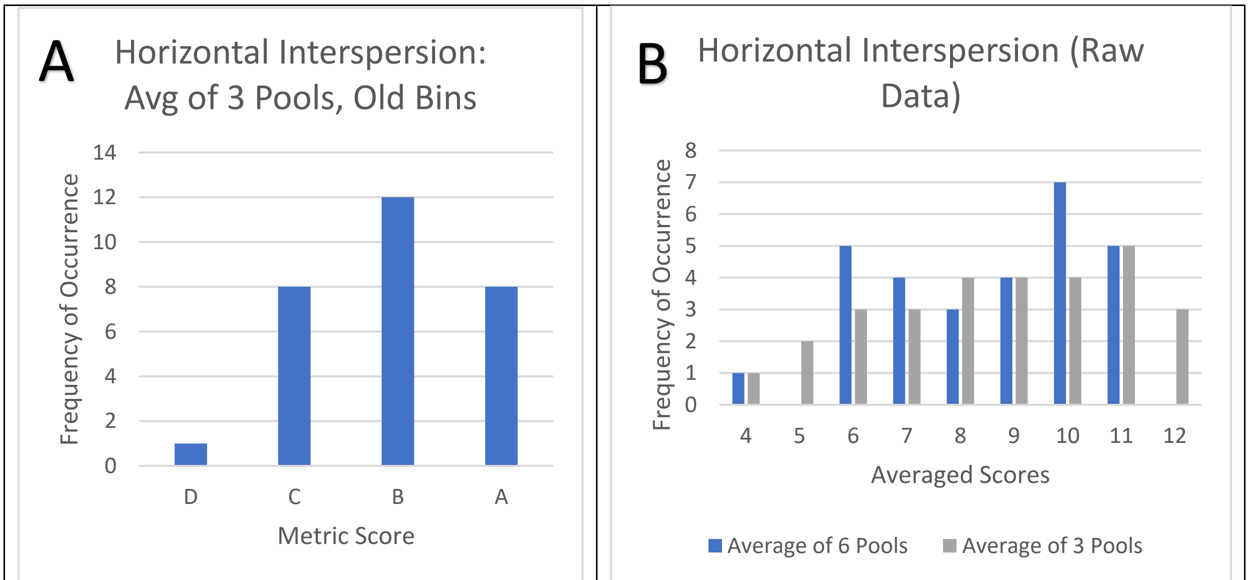
Figure 8. A) Score distribution for Topographic Complexity under version 6.1 B) Topographic Complexity raw data C) Scoring bins for Topographic Complexity D) Score distribution for Topographic Complexity under version 6.2

The CRAM development team decided that to enhance and streamline the assessment method, the revised method would include sampling of three pools within each AA. To provide a better representation of condition range among AAs, the Topographic Complexity quartile bins were modified to better represent the range of condition. Previously, the Version 6.1 bins compressed the distribution of scores to over represent intermediate scores of B's and C's

(Figure 8A). The scoring bins were revised (Figure 8C) to reflect the range of calculated averages (Figure 8D).

Horizontal Interspersion and Zonation

The Horizontal Interspersion and Zonation metric scoring process for v6.1 similarly averaged several individual pools to determine the metric score. To evaluate redundancy, metric sores were calculated using average scores from six and three pools (Figure 9B) and found not to be significantly different (two-sample t-test, where $t(54) = -0.5$, $P = 0.62$). The Horizontal Interspersion scoring (average of three pools) bins were revised to improve the distribution of scores (Figure 9).



C

Rating	Old Bins	New Bins
A	≥ 11	≥ 11
B	8-10	9-10
C	5-7	7-8
D	≤ 4	≤ 6

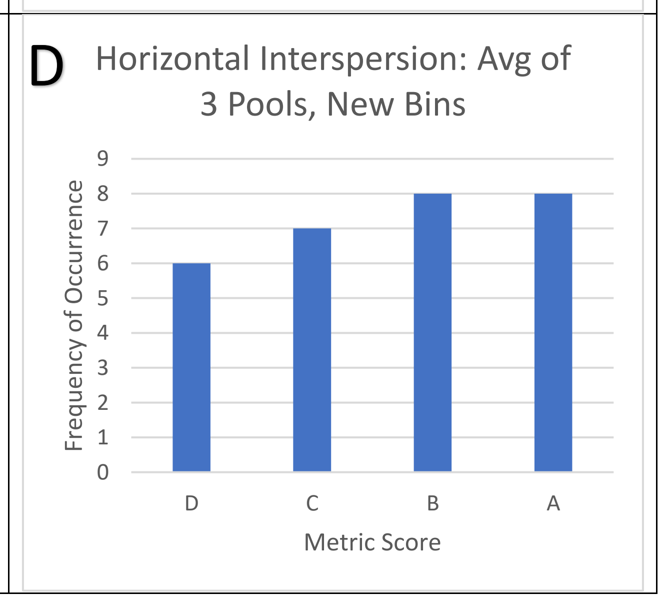
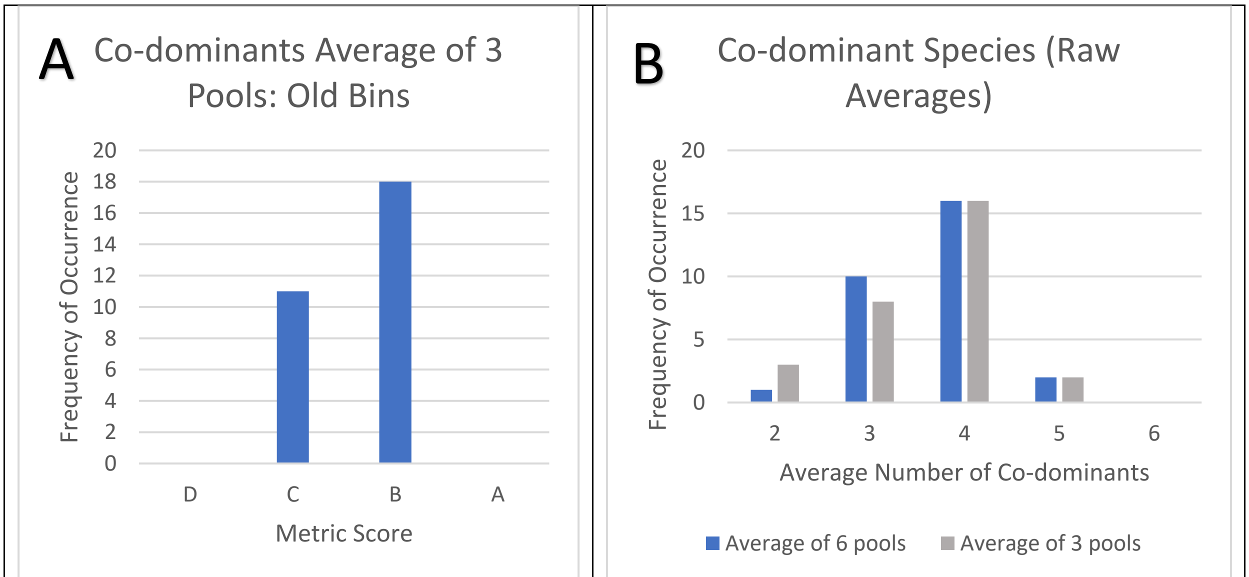


Figure 9. A) Score distribution for Horizontal Interspersion under version 6.1 B) Horizontal Interspersion raw data C) Scoring bins for Horizontal Interspersion D) Score distribution for Horizontal Interspersion under version 6.2

Plant Community Submetric A: Number of Co-dominant Species

The Plant Community Submetric A: Number of Co-dominant Species is calculated by averaging the total number of co-dominant plant species in each replicate pool. Similar to previous metrics, the averaging of values from 6 individual pools led to a convergence of scores towards a central value, and version 6.1 resulted in only B's and C's (Figure 10A) for this metric. No significant difference was found when the co-dominant submetric was calculated using three or six individual pools. New scoring bins were designated to improve the range of scores calculated from species counts within three pools (Figure 10C and D).



C

Rating	Old Bins	New Bins
A	≥ 6	≥ 5
B	4-5	4
C	2-3	3
D	1	≤2

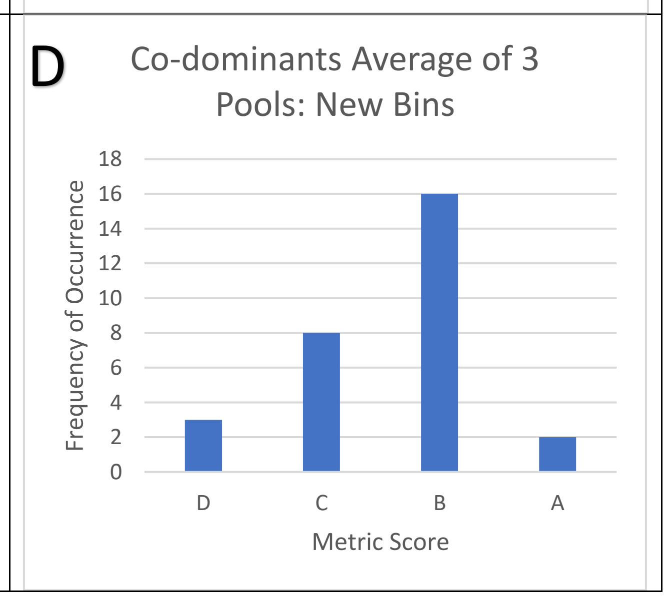
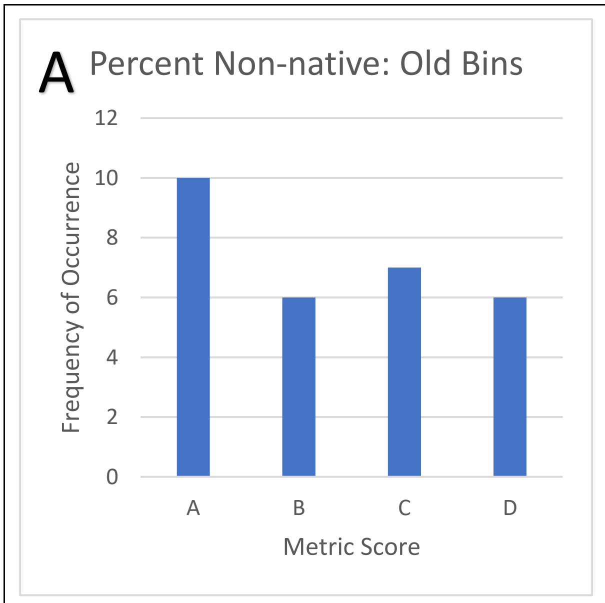
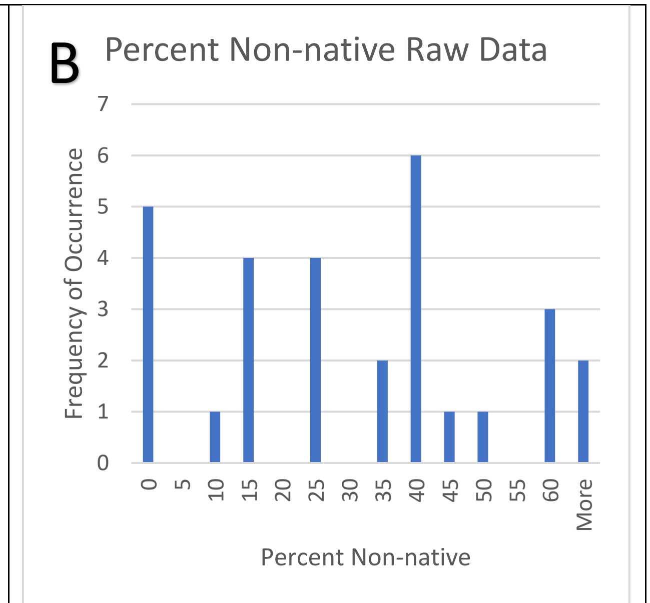


Figure 10. A) Score distribution for Number of Co-dominant Species under version 6.1 B) Number of Co-dominant Species raw data C) Scoring bins for Number of Co-dominant Species D) Score distribution for Number of Co-dominant Species under version 6.2

Plant Community Submetric B: Percent Non-native

The percent of co-dominant plant species that are non-native (Figure 11B) are tallied to generate Percent Non-native submetric scores. The distribution of scores using version 6.1 was somewhat skewed toward the A category (Figure 11A). Version 6.1 (Figure 11C) allowed up to 20% non-native species in the A range. However, other calibrated CRAM modules restrict the A category to less than 15% invasive species. The CRAM development team determined that the scoring bins from other CRAM modules were more appropriate. Re-scoring of bins maintained a large number of high condition “A” scores, but the adjusted bins (Figure 11C) resulted in a more even distribution of scores (Figure 11D). This adjustment achieved a primary goal of the calibration exercise; to effectively differentiate between sites of different condition.





C

Rating	Old Bins	New Bins
A	0-20%	0-15%
B	21-33%	16-30%
C	34-49%	31-45%
D	≤50%	46-100%

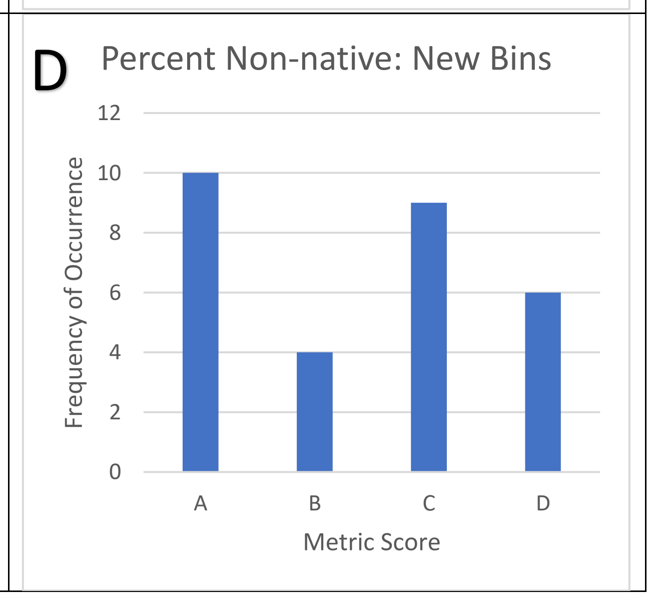
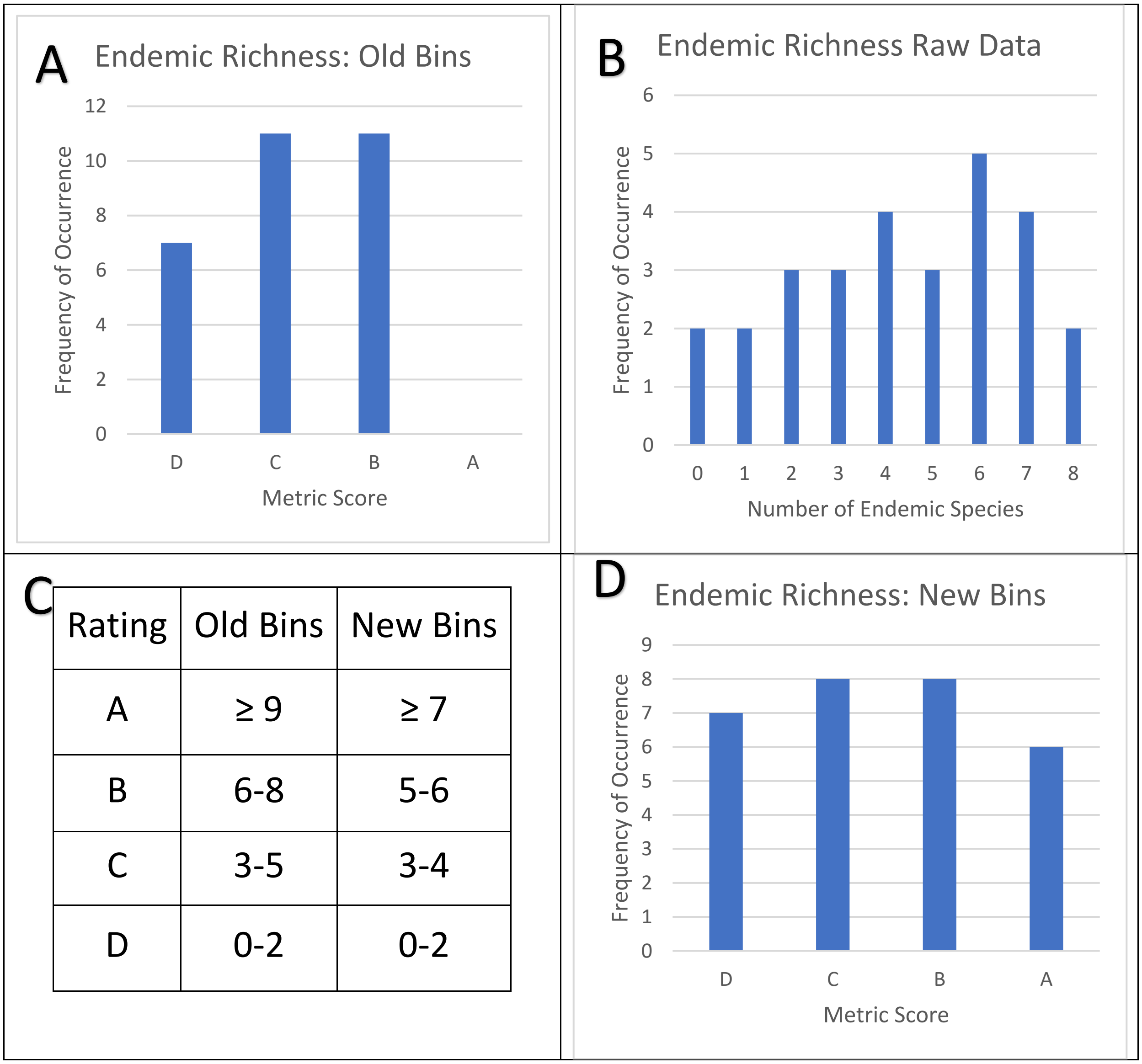


Figure 11. A) Score distribution for Percent Non-native under version 6.1 B) Percent Non-native raw data C) Scoring bins for Percent Non-native D) Score distribution for Percent Non-native under version 6.2

Plant Community Submetric C: Endemic Species Richness

The Endemic Species Richness submetric tallies the total number of vernal pool endemic species that are noted as co-dominant species in any of the three replicate pools. Practitioners have noted that previous versions of the endemic species list (Appendix 1), did not include some species that are specific (and considered endemic) to vernal pools in southern California. To address this concern, during CRAM tool validation, the field team made note of any plants that were not included on the endemic list but were characteristic of Southern California vernal pools and likely good candidates to be added to the list. We also consulted with vernal pool experts in the region to identify any other plants that should be added to the list. Through this process we identified two additional plants that warranted inclusion in the list: *Eryngium pendletonense* (Pendleton button-celery) and *Marsilea vestita* (hairy waterclover). A similar revision process occurred during the initial CRAM vernal pool module development that led to the addition of plants to the endemic list that are considered vernal pool indicators, which limited the need to include additional unique southern California plants.

The scoring bins for this metric were found to skew CRAM scores. The previous version of the method required a minimum of 9 endemic species to be scored as an A. Given that each co-dominant species must comprise at least ten percent of one pool, it is very unlikely that any particular AA would have more than 9 endemic co-dominant species. None of the sites within the validation dataset included more than 8 endemic co-dominant species (Figure 12). Bins were adjusted to improve the distribution of CRAM metric scores (Figure 12).



Rating	Old Bins	New Bins
A	≥ 9	≥ 7
B	6-8	5-6
C	3-5	3-4
D	0-2	0-2

Figure 12. A) Score distribution for Endemic Species Richness under version 6.1 B) Endemic Species Richness raw data C) Scoring bins for Endemic Species Richness D) Score distribution for Endemic Species Richness under version 6.2

Validation Results

An effective rapid assessment method must be responsive to a range of conditions and be sensitive to human disturbance (Sutula et al. 2006, Stein et al. 2009). The CRAM Index score is a composite of the four Attribute scores and is intended to represent the overall ecological condition of the wetland. The CRAM tool generates a minimum value of 25 and a maximum value of 100. The CRAM Index scores collected for this project ranged from 55 to 92, with a median score of 75 (Figure 13).

We determined that the resulting CRAM Index scores for the 29 validation sites were not biased towards high or low values (skewness = -0.02). The broad range of Index scores calculated from a population of vernal pools reflected the site selection process which actively sought a range of condition, documenting the responsiveness of the Vernal Pool CRAM module.

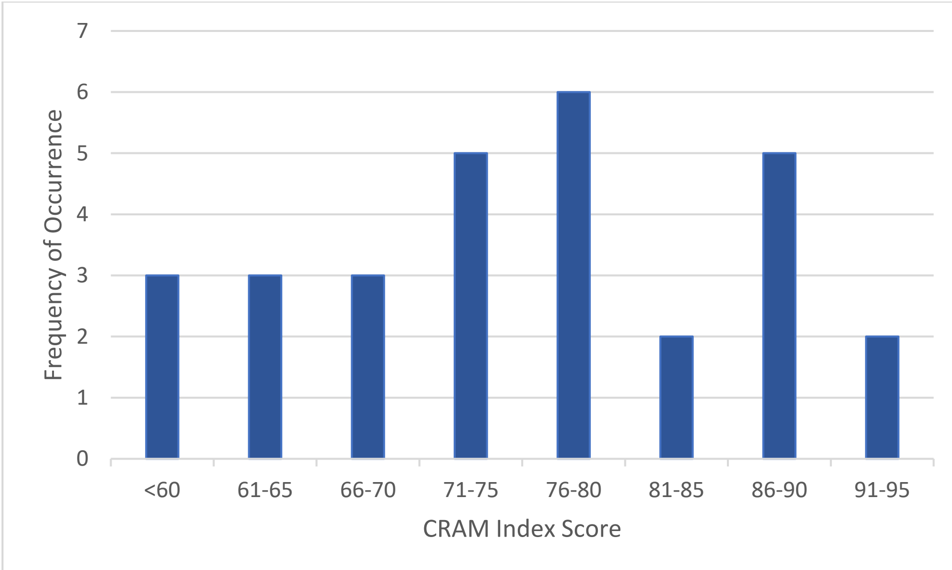


Figure 13. Histogram of CRAM Index scores (n = 29)

A broad range of scores were measured for each CRAM Attribute (Buffer and Landscape Context 45-93, Physical Structure 33-100, and Biotic Structure 25-96), except the Hydrology Attribute (67-100) (Figure 14). Both the Buffer and Landscape Context and Hydrology Attributes scores were skewed towards higher scores for this CRAM module. Due to the constraints for site selection within this Validation exercise (limited to sites with available Level 3 data), we were unable to select sites with a complete range of Hydrology scores. Both the Buffer and Landscape Context and Hydrology Attributes tend to be skewed towards higher scores for most CRAM modules, because they are only reduced in score when there is a direct impact in the immediately adjacent area. Hydrology Attribute scores may also be skewed positively due to development that converted one wetland class to another, for example where urban runoff extended the hydroperiod of a vernal pool and converted it to a depressional wetland. Specifically, many California vernal pools with severely altered hydrology are no longer classified as vernal pools and therefore are removed from the sample population. In other cases, landscape alterations such as deep tilling or water diversion have altered vernal pool landscapes so that they are no longer wetlands at all. Through conversations among team experts, we determined that each Attribute (including the Hydrology Attribute) is responsive to varying conditions and scores represent the range of condition for these wetlands.

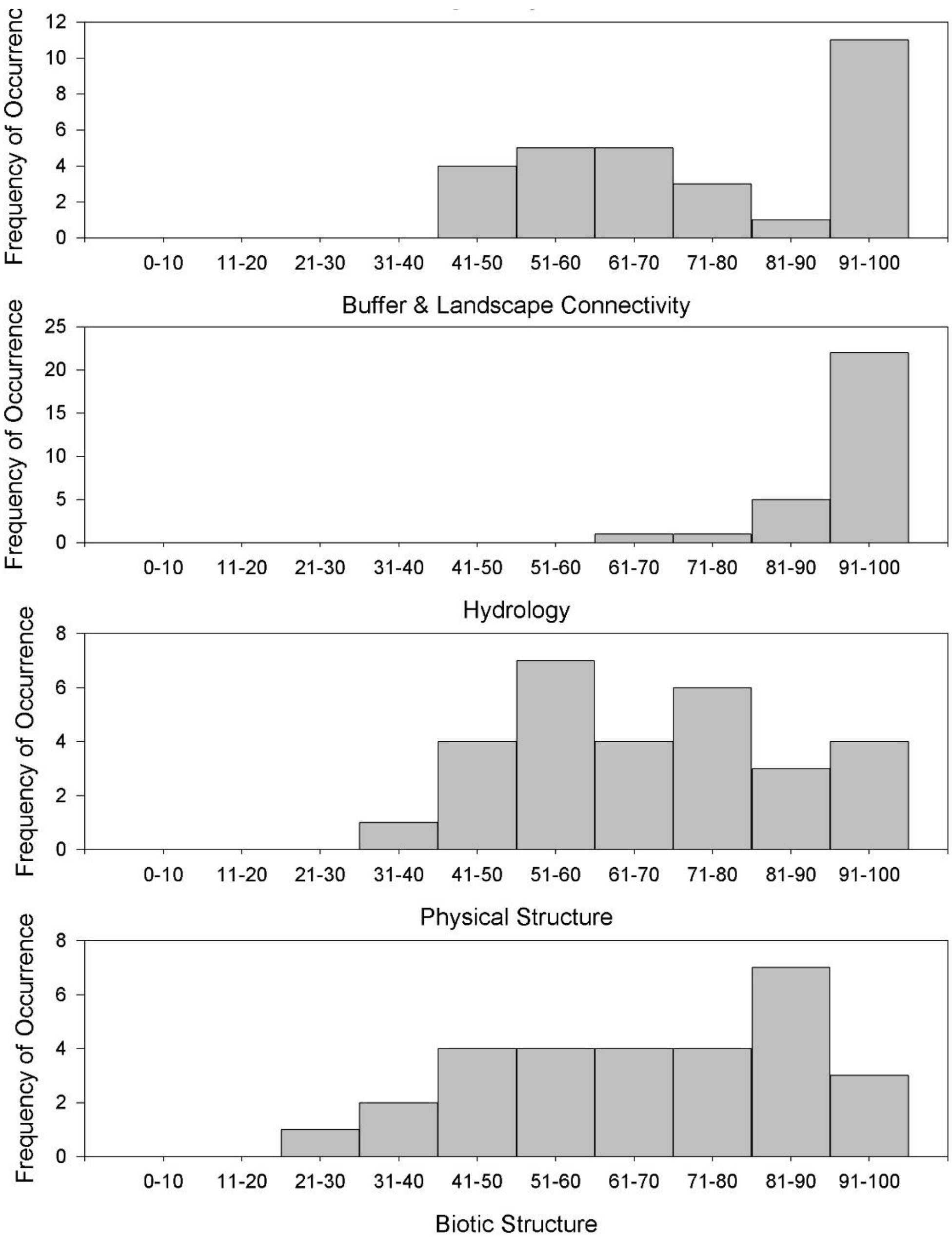


Figure 14. Histograms showing the distribution of data for each CRAM Attribute

The overall CRAM Index score and each Attribute score were tested for significant correlations with Level 3 data, including invertebrate and plant metrics (see Table 2 for expected relationships). Tables 3 and 4 list the results of all analyses with p-values with significant correlations shown in bold font ($\alpha \leq 0.05$). The CRAM Index score was significantly correlated with large branchiopod species richness and the Shannon evenness index for plants. Physical and Biotic Structure were both significantly correlated with large branchiopod species richness and the Shannon diversity index for plant species, while Biotic Structure was also correlated with Shannon evenness index for plants. Buffer and Landscape Context was correlated with large branchiopod species richness. The Hydrology Attribute was negatively correlated with plant species richness (counter to expected results), likely the result of site selection challenges which limited the distribution of Hydrology Attribute scores and compromised statistical correlation analysis with other Level 3 data sets. The individual Attributes were significantly correlated with Level 3 indicators, specifically large branchiopod species richness (Figure 14).

Table 3. Pearson Correlation coefficients

	Log trans Invert Sp Rich	Large Branchiopods	Plant Sp Richness	VP Endemic Species Richness	% Native Cover	% Non-native Cover	Shannon Diversity Index	Shannon Evenness Index
CRAM Index	0.34	**0.77**	0.16	0.23	0.34	-0.24	0.33	**0.52**
p-value	0.16	**<0.0001**	0.44	0.27	0.14	0.30	0.18	**0.03**
n	19	21	26	26	20	20	18	18
Physical Attribute	0.22	**0.57**	0.11	0.09	0.08	-0.14	**0.55**	0.30
p-value	0.36	**0.01**	0.60	0.64	0.73	0.55	**0.02**	0.22
n	19	21	26	26	20	20	18	18
Biotic Attribute	0.33	**0.52**	0.26	0.30	0.41	-0.24	**0.55**	**0.68**
p-value	0.16	**0.02**	0.20	0.13	*0.07*	0.31	**0.02**	**0.001**
n	19	21	26	26	20	20	18	18

Table 4. Kendall's Tau b correlations

	log transformed Invert Sp. Richness	Large Branchio pods	Plant Species Richness	VP Endemic Species Richness	Native % Cover	Non-native % Cover	Shannon Diversity Index	Shannon Evenness Index
Buffer and Landscape Attribute	0.28	**0.64**	0.14	0.20	0.10	-0.05	-0.26	0.02
p-value	0.13	**0.0003**	0.36	0.19	0.55	0.75	0.17	0.90
n	19	21	26	26	20	20	18	18
Hydrology Attribute	-0.11	0.02	**-0.33**	-0.19	0.06	-0.03	-0.21	-0.12
p-value	0.57	0.92	**0.04**	0.22	0.75	0.86	0.27	0.54
n	19	21	26	26	20	20	18	18

CRAM Index Correlations

The distribution of CRAM Index scores correlated with both large branchiopod species richness and Shannon evenness for endemic plant species (Figure 15). These correlations support the intent of CRAM validation to generate an assessment tool that is responsive to variation in different ecological functions and trophic level communities.

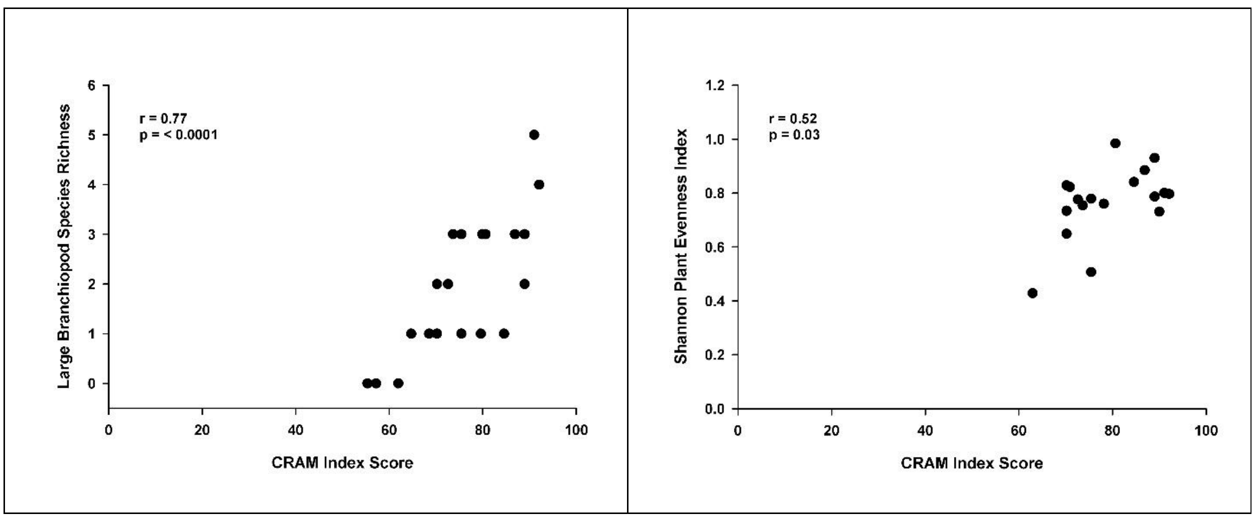


Figure 15. Correlation plots of CRAM Index Score vs. large branchiopods and Shannon evenness

CRAM Attribute Correlations

The individual CRAM Attributes were also correlated with several of the Level 3 indicators, including large branchiopod species richness, plant species richness, and the Shannon diversity index for plants (Figure 16).

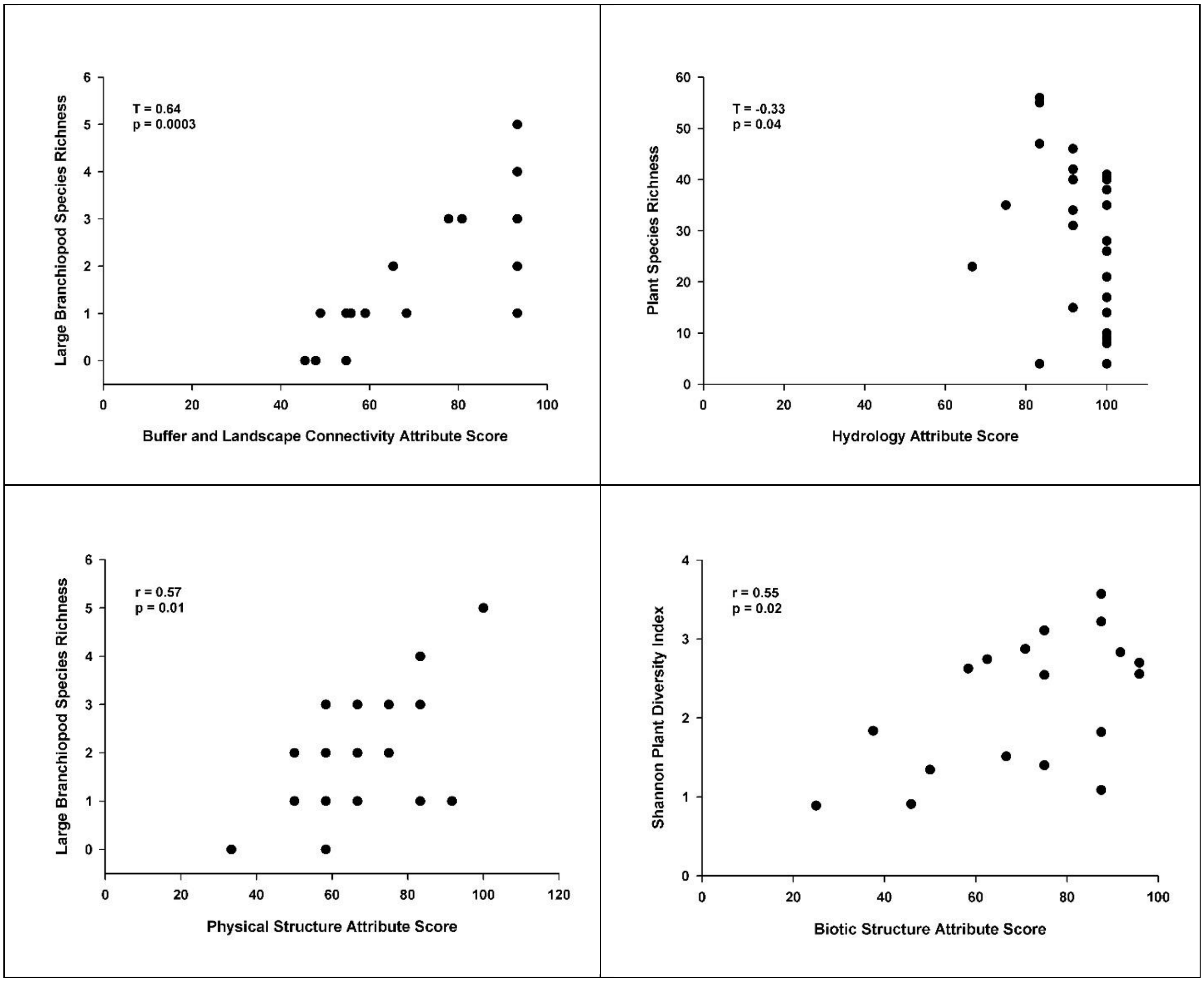


Figure 16. Correlation plots of CRAM Attributes and selected Level 3 indicators

Full condition range of each metric

The CRAM validation process seeks to establish metric condition descriptions that represent a full range of wetland condition within California. One test for condition representativeness of metrics is to determine if wetlands within the sample frame (representing a range of condition based on local best professional judgement) have a range of metric conditions, leading to one or more wetlands within each bin of each metric.

For the vernal pool module, this objective was not fully achieved (Table 5). Poor scores (D's) for Buffer and Landscape and Hydrologic metrics were not found within the validation exercise (n=29). CRAM development team members discussed the absence of low condition scores and determined that low scores for these metrics are possible (although less likely because of wetland type change considerations) but were not found within this sample set because of limitations in site selection to sites where other data have been collected.

Table 5. List of metric scores found within validation sites (N=29)

Aquatic Area Abundance	% AA with Buffer	Average Buffer Width	Buffer Condition	Water Source	Hydroperiod	Hydrologic Connectivity
A	A	A	A	A	A	A
B	B	B	B	B	B	B
C	C	C	C	C	C	
D						
Structural Patch Richness	Pool and Swale Density	Topographic Complexity	Interspersion and Zonation	Number of Codominants	Percent Non-native	Endemic Species Richness
A	A	A	A	A	A	A
B	B	B	B	B	B	B
C	C	C	C	C	C	C
D	D	D	D	D	D	D

Discussion

The goal of this project was to validate the CRAM module for vernal pool wetlands in California. To ensure that the CRAM method meets established CRAM development guidelines (Stein et al. 2009), the CRAM Validation team set out to confirm that a CRAM module for vernal pool systems could generate scores which appropriately represent a full range of wetland conditions found within the state. The tool should also be repeatable and correlate with other trophic or function specific indicators of condition.

The site selection process ensured that sampled wetlands represented a broad range of climatic and ecological condition found in California. Because vernal pools are clustered geographically in certain parts of the state, the selected sites were concentrated in those areas. Selected sites spanned a range of latitude from San Diego (32.5 degrees North) to the northern Sacramento valley (40.5 degrees North). Selected vernal pools ranged east to west in longitude from -116.9 degrees in San Diego to -122.8 degrees in Santa Rosa (Figure 1). Selected sites exhibited a range of condition and adjacent landscape disturbance, with some sites located in open space preserves and other sites within urban areas and higher intensity rural land uses (off-road vehicle use, etc.). By partnering with wetland scientists throughout the state with extensive experience in California vernal pools, we have developed a tool that can be used successfully by California wetland practitioners.

Our analysis found that CRAM Index scores were significantly correlated with large branchiopod species richness and the Shannon evenness index for plant cover. Buffer and Landscape

Context, Physical Structure, and Biotic Structure attributes correlated with large branchiopod species richness. In addition, the Physical and Biotic Structure attributes correlated with the Shannon diversity index for plants, and the Biotic Structure attribute correlated with the Shannon evenness index for plants. Hydrology was negatively correlated with the Shannon evenness index, likely because the selected sites did not include a full range of hydrologic condition, leading to a reduction in the expected range of scores.

Higher diversity of plants and animals is associated with better condition wetlands (Lopez and Fennessy 2002). Large branchiopod diversity strongly correlated with the CRAM Index score and three of the CRAM Attributes. This was an expected relationship, specifically because CRAM was designed to responds to environmental factors that promote or inhibit populations of these special status invertebrates. The Shannon diversity and evenness indices correlated with the CRAM Index score and two of the CRAM Attributes, Physical and Biotic Structure. CRAM is sensitive to impacts on plant communities and assigns higher scores to sites that have intact plant ecology.

The negative correlation between the Hydrology Attribute and the plant species richness indicator is likely an artifact of the skewed nature of hydrology condition of selected sites. Of the 26 sites analyzed for correlation between Hydrology and plant species richness, over half of the sites received scores of 100 for Hydrology and only two sites had scores less than 80. Two sites with the highest plant species diversity had moderate Hydrology scores of 83, which likely drove unrepresentative negative correlations (Figure 14 upper right).

CRAM validation aims to document predicted correlations with multiple L3 metrics that represent a range of ecological functions and services. However, we did not expect high correlation coefficient values. CRAM is meant to measure multiple potential wetland functions rather than a single function; the intent of L3 data collection. This study verified that CRAM scores correlate as predicted with indicators of plant and invertebrate diversity.

Conclusions

This validation exercise was presented to the Level 2/Rapid Assessment Committee of the CWMW in July, 2017, and their advice contributed to further analyses and narrative improvements. The Level 2/Rapid Assessment Committee approved the validation of the Vernal Pool CRAM module at the October, 2017 meeting.

The CRAM Vernal Pool Systems Field Book Version 6.2 is considered validated and meets the goals defined by the Level 2 Committee. Our analysis shows that there is a significant correlation between CRAM Index and Attribute scores and Level 3 intensive measures of condition and function. Therefore, we conclude that the Vernal Pool CRAM module provides a meaningful, repeatable, and accurate assessment of wetland condition across the state of California.

All CRAM materials can be found on the CRAM website: www.cramwetlands.org

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