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

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Executive Summary

Vernal pools are shallow ponds that fill up during winter and spring, but are dry for the rest of the year. They support high levels of endemic species, both plants and animals, mainly invertebrates such as fairy shrimp. Due to their special status and continued development pressure in vernal pool habitats, there is a need to assess their condition at watershed and local scales in order to assess impacts, establish protection strategies, and initiate restoration efforts. The Wetland and Riparian Area Monitoring Plan (WRAMP) was created as a framework for monitoring and assessment to achieve this. The California Rapid Assessment Method (CRAM) is part of this framework and is used to rapidly characterize the overall health of wetlands.

The CRAM development process includes prescribed steps to completion, including validation by confirming correlations with more intensive assessment measures. The CRAM validation process for the Vernal Pool Systems CRAM wetland module is described in this report.

The intensive measures of condition used to validate the vernal pool module included detailed plant and invertebrate surveys. The 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 Systems CRAM module 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 up during winter and spring in areas of California with Mediterranean climate patterns (Zedler 1987). They experience drastic shifts in hydroperiod, with inundation during some wet seasons and dry conditions for most of the year. Due to these challenging conditions, there are high levels of endemism in vernal pools, where both plants and animals exhibit specialization for the habitat (King et al. 1996). Vernal pools have been lost or severely impacted by land use changes including urban development and agriculture over the last century, resulting in many of the endemic flora and fauna being listed as endangered (Zedler 1987). Due to their special status and continued development pressure in vernal pool habitats, there is a need to assess their condition at watershed and local scales (Jones 2009).

WRAMP

The California Water Quality Monitoring Council (Council) was convened 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 established 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 assessment. 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, such as water quality or species sampling.

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 main "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	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 phase
2. Basic design phase
3. Verification phase
4. Validation phase
5. Module production phase
6. Ambient survey phase

Previous work accomplished phases one through three. Vernal pool experts were convened to design the vernal pool CRAM module and test it in the field for verification. However, vernal pool CRAM has not been fully validated by examining correlations between CRAM and level 3 data. This project completed the validation phase of vernal pool CRAM development. Validation has been defined as “the process of documenting relationships between CRAM results and independent measures of condition in order to establish CRAM’s defensibility as a meaningful and repeatable measure of wetland condition” (Stein et al. 2009). Validation of the vernal pool module will establish its scientific credibility and further its use in local, state, and federal programs.

Methods

Identify the gradient of stress

Vernal pools can be impacted by surrounding land use, and landscape conditions can be an effective predictor of wetland health (Roth et al. 1996, Micacchion and Gara 2008). Adjacent and upstream land cover affects wetlands through many processes, including polluted runoff, habitat loss, and alteration of hydrologic dynamics. When wetlands are surrounded by natural open space they are much more likely to support flora, fauna, and important wetland functions. Conversely, when they are close to developed areas such as urban or agricultural land covers, they are more likely to have reduced function and diversity. This study selected a range of sites along a gradient of development pressure, including some sites in open space preserves or parks, and others in cities and agricultural areas.

Select Level 3 data

This study relied on partners to provide previously collected Level 3 data. We did not have the resources to collect new data, as vernal pool surveys require specialized knowledge and often have a very short time frame for collection. Fortunately, due to vernal pools' unique nature and prevalent special status species, they are often studied in depth. With gracious help from several project partners we were able to leverage previously collected data. The ideal validation dataset is graduated along a condition gradient, covers the entire state, has standardized collection methods, is collected concurrently with CRAM, and indicates the health of the wetland. Vegetation and invertebrate measurements were identified as the optimal dataset. The data available did not necessarily fulfill all of the optimal criteria, but there were tradeoffs between the cost of collection and the availability of data. There are some standard protocols for vernal pool sampling of vegetation and invertebrates, but the specific methods used varied quite a bit across sites. However, we were able to extract standard metrics from the data we obtained.

Identify metrics from Level 3 data

Standard Level 3 metrics were extracted from the data available. Although the collection protocols and level of effort varied widely, most sites had a minimum dataset for vegetation and/or invertebrates. The metrics selected 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 was available, the level of sampling varied, 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 types of species are often the focus of vernal pool surveys. It was more common to receive data with a list of large branchiopods than with comprehensive macroinvertebrate counts. Some sites did have complete samples of all invertebrates, and for those the total species richness of all invertebrates was tallied.

Vernal pools also have many threatened and endangered plants, such as Contra Costa goldfields (*Lasthenia conjugens).* Due to the presence of special status species, many vernal pools are monitored for vegetation. The relevé method is commonly used for plant surveys (Sawyer and Keeler-Wolf 1995). Many of the sites had intensive plant surveys that enabled the calculation of several plant metrics, although the level of detail varied considerably. Several metrics were calculated from the vegetation data available. The first is simply the total plant species richness, a tally of the number of all plant species present at a site. Some plant species are specifically adapted to vernal pools and designated as vernal pool endemic species, so the number of endemics at each site with species lists was tallied. Some sites did not have raw data but had metrics such as percent native cover. For this analysis the 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 is a measure of the diversity of species that combines the overall number of 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 taking the cover class midpoint or absolute cover value for each plant species and dividing 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 (easycalculation.com 2017). 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. Generally, high species richness of both flora and fauna indicates good condition. Therefore, the first four metrics that address species richness of various types were expected to correlate positively with CRAM Index scores. Higher percent native plant cover is also considered an indicator of better condition, so it was expected to show a positive correlation with CRAM Index scores. Conversely, higher non-native cover is associated with disturbance and degraded conditions, so it was expected to correlate negatively with CRAM Index scores. The last two Shannon metrics have higher values with better ecological function, so they should have a positive correlation with CRAM Index scores.

Identify field sites

Field site selection was constrained to sites that had previously collected data available. The goal was to identify sites that had a range of ecological condition and surrounding disturbance, while also achieving broad geographic coverage across the state. Vernal pools are not ubiquitous in the landscape, but are only found in areas with particular climatic and geologic conditions, so these regions were targeted. The primary areas of California that have vernal pools are the Central Valley, the 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 spread throughout these areas, although there weren't any available in the Modoc region. Project partners graciously provided help with identifying sites, gaining access, and providing data. John Vollmar of Vollmar Natural Lands Consulting provided sites in the Central Valley and Bay Area. Larry Stromberg, wetlands consultant, connected the project with sites in the North Bay Area in the 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 on vernal pools at 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 as well as Camp Pendleton (US Marine Corps) and the Marine Corps Air Station Miramar. A total of 29 CRAM assessment areas were sampled for the project (Figure 1).

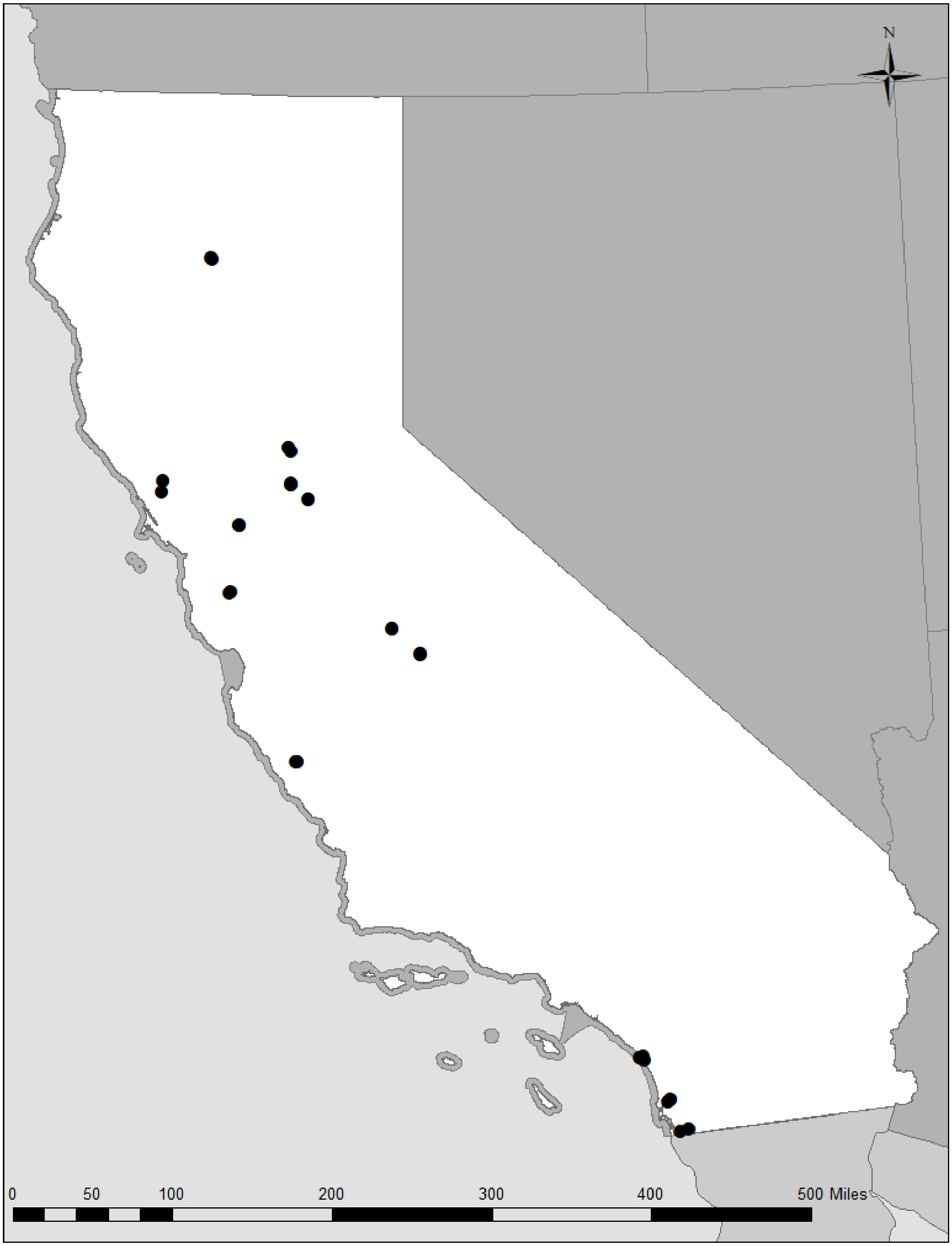

Figure 1. Map of vernal pool validation sites

Conduct field assessments

Field assessments were conducted using the CRAM Vernal Pool Systems module (version 6.1) at 29 sites for this project 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

Intensive Level 3 data from the selected sites was compiled from colleagues who graciously shared data with us. John Vollmar provided data for all of the Central Valley sites and some of the Bay Area sites. The same folks who arranged access to the rest of the sites also shared data for those sites. The level of detail and the collection methods varied, but the data was compiled into one master list and standardized as much as possible.

For sites with invertebrate data, the total number of species was tallied for the 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. There were 19 sites with multiple classes of invertebrates sampled, and 21 sites with data on large branchipods.

Vegetation data was available for 20 sites, and 18 of those provided raw data on species cover that enabled calculation of the Shannon indices. The remaining two sites had data on native and non-native cover, but not specific species data.

Analyze correlations between CRAM and Level 3 data

Each variable was tested for normality using the Shapiro-Wilk test, and some were transformed if necessary to conform to a normal distribution. The Buffer and Landscape Context and Hydrology Attributes were both skewed to the right, so square root and log transformations were attempted. However, these did not result in normal distributions, so the original data were retained. The invertebrate species richness metric was skewed to the left, and was successfully log transformed. The CRAM Index score and all four Attribute scores were tested for correlation with all of the 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 based on expert knowledge of vernal pool specialists and structured within the framework of other CRAM modules. However, it was not fully verified or validated. When practitioners began to use it, they noted several problems with the functionality of some metrics. There were also some formatting issues and typographical errors that needed to be addressed. Based on this feedbac, several revisions were proposed and tested during field data collection, or through desktop analyses.

The new version will be designated the CRAM Vernal Pool Systems Field Book Version 6.2. The most fundamental change was a reduction in the number of replicate pools sampled for each assessment area (AA). In version 6.1, up to six pools were sampled individually for Topographic Complexity, Plant Community, and Horizontal Interspersion. The individual scores from each pool were combined for an overall metric score for the AA. This was an exhaustive process that took a lot of time and resulted in redundant information. Therefore, we proposed to reduce the replication to three pools rather than six. The implications of this were tested by comparing the results from three pools versus six pools at all sites visited for this project. Most of the other changes involved adjusting scoring bins to ensure a more even distribution of scores. Although the sites sampled for this project were not probabilistically sampled, as in an ambient survey, they do represent a broad cross section of vernal pool condition. If anything, the sites may be skewed towards higher condition, as many of them were in preserves or other open space areas. This factor was considered in adjusting scoring bins.

Aquatic Area Abundance

The first metric that was adjusted was Aquatic Area Abundance, based on extreme skewness in the scoring under the v6.1 field book, where almost all sites got A’s, some got B’s and C’s, and none got D’s (figure 2).

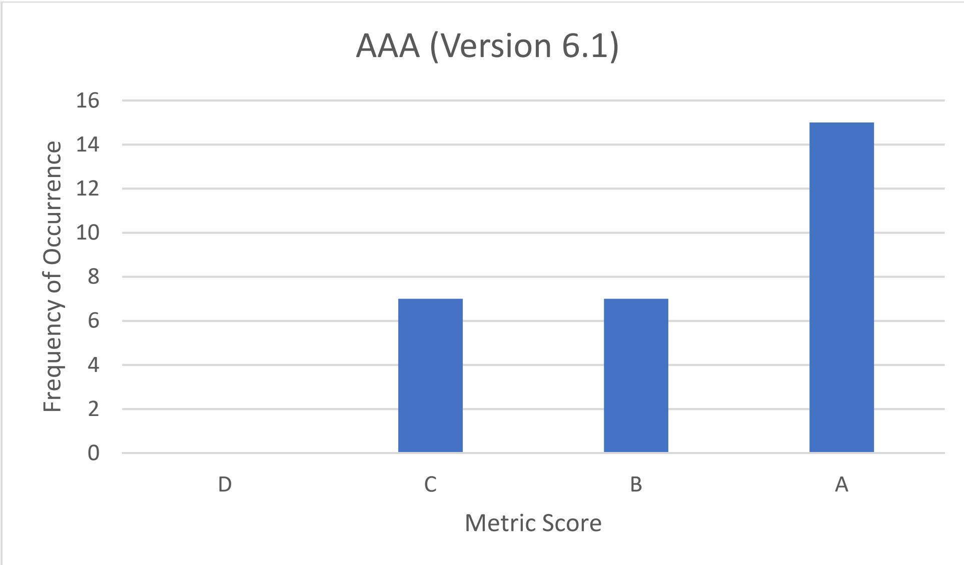

Figure 2. Score distribution for Aquatic Area Abundance under version 6.1

The raw data for percent aquatic area was examined to determine more appropriate bins (figure 3).

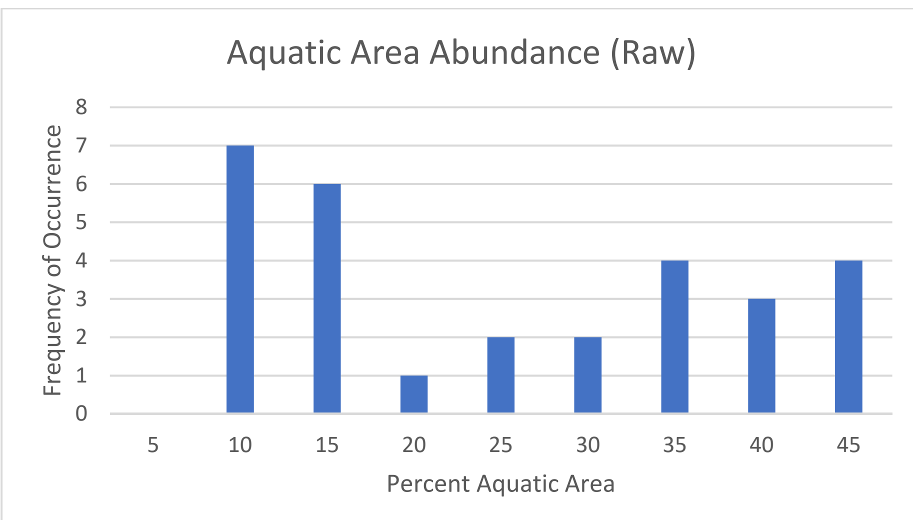

Figure 3. Aquatic Area Abundance raw data

Based on the distribution of raw data for Aquatic Area, new scoring bins for the metric were proposed.

Table 2. Scoring bins for Aquatic Area Abundance

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%

This resulted in a much more even distribution of scores (Figure 4).

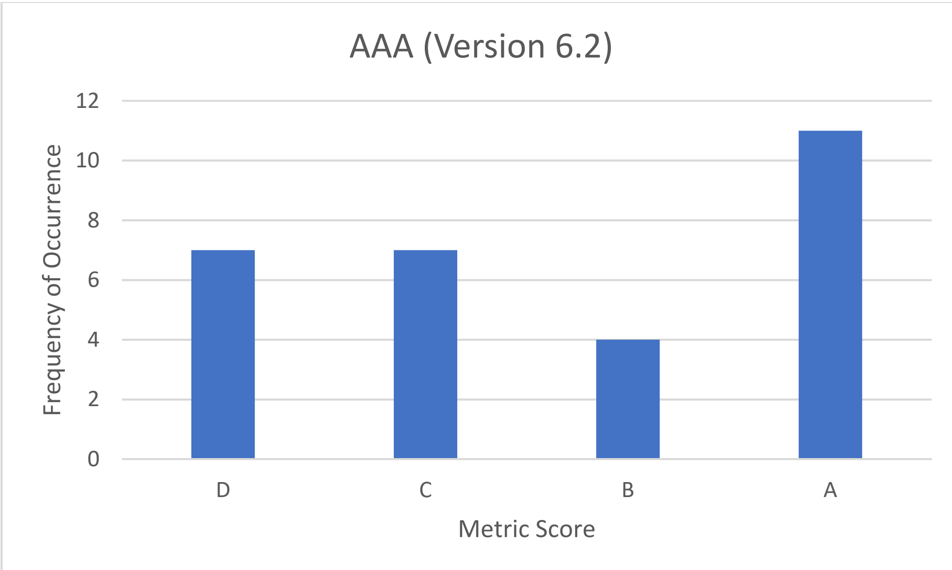

Figure 4. Score distribution for Aquatic Area Abundance under new version

Structural Patch Richness

The Structural Patch Richness benefited from clarification of the definitions of some of the patch types. When the definitions were constrained a bit more, some sites no longer had certain patches that were marked as present under version 6.1, which resulted in a lower total number of patches. However, even with a reduction in the number of patches, none of the sites received a D score, and most scored in the B range.

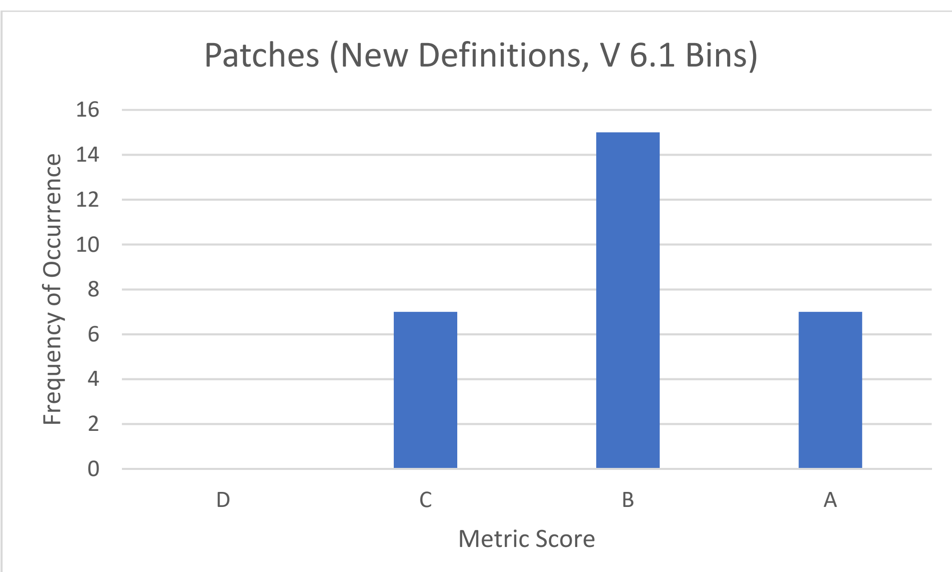

Figure 5. Score distribution for Structural Patch Richness under version 6.1

Due to the imbalance in scoring, we looked at the raw data for the number of patches for all of the sites to determine more appropriate binning.

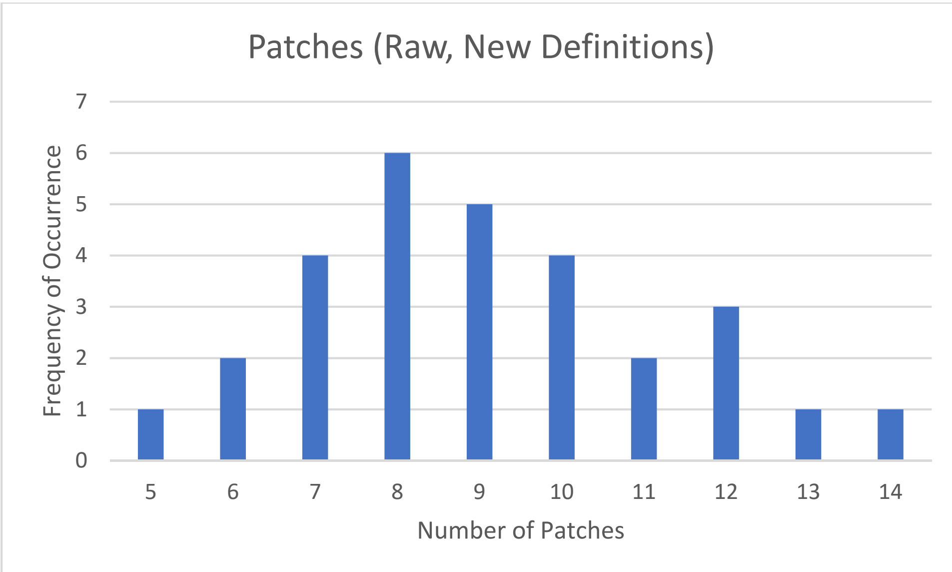

Figure 6. Structural Patch Richness raw data

Table 3. Scoring bins for Structural Patch Richness

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

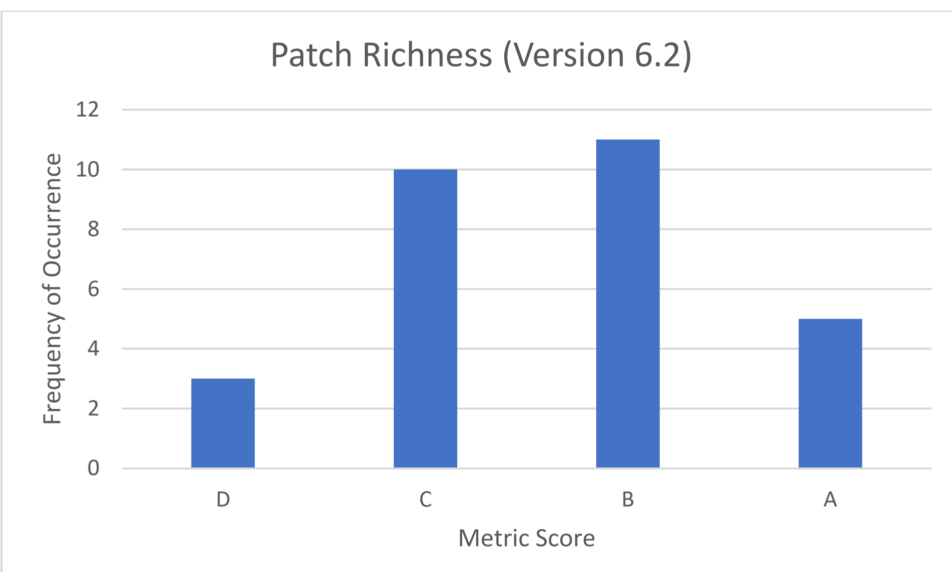

Figure 7. Score distribution for Structural Patch Richness under version 6.2

The new scoring bins resulted in a much more even distribution of metric scores among the sites sampled (Figure 7).

Pool and Swale Density

The Pool and Swale Density metric measures the distribution of aquatic feature within the AA. One issue that was raised by practitioners was that measuring the pools and swales along north and south axes doesn't always capture the arrangement of features in the AA. For example, if the AA is oriented northeast to southwest, the transects in the cardinal directions will be very 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 8). Another issue was the method used to calculate the final average density of aquatic features. In Version 6.1 each of the four transects originating at the center were measured separately and then averaged for the overall pool and swale density, which resulted in unequal weighting of the shorter transects. To correct this, the total length of all pools and swales along the transects is divided by the total length of both transects, so that no particular segment is weighted more heavily.

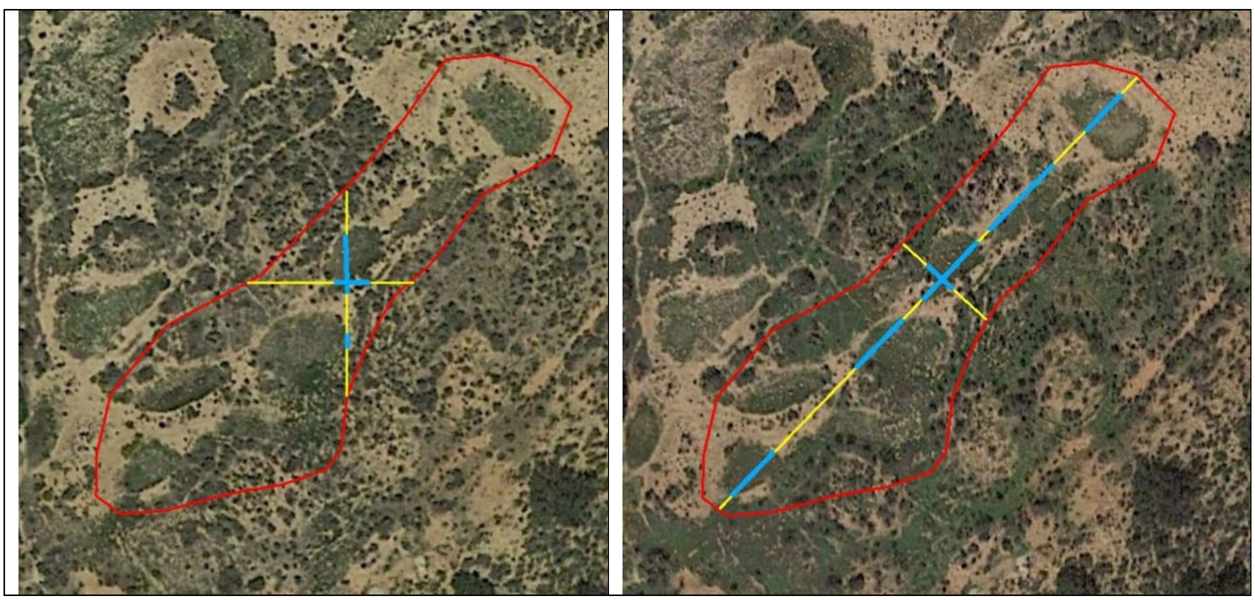

Figure 8. Transects for Pool and Swale Density as measured in v6.1 (left) and in the revised version (right)

With the new method for measuring pool and swale density along dominant axes, we looked at the distribution of raw data for the overall percent pools and swales (Figure 9). These numbers were run through the scoring bins from Version 6.1 (Figure 10), and found to be skewed toward the upper end of scores, with many A's and very few D's. The bins were adjusted to better reflect the raw data (Figure 11, Table 4).

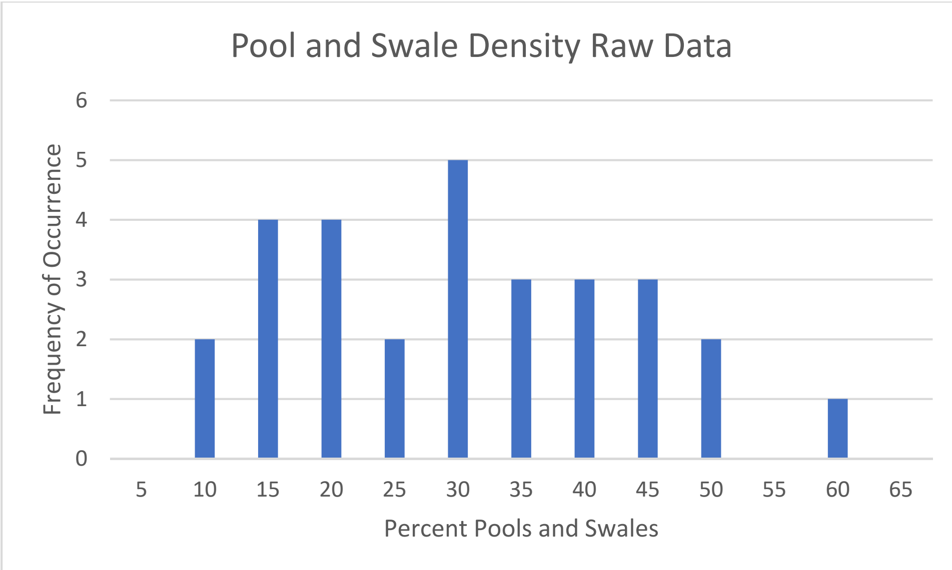

Figure 9. Percent pools and swales raw data

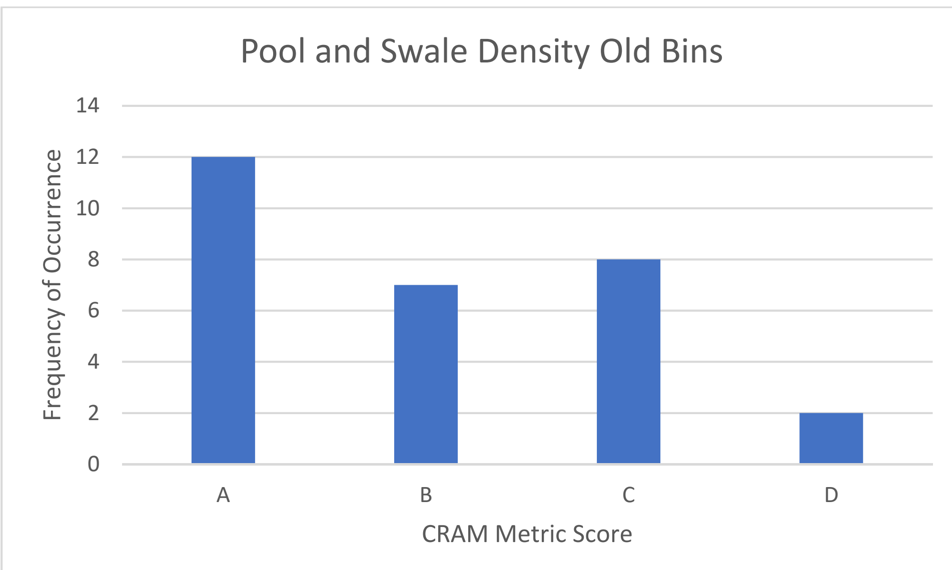

Figure 10. Pool and Swale Density metric scores with bins from Version 6.1

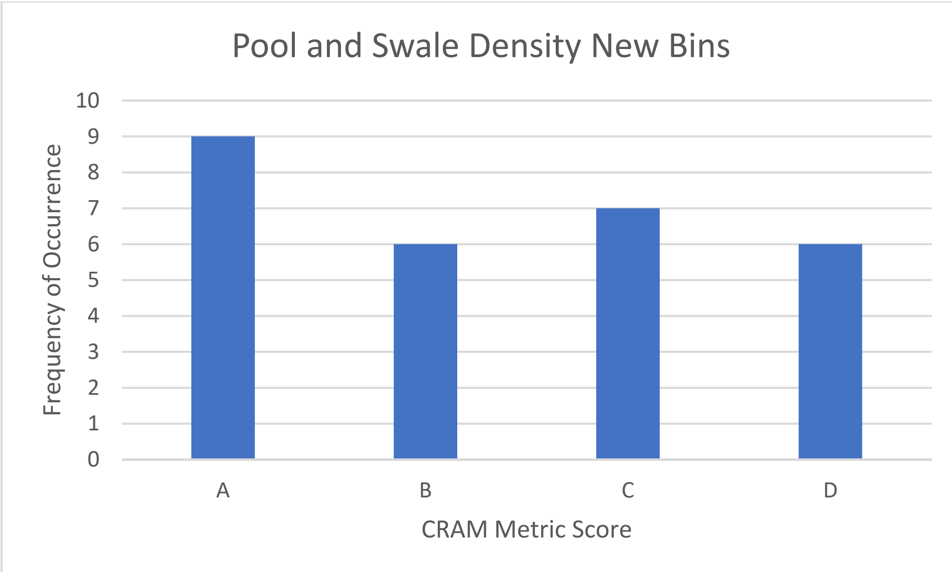

Figure 11. Pool and Swale Density metric scores with updated bins

Table 4. Scoring bins for Pool and Swale Density

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%

The next few metrics are ones that are replicated at multiple pools within the AA. One of the main issues with the scoring for these metrics was that it didn't take into account the convergence of values that happens when multiple scores are averaged. As a result, most sites got B's and C's, but very few A's or D's, if any.

Topographic Complexity

Each pool is scored separately for Topographic Complexity, and the results are averaged to determine the overall score for the AA for this metric. We looked at the raw data that combines multiple scores for all six pools and for only three pools, and the ranges were not significantly different according to a two-sample t-test, where $t(9) = -0.13$, $P = 0.89$ (Figures 12).

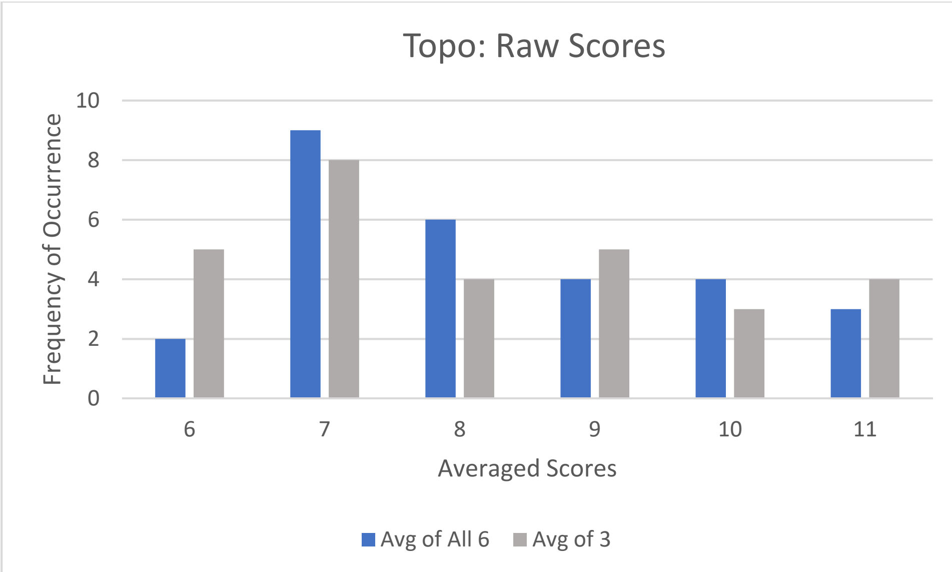

Figure 12. Topographic complexity raw metric scores comparing averages for all 6 pools and 3 pools

We determined to move forward with the more streamlined assessment, sampling three pools within each AA. When the raw scores were run through the Version 6.1 scoring bins, they were compressed to the middle scoring range of B's and C's (Figure 13). The scoring bins were revised to reflect the range of calculated averages (Figure 14).

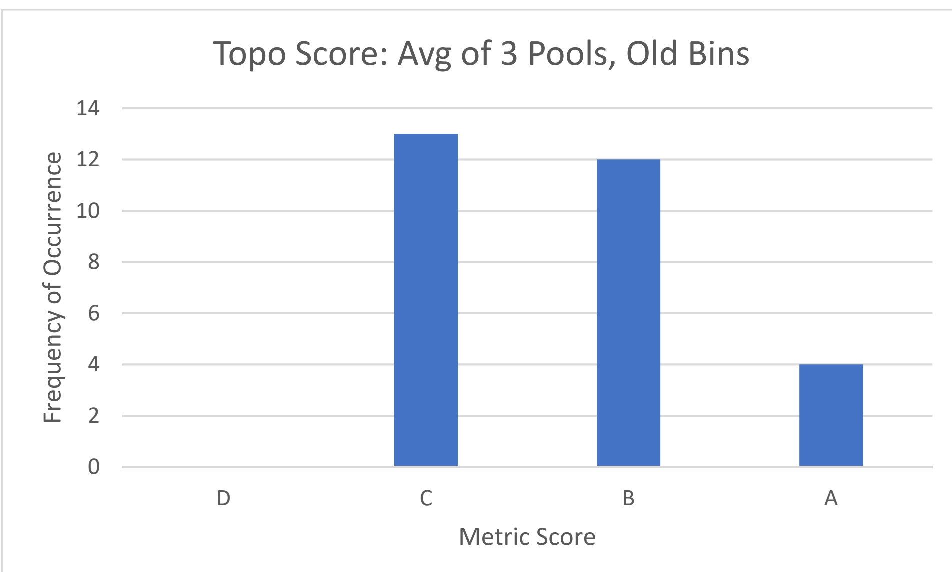

Figure 13. Topographic Complexity metric scores with bins from version 6.1

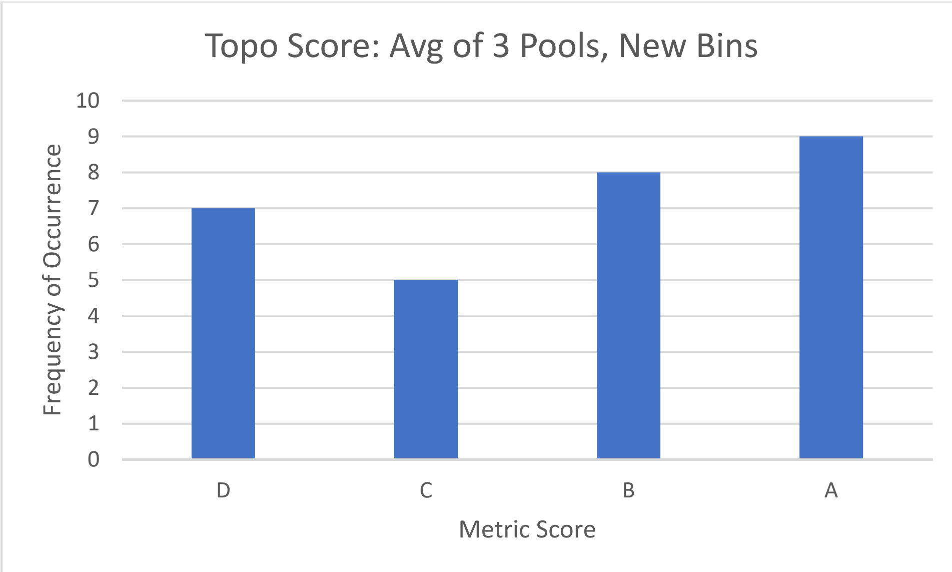

Figure 14. Topographic Complexity metric scores with bins from version 6.2

Table 5. Scoring bins for Topographic Complexity

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

Horizontal Interspersion and Zonation

This is another metric where scores from individual pools are averaged to determine the overall metric score. We looked at the averages for each site with all six pools and limited to three pools, and they were not significantly different from each other according to a two-sample t-test, where $t(54) = -0.5$, $P = 0.62$ (Figure 16).

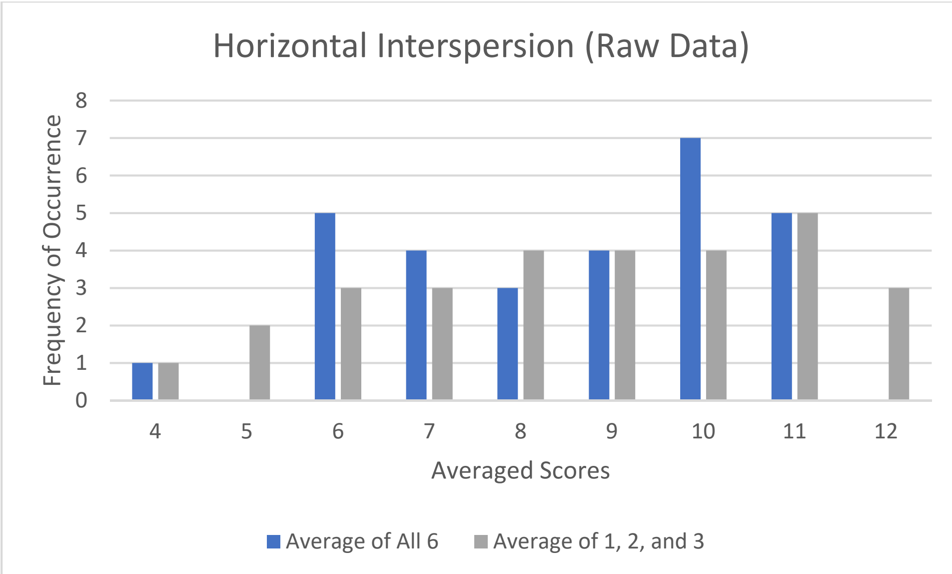

Figure 15. Horizontal interspersion raw metric scores comparing averages for all 6 pools and 3 pools

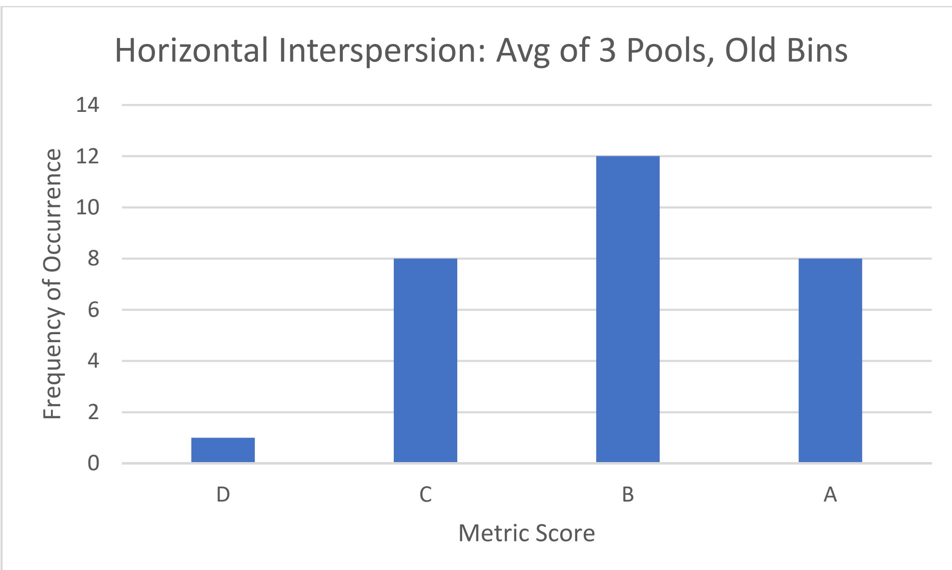

Figure 16. Horizontal Interspersion metric scores with bins from version 6.1

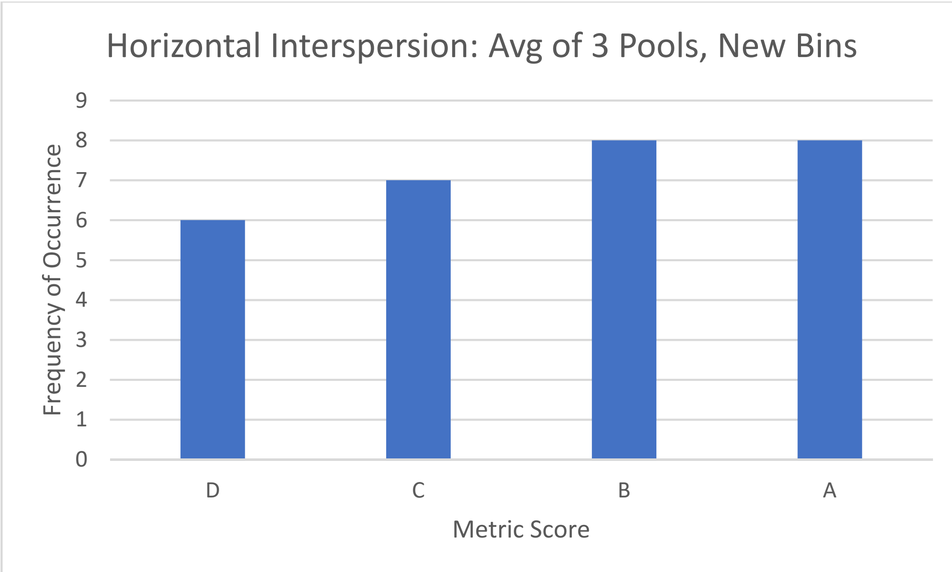

Figure 17. Horizontal Interspersion metric scores with bins from version 6.2

The scoring bins were revised to improve the distribution of scores (Figures 16-17).

Table 6. Scoring bins for Horizontal Interspersion

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

Plant Community Submetric A: Number of Co-dominant Species

The Plant Community Submetric A: Number of Co-dominant Species is an average of the total number of co-dominant plant species in each replicate pool. Because it is an average of several values, the mean tends to converge towards a central value, and the scoring bins from version 6.1 result in only B's and C's (Figure 19). Based on the raw data on average number of co-dominant species, new scoring thresholds were designated to improve the overall range of scores (Figure 20, Table 7).

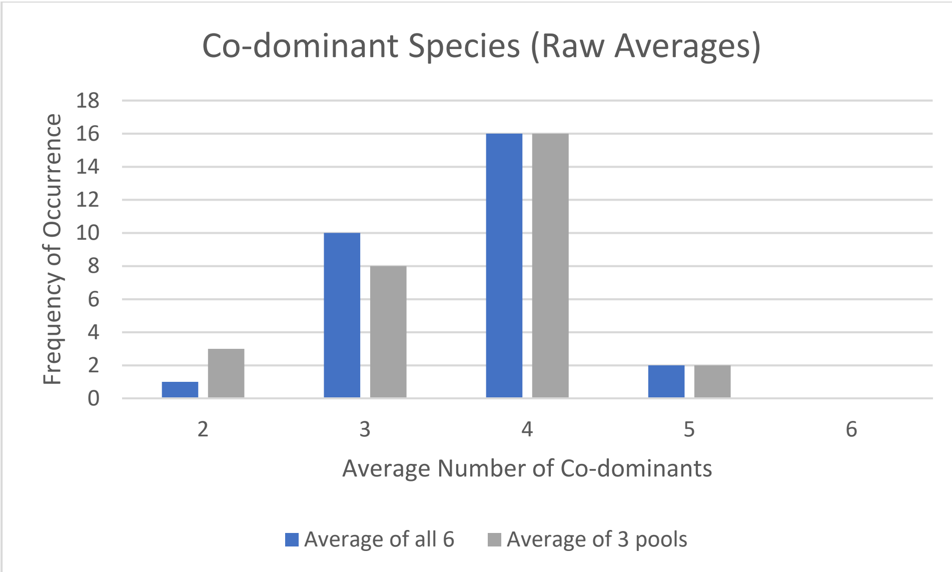

Figure 18. Plant Community Submetric A: Number of Co-dominant Species raw data

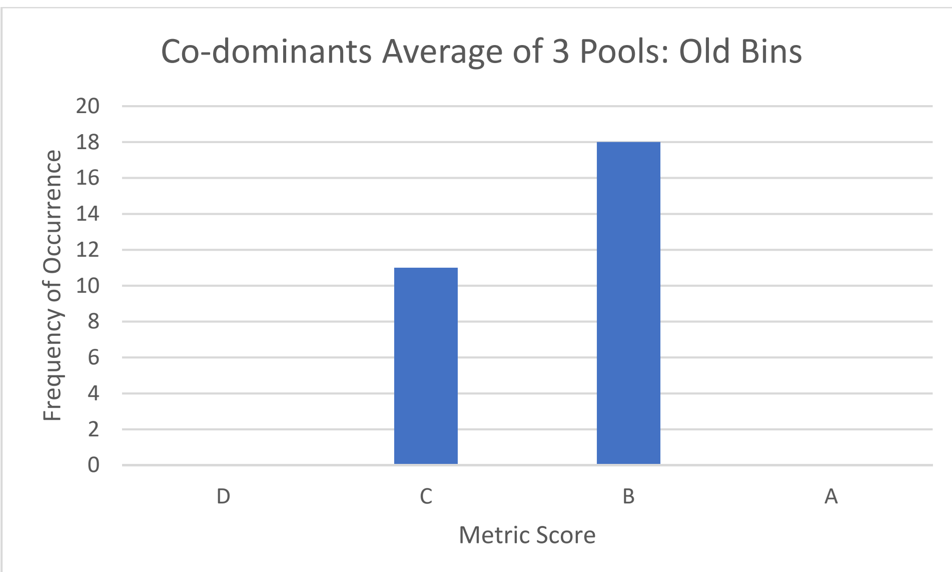

Figure 19. Plant Community Submetric A: Number of Co-dominant Species metric scores with scoring bins from version 6.1

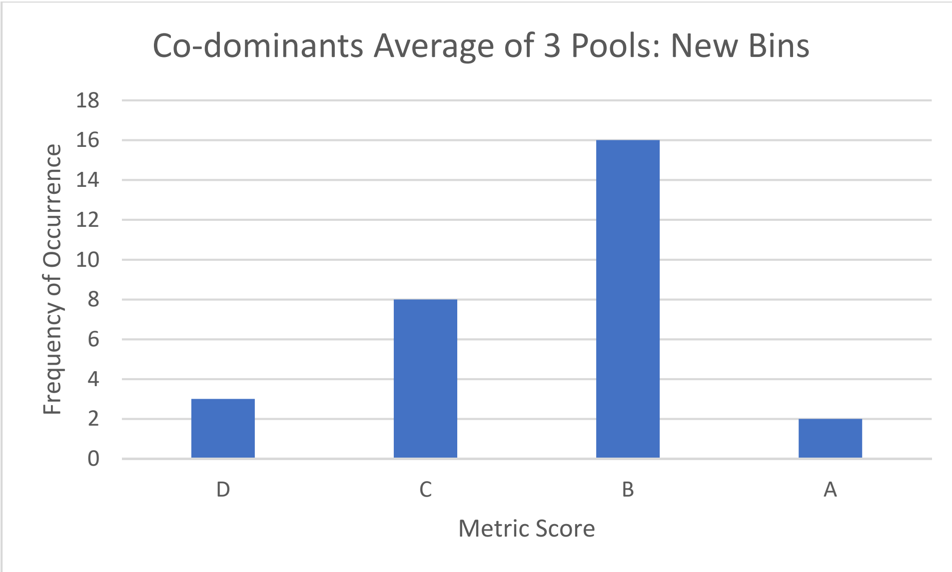

Figure 20. Plant Community Submetric A: Number of Co-dominant Species metric scores with scoring bins from version 6.2

Table 7. Scoring bins for Plant Community Submetric A: Number of Co-dominant Species

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

Plant Community Submetric B: Percent Non-native

This metric had a range of values from the raw data on percent non-native (Figure 21). The overall distribution of scores using the scoring bins from version 6.1 was pretty good (Figure 22). However, we wanted this module to be more in line with other CRAM modules, so the scoring bins were adjusted to be the same as the bins for percent invasive in other modules. Although both versions have a high number of A's (Figures 22-23), the new bins put the maximum percentage for an A at 15% rather than 20% (Table 8), so in the long run as new sites get assessed it will result in less sites receiving an A. This is a net positive result, as in the previous version too many sites had high scores, resulting in an inability to truly differentiate between sites of different condition.

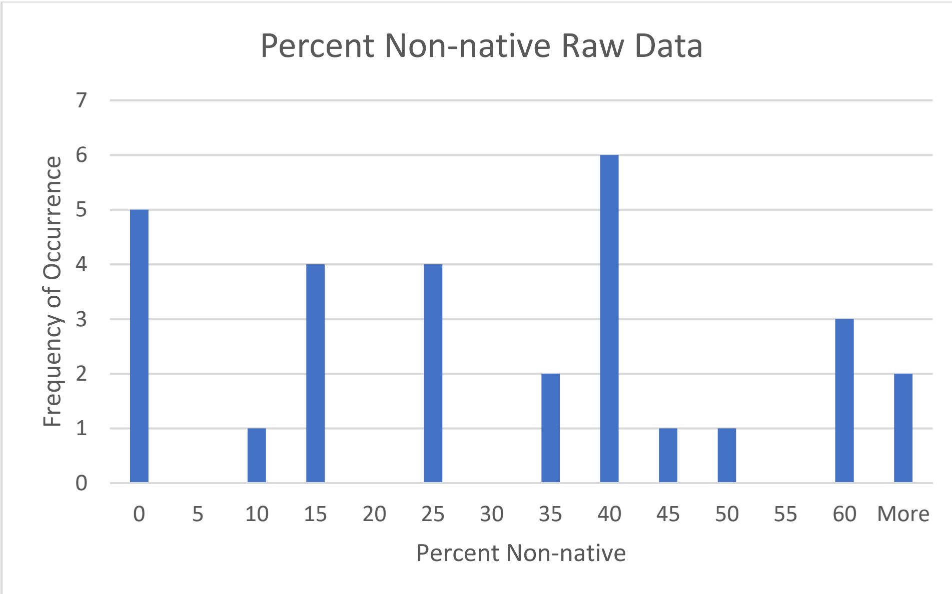

Figure 21. Plant Community Submetric B: Percent Non-native raw data

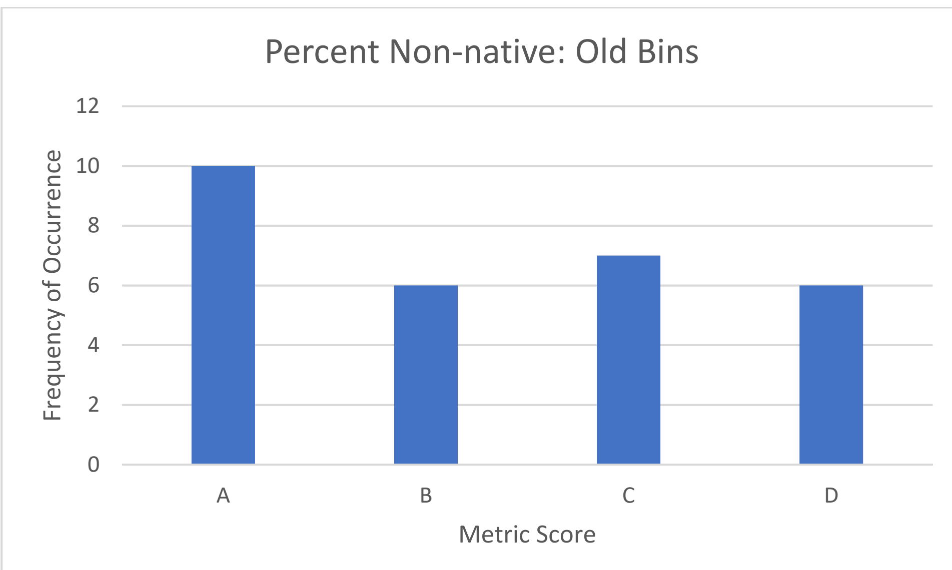

Figure 22. Plant Community Submetric B: Percent Non-native metric scores with scoring bins from version 6.1

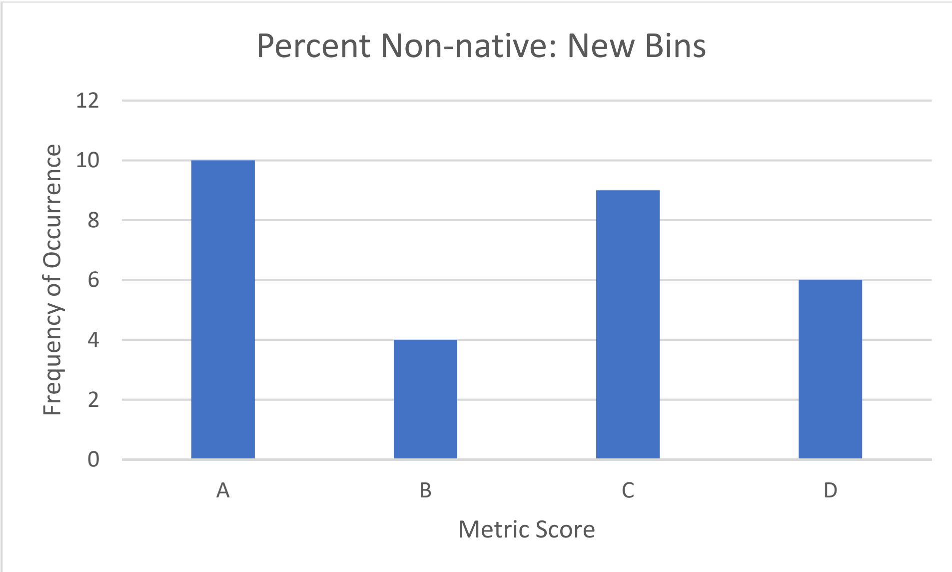

Figure 23. Plant Community Submetric B: Percent Non-native metric scores with scoring bins from version 6.2

Table 8. Scoring bins for Plant Community Submetric B: Percent Non-native

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

Plant Community Submetric C: Endemic Species Richness

This metric tallies the total number of vernal pool endemic species that are co-dominant species in any of the replicate pools. Practitioners have noted that previous versions of Appendix 1, which lists species that are considered vernal pool endemics, may not have included some species that are specific to vernal pools in southern California. As we collected CRAM data and compiled level 3 data on pools in the region, we made note of any plants that were not included on the endemic list but may be good candidates to be added. We also consulted with experts on vernal pools in the region to see if any other plants are strong contenders for addition to the list. There were only a couple of plants that warranted additional inclusions in the list: *Eryngium pendletonense* and *Marsilea vestita*. A previous revision to the list broadened the scope of the list to include any plants that are considered vernal pool indicators, so that action likely gathered in many species that were not previously included.

The scoring bins for this metric were also problematic. The minimum number of endemic species required to get a score of A was 9 species, which is almost impossible given that each species has to comprise at least ten percent of one pool. Even with multiple pools sampled as replicates, none of the AAs in the validation dataset had more than 8 endemic co-dominant species. We looked at the raw data on endemic species (Figure 24), and adjusted the bins to improve the distribution (Figures 25-26, Table 9).

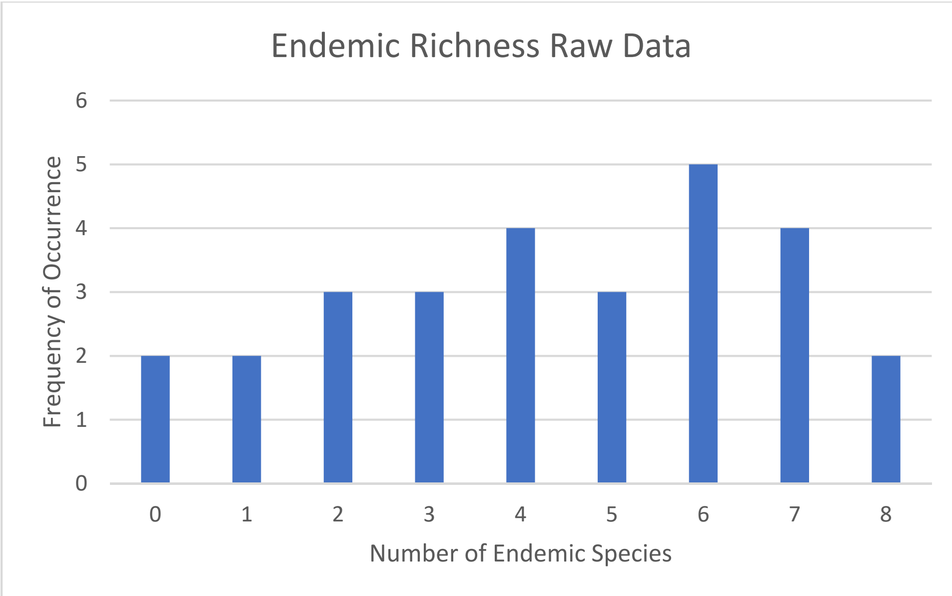

Figure 24. Plant Community Submetric C: Endemic Species Richness raw data

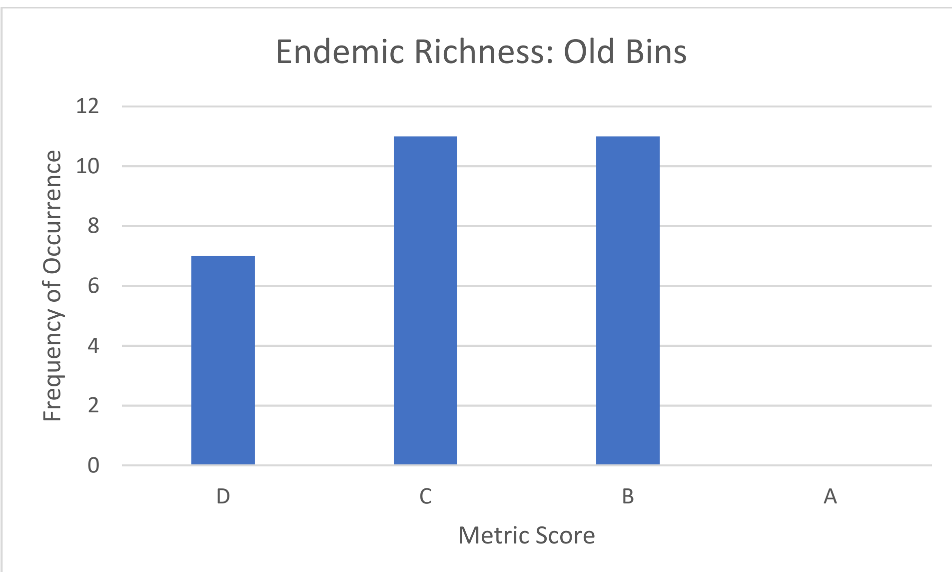

Figure 25. Plant Community Submetric C: Endemic Species Richness metric scores with scoring bins from version 6.1

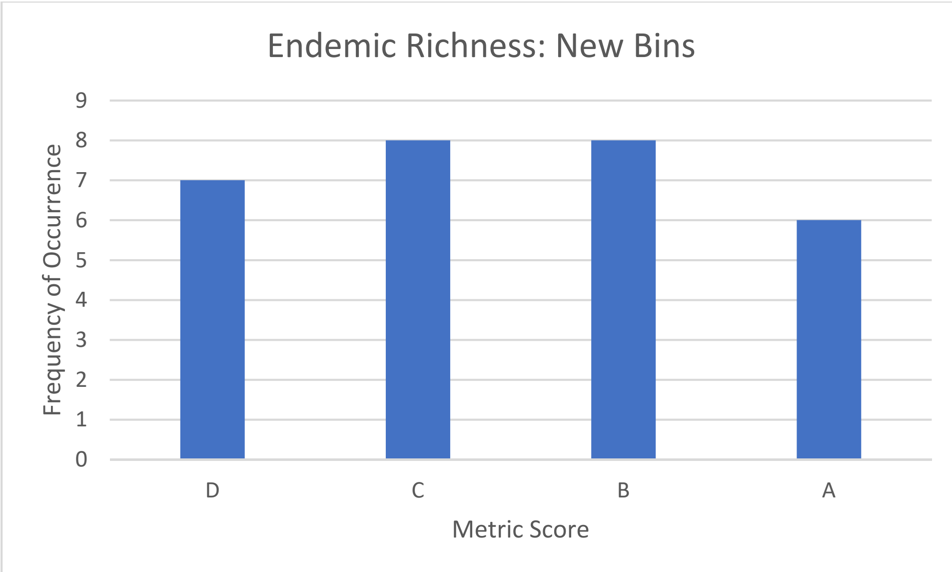

Figure 26. Plant Community Submetric C: Endemic Species Richness metric scores with scoring bins from version 6.2

Table 9. Scoring bins for Plant Community Submetric C: Endemic Species Richness

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

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 represents 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 5). We determined that the scores are not biased towards high or low values (skewness = -0.02). The broad range of scores confirms the responsiveness of the Vernal Pool Systems CRAM module.

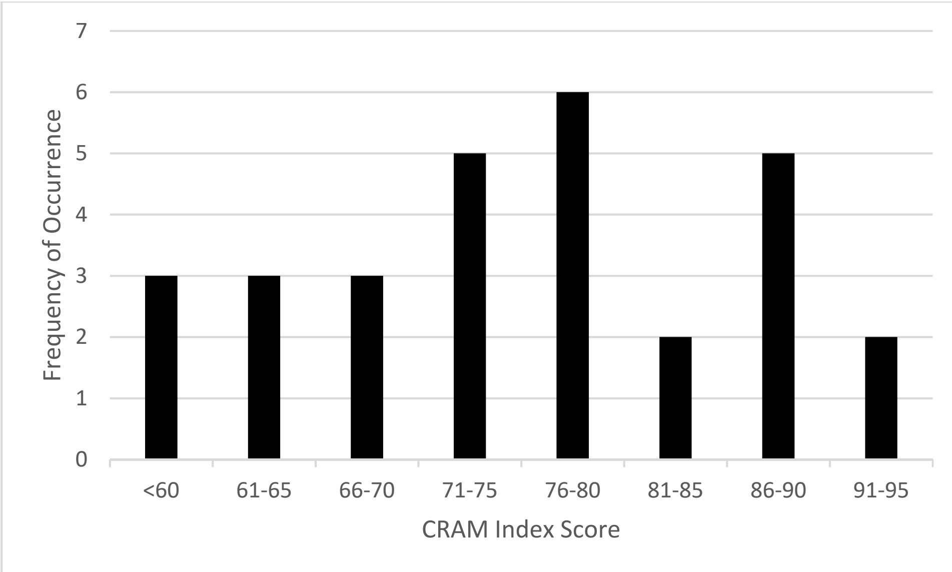

Figure 27. Histogram of CRAM Index scores (n = 29)

An extensive range of scores were measured for each CRAM Attribute: Buffer and Landscape Context 45-93, Hydrology 67-100, Physical Structure 33-100, and Biotic Structure 25-96 (Figure 28). Although there is some skewness in some of the Attributes, that is to be expected for certain Attributes that are influenced by the surrounding landscape. 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. We determined that each Attribute is responsive to varying conditions in and around the wetland of interest.

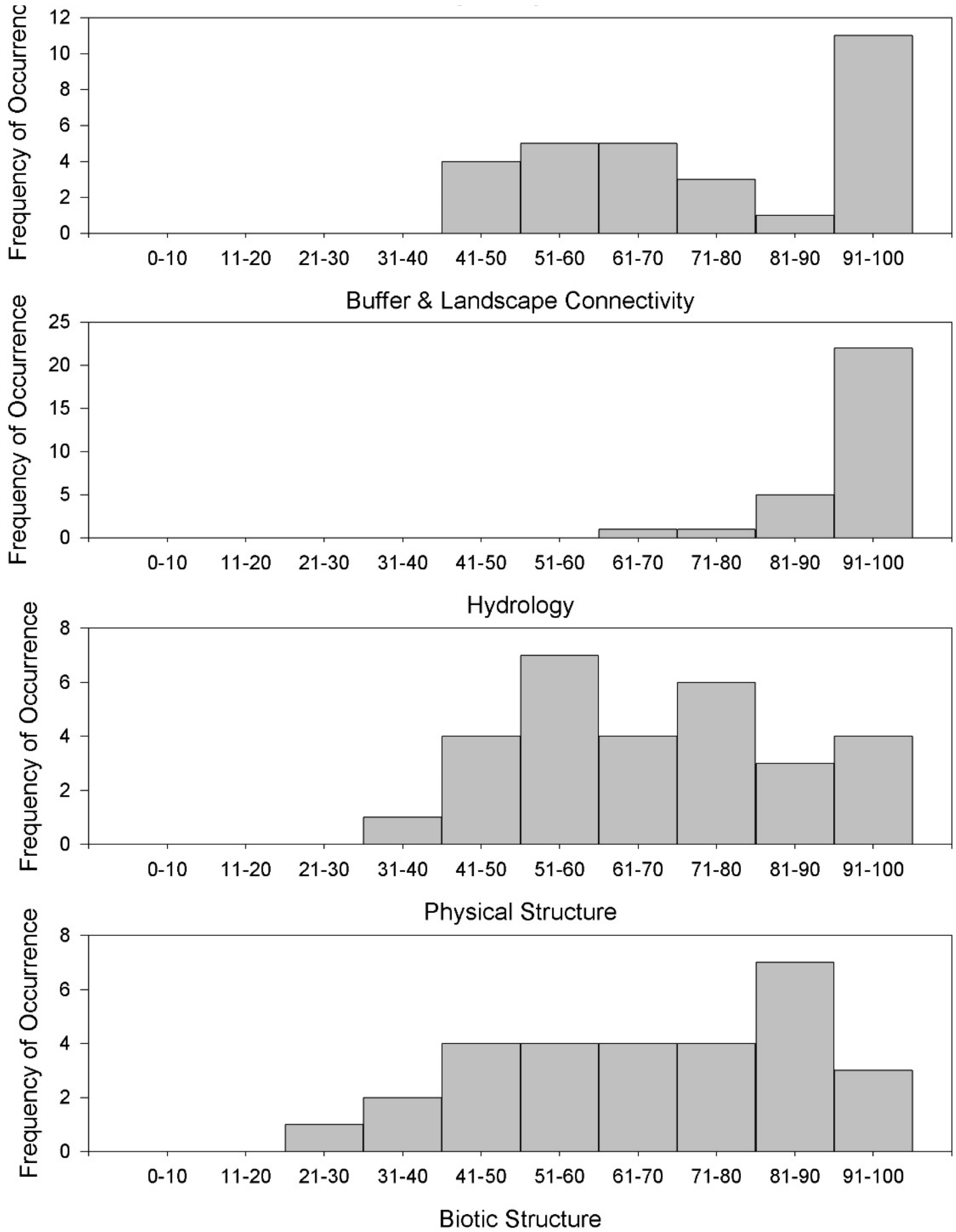

Figure 28. Histograms showing the distribution of data for each CRAM Attribute

The overall CRAM Index score and each Attribute score were tested for significant correlations with Level 3 data, including invertebrate and plant metrics.

Tables 10 and 11 list the results of all analyses with significant correlations' p-values shown in bold font (significant when compared to α = 0.05). The CRAM Index score was significantly correlated with large branchiopod species richness and the Shannon evenness index. Physical and Biotic Structure were both significantly correlated with large branchiopod species richness and the Shannon diversity index, while Biotic Structure was also correlated with Shannon evenness. Buffer and Landscape Context was correlated with large branchiopod species richness. The Hydrology Attribute was negatively correlated with plant species richness, which was somewhat surprising. The Hydrology Attribute was somewhat skewed, so this may have influenced the correlation.

Table 10. Pearson Correlation coefficients

	Log trans Invert Sp Rich	Large Branchio pods	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	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	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 11. Kendall's Tau b correlations

	log transformed Invert Sp Richness	Large Branchio pods	Species Richness	VP Endemic Species Richness	Native % Cover	Non-native % Cover	Shannon Diversity Index	Shannon Evenness Index
Buffer and Landscape	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	-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

The CRAM Index score merits particular attention as it is the overall measure of wetland health. It was correlated with both large branchiopod species richness and Shannon evenness (Figure 29).

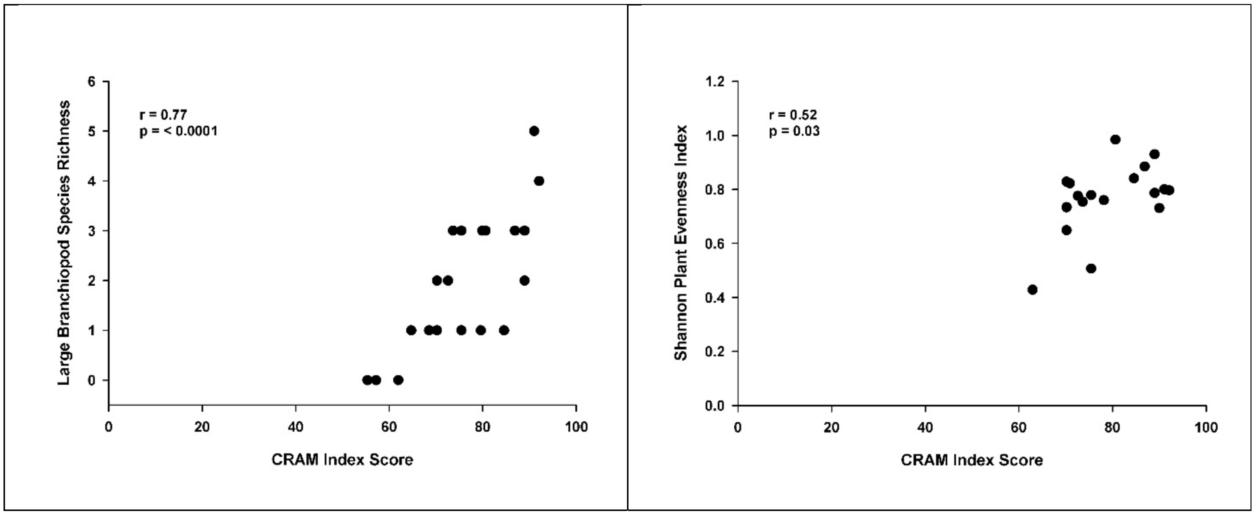

Figure 29. Correlation plots of CRAM Index Score vs. large branchiopods and Shannon evenness

The individual Attributes were also correlated with some of the Level 3 indicators, particularly large branchiopod species richness (Figure 30).

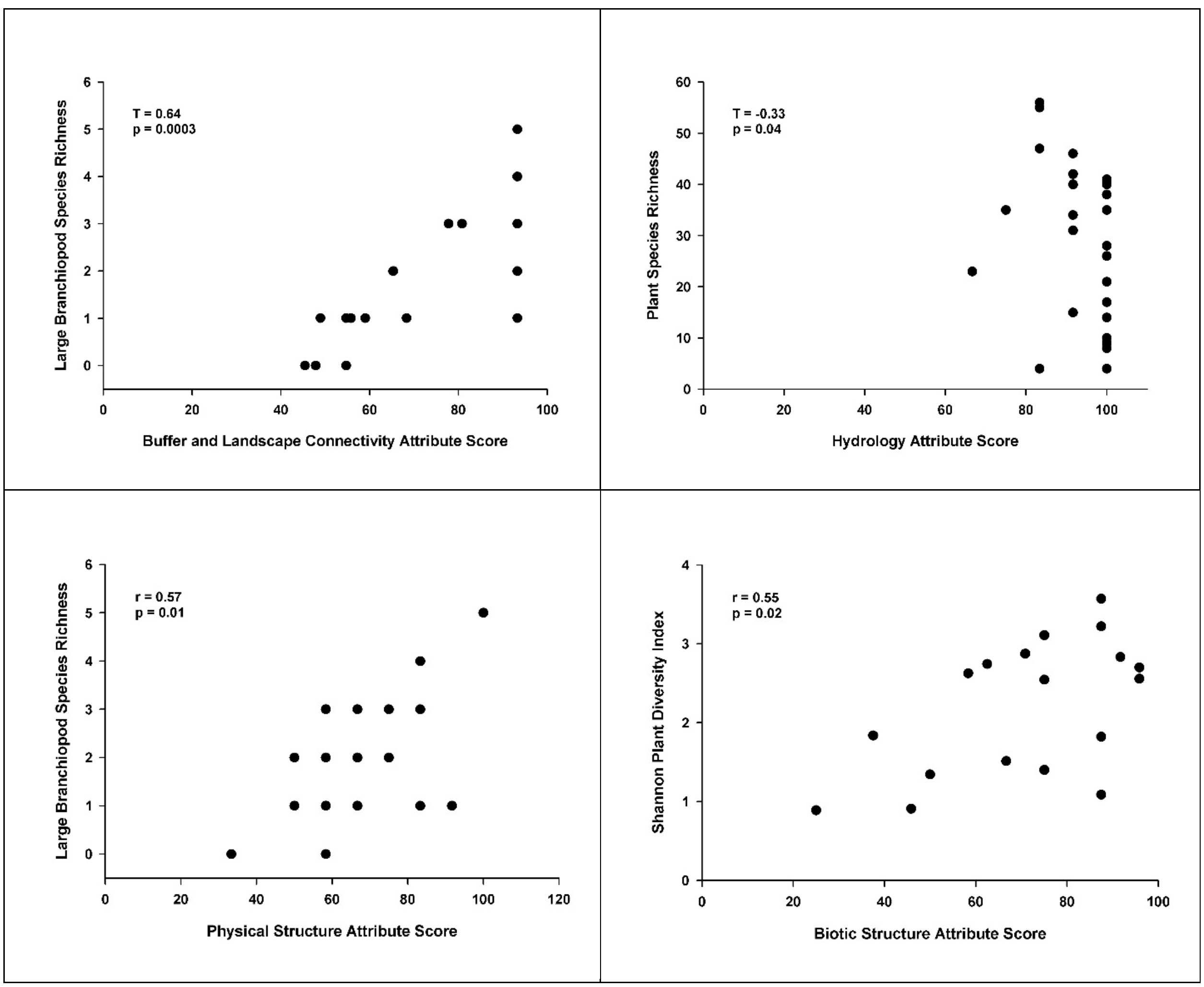

Figure 30. Correlation plots of CRAM Attributes and selected Level 3 indicators

Discussion

The goal of this project was to validate the CRAM module for vernal pool wetlands. 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 met a set of key criteria. A validated CRAM module should 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 the full 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. However, they spanned a range of latitude from 32.5 degrees in the San Diego area to 40.5 degrees up in the northern Sacramento valley. They ranged east to west in longitude from 116.9 degrees in San Diego to 122.8 degrees in Santa Rosa (Figure 1). We targeted sites that exhibited a range of condition and surrounding landscape disturbance, with some sites in open space preserves and others in urban areas or with 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. We created a conceptual model from which we predicted and tested relationships between CRAM scores and various Level 3 indicators of condition.

At least one Level-3 metric correlated significantly, and in the expected direction, for each CRAM Attribute, with the exception of Hydrology, which had an unexpected correlation. Our analysis found that CRAM Index scores were significantly correlated with large branchiopod species richness and the plant cover Shannon evenness index. Buffer and Landscape Context, Physical Structure, and Biotic Structure were all correlated with large branchiopod species richness. In addition, Physical and Biotic Structure were correlated with the Shannon diversity index, and Biotic Structure was further correlated with the Shannon evenness index. Hydrology was negatively correlated with the Shannon evenness index.

In general, higher diversity is associated with better condition (Lopez and Fennessy 2002). Large branchiopod diversity was strongly correlated with the CRAM Index score and three of the CRAM Attributes. CRAM responds to some of the same factors that promote populations of these special status invertebrates. The Shannon diversity and evenness indices were 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 puzzling, but probably just an artifact of the skewness of the Hydrology Attribute, where most sites got very high scores for this Attribute. Of the 26 sites analyzed for correlation between Hydrology and plant species richness, over half had Hydrology scores of 100, and only two sites had scores less than 80. The two sites with the highest plant species diversity had moderate Hydrology scores of 83, and those sites may have been driving the negative correlation (Figure 30 top right).

In validating this CRAM module, the goal was to have broad correlation with multiple L3 metrics that represent a range of ecological functions and services. However, we did not expect those correlations to be tight, with high correlation coefficient values, as this would negate the need for developing a new method of assessment. CRAM is meant to measure multiple potential wetland functions, not any single function, as represented by the L3 data. This study confirmed that CRAM scores correlate with both plant and invertebrate diversity indicators, which validates its efficacy.

Conclusions

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

The Vernal Pool CRAM module is now 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.

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