Validation of the California Rapid Assessment Method Depressional Wetland Module: Final Report

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Executive Summary

Depressional wetlands are abundant and widespread in California. State agencies and wetland scientists have determined that there is a need to characterize their condition 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 Depressional CRAM wetland module is described in this report.

The intensive measures of condition used to validate Depressional CRAM were a benthic macroinvertebrate index of biotic integrity (IBI), an algae IBI, and several water chemistry parameters.

The overall CRAM Index score and individual CRAM Attribute scores were significantly correlated with the macroinvertebrate IBI, the algae IBI, and several of the water chemistry parameters.

The Depressional CRAM module provides a meaningful, repeatable, and accurate assessment of wetland condition across the state of California.

Introduction

Depressional wetlands are abundant and widespread in California. Freshwater wetlands comprise 60% of all wetlands in the state (NRA 2010). Many of these wetlands are isolated geographically and vulnerable to development pressure (Brown et al. 2016). State agencies and wetland scientists have determined that there is a need to characterize their condition in order to assess impacts, establish protection strategies, and initiate restoration efforts.

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.

California has the highest loss of historical wetlands in the lower 48 states at 91% reduction over the 20th century (Dahl 1990). The state has prioritized the assessment and protection of any remaining wetlands, which are still very diverse. Rapid assessment of wetlands allows for cost-effective and repeatable characterization of wetland health at scales from local to watershed to region or state wide. 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 depressional wetlands
	Topographic Complexity	Complexity of micro- and macro-topographic features
Biotic Structure	Number of Plant Layers	Number of plant height classes that cover at least 5% of the area
	Number of Co-dominant Species	Total number of living plant species that comprise at least 10% of any plant layer
	Percent Invasive Species	The percent of the total number of co-dominant species that are listed by Cal-IPC as invasive
	Horizontal Interspersion	The complexity of plant zones (species assemblages or mono-specific stands)
	Vertical Biotic Structure	Two method options: 1) wetlands with woody vegetation score overlap of layers; 2) wetlands with emergent marsh plains score entrainment and vegetation canopy

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, funded by the USFWS (Agreement # M11AF00103), accomplished phases one through three. Verification was completed in 2012 and 2013 with a statewide survey across a gradient of hydroperiod (Clark and O'Connor 2014). This study was a solid foundation to launch the current project, as it verified that the depressional module was effectively differentiating between "good", "fair", and "poor" sites as categorized a priori by the development team. The field book for Depressional CRAM was revised to improve its performance and utility.

This project aimed to complete the validation phase of Depressional 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 Depressional module will establish its scientific credibility and further its use in local, state, and federal programs.

Methods

Validation of the Depressional CRAM module followed the systematic process described by Stein et al. (2009), which prescribed several steps to validation:

1. Identify the gradient of stress
2. Identify appropriate Level 3 data to validate the CRAM module
3. Identify metrics that will be calculated from the detailed Level 3 data
4. Create conceptual models of the expected relationship between the detailed data and CRAM scores
5. Identify field sites where Level 3 data are available or possible to collect
6. Conduct CRAM assessments at the sites identified
7. Analyze correlations between CRAM scores and Level 3 metrics

Identify the Gradient of Stress

Depressional wetlands can be impacted by surrounding land use. 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 depressional 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 project benefited from previous work on depressional wetlands. Lunde and Resh (2012) developed a macroinvertebrate index of biotic integrity (IBI) for depressional wetlands in the San Francisco Bay Area. Brown et al. (2016) expanded this work in southern California to incorporate multiple indicators of wetland health, including macroinvertebrates, algae, water quality, and habitat assessment. Our colleagues at the Southern California Coastal Water Research Project (SCCWRP) and the Bay Area Regional Water Quality Control Board (RB2) graciously shared their data with us. The Level 3 tools were in place but had only been used in particular regions of the state. We were able to use the standard protocols developed for sampling macroinvertebrates, algae, and water quality (Fetscher at al. 2015) to expand the geographic range of the validation sites.

Identify Metrics from Level 3 Data

The macroinvertebrate IBI is a combination of several metrics based on the assemblage of species found in each sample. These include scraper richness (a functional group); percent Ephemeroptera, Odonata, and Trichoptera (EOT); EOT richness; Oligochaeta richness; and several others. The final IBI score is on a scale of 1-100 and results from combining all of the selected metrics. We used the overall IBI score as the comparison metric.

The diatom algae assemblages are scored using the D18 index, which combines several metrics including: proportion sediment tolerant; proportion low P indicators; proportion N heterotrophs, proportion requiring > 50% DO saturation; and proportion halobiontic (Fetscher et al. 2014).

Standard water chemistry and water quality parameters were selected for analysis as well. These included turbidity, temperature, pH, specific conductance, salinity, dissolved oxygen (DO), and alkalinity.

Conceptual Models

The expected relationship between CRAM Index and Attribute scores and Level 3 data were predicted a priori for each Level 3 indicator. Both the macroinvertebrate and diatom algae IBIs are scored from low to high, with a higher score indicating better quality wetlands. Sites with higher IBI scores provide more intact functions and have fewer stressors. Therefore, a positive relationship is expected between CRAM Index and Attribute scores and invertebrate and algal IBIs.

The water quality parameters are generally more variable and it was difficult to predict relationships with condition indices such as CRAM. Water chemistry can be affected by many factors, which may not necessarily be related to the local condition or a local disturbance. Water chemistry integrates all of the upstream land uses, and may be affected more by impacts upstream than nearby conditions. However, some water quality indicators may be related to the condition of the adjacent aquatic system. Specific conductance is a general measure of water quality and can be increased by rising levels of salts or other inorganic compounds, often caused by human disturbance (EPA 2017). Therefore, as specific conductance (salinity) increases, CRAM scores are expected to decrease. Human actions such as water extraction for irrigation or additions of wastewater runoff to wetlands can also affect conductance. Increases in salinity can be stressful for many aquatic biota (EPA 2017). We predicted that higher salinity levels would correlate with lower CRAM scores. Other water chemistry measures were not predicted to correlate with CRAM scores.

Table 2. Predicted relationships between CRAM and Level 3 metrics

	CRAM Index Score	Buffer and Landscape	Hydrology	Physical	Biotic
BMI IBI	+	+	+	+	+
Algae IBI	+	+	+	+	+
Turbidity	-	-	-		
Temperature	-	-	-		-
pH	+				
Specific Conductance	-				
Salinity	-				
Dissolved Oxygen (mg/L)					

Dissolved Oxygen (%)					
Alkalinity					

Identify Field sites

The project benefited from data previously collected in Southern California and the San Francisco Bay Area. However, for full validation assessment sites were needed across the state. We selected sites in several regions, including the Sierra Nevada, the Central Valley, the Modoc region, and the North Coast. Sites were selected to represent the gradient of human disturbance and stress. Site access permission was also a consideration in site selection. Most sites were on public land, while several were located within private preserves or on school campuses. We included a sub-set of sites from the previously sampled areas in Southern California and the Bay Area. To minimize regional bias, only 15 sites were selected from each of these areas for synthesis with 15 sites sampled in other regions of the state. A total of 45 sites were included in the analysis (Figure 1).

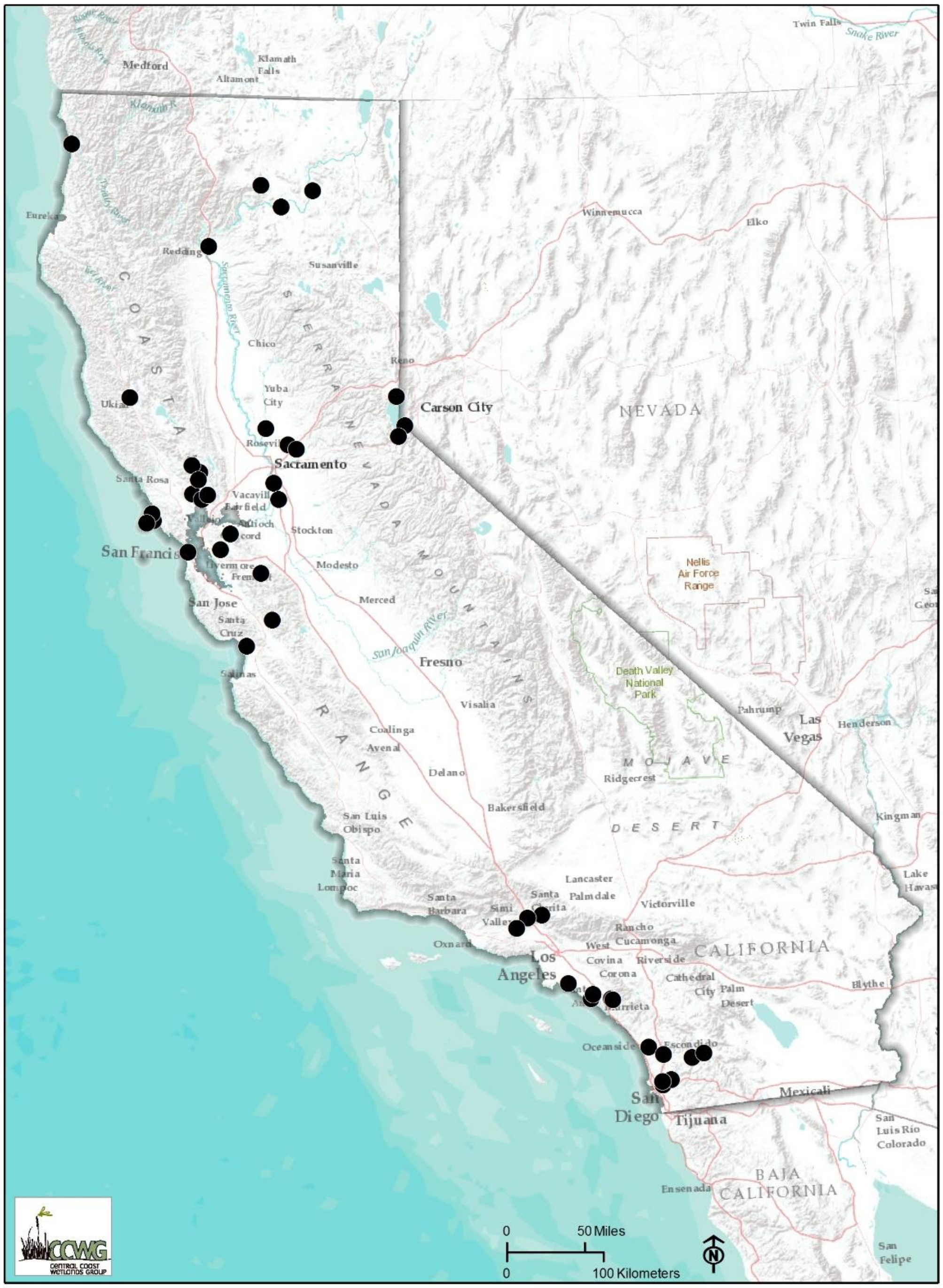

Figure 1. Map of sites selected for sampling and analysis

Conduct Field Assessments

Field assessments were conducted using the Depressional Wetland CRAM module (version 6.1) at fifteen new sites for this project during spring and summer 2014 (Figure 2). CRAM had previously been conducted at the sites in Southern California and the Bay Area using the same version of the protocol. All assessments followed the quality assurance procedures outlined in the CRAM QA Plan (CWMW 2016) and the QAPP for this project (CCWG 2014).

Figure 2. Field team conducting CRAM assessment and collecting invertebrate samples at Mendocino College pond

At each site, the same suite of Level 3 indicators was collected. This included sampling macroinvertebrates, algae, and water chemistry according to standard protocols (Fetscher et al. 2015). Sampling was distributed around each wetland along ten "nodes" where individual samples were collected (Figure 3). The nodes were evenly spaced around the wetland by measuring the circumference of the pond and dividing that length into ten segments. Each of the sampling nodes has three parallel transects: one for water chemistry, one for macroinvertebrate sampling, and one for algae sampling.

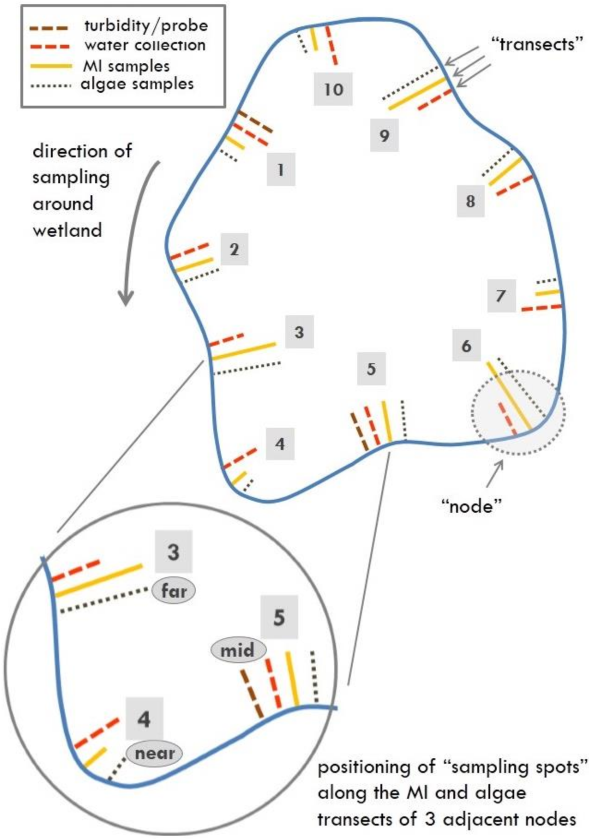

Figure 3. Sampling regime for Level 3 protocols

Process Level 3 data

Macroinvertebrate samples (Figure 4) were processed by the Aquatic Bioassessment Laboratory and used the standard taxonomic effort naming convention of the Southwest Association of Freshwater Invertebrate Taxonomists. Algae samples were processed by EcoAnalysts, Inc. according to Surface Water Ambient Monitoring Program (SWAMP) standards.

Figure 4. Field team sifting invertebrate sample at Ash Creek in preparation for delivery to the lab for analysis

Macroinvertebrate IBI scores were calculated according to Lunde and Resh (2012). The raw macroinvertebrate data were run through an R script to calculate the IBI with gracious help from Jeff Brown at the Southern California Coastal Water Research Project (SCCWRP). The diatom algae IBI was calculated using SCCWRP's online tool (SCCWRP 2016) with troubleshooting assistance from Betty Fetscher. The diatom algae IBI was developed for Southern California streams (Fetscher et al. 2014) but has been used in depressional wetlands as well (Brown et al. 2016).

Analyze Correlations Between CRAM and Level 3 Data

Spearman rank correlations were conducted for the overall CRAM Index score and each of the CRAM Attributes against the BMI IBI, algae IBI, and all water quality parameters. Percent dissolved oxygen was not used due to errors in the data. The non-parametric Spearman rank correlation was used because it does not require an assumption of bivariate normality (Dodge 2010). To account for the large number of correlations and to control for Type-I error, p-values were corrected using the false discovery rate (fdr, Benjamini and Hochberg 1995). Each metric within CRAM was treated as independent of each other, so corrected p-values were calculated using fdr separately for each CRAM metric and independent measures (BMI IBI, IBI D18, turbidity, water temperature, etc.). All calculations were conducted using SAS 9.3 software (SAS Institute Inc. 2011).

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 31 to 96, with a median score of 60 (Figure 5). We determined that the scores are not biased towards high or low values (skewness

= -0.04). The broad range of scores confirms the responsiveness of the depressional CRAM module.

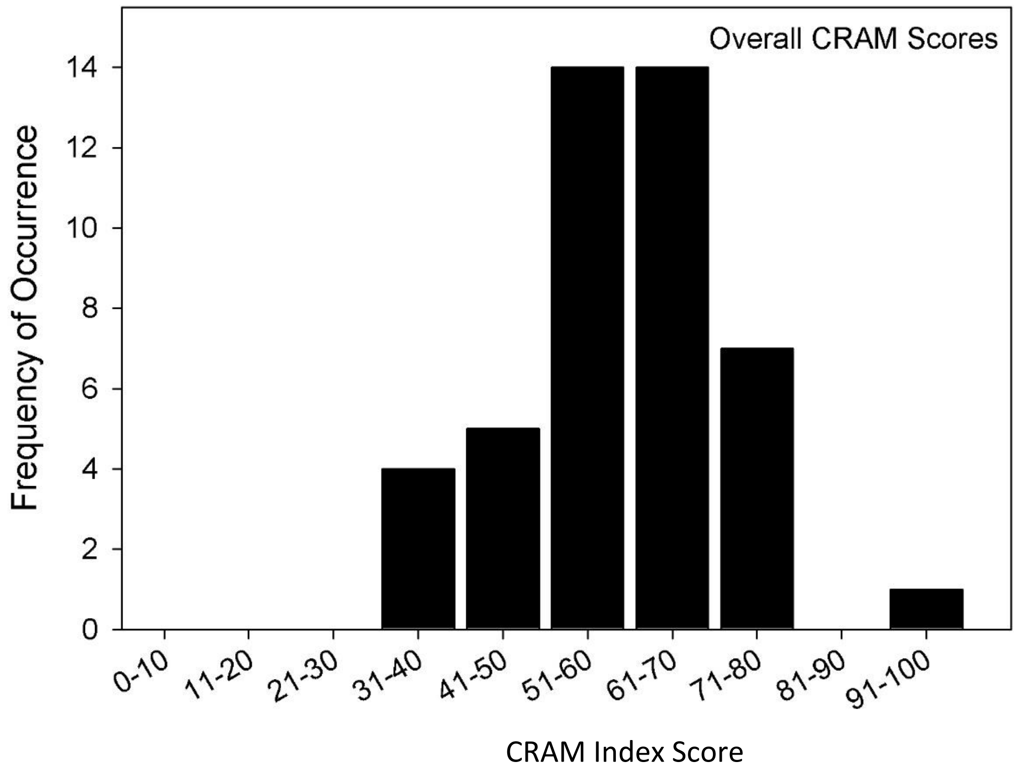

Figure 5. Histogram of CRAM Index scores (n = 45)

An extensive range of scores were measured for each CRAM Attribute: Buffer and Landscape Context 25-93, Hydrology 33-100, Physical Structure 25-100, and Biotic Structure 25-97 (Figure 6). We determined that each Attribute is responsive to varying conditions in and around the wetland of interest.

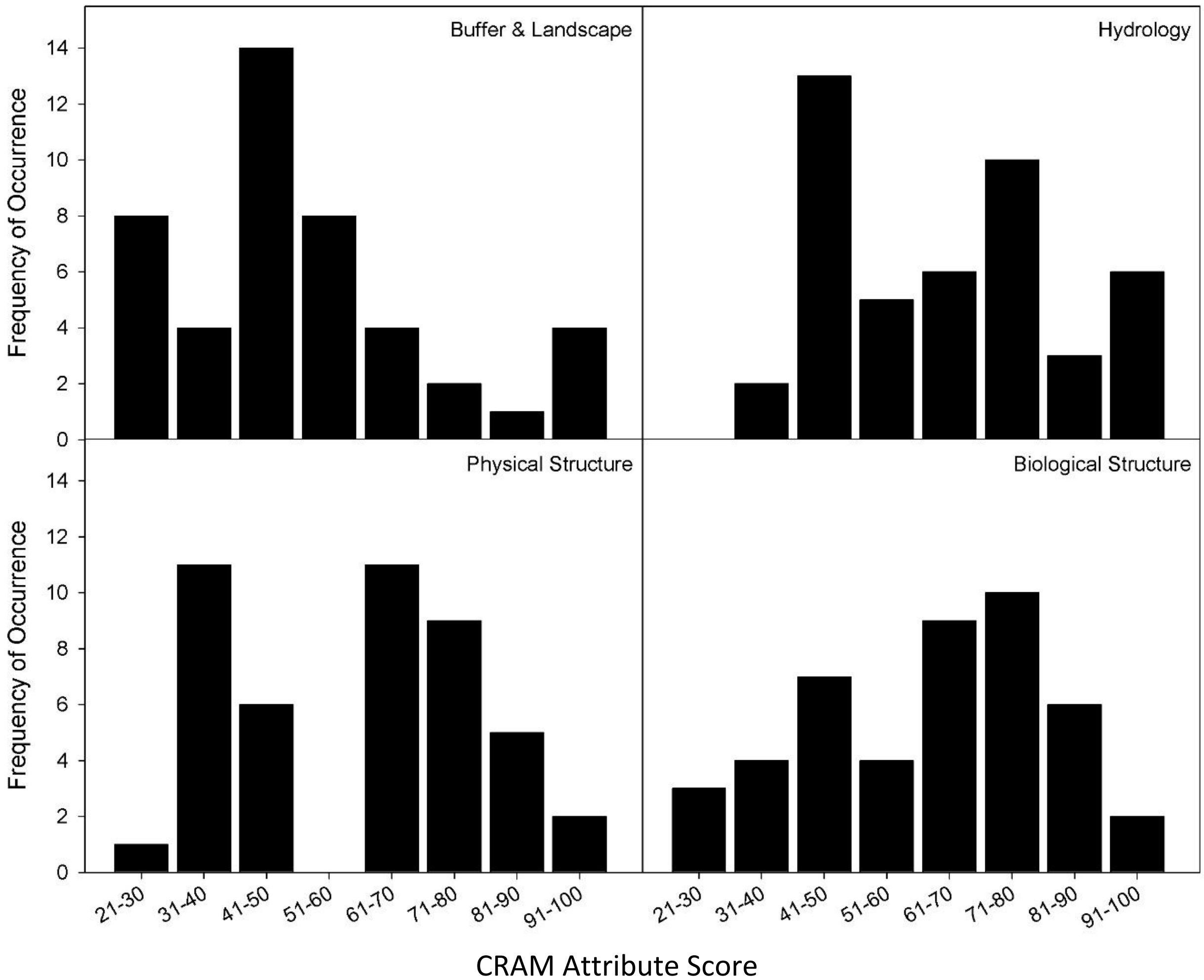

Figure 6. Histograms showing the distribution of data in each CRAM Attribute

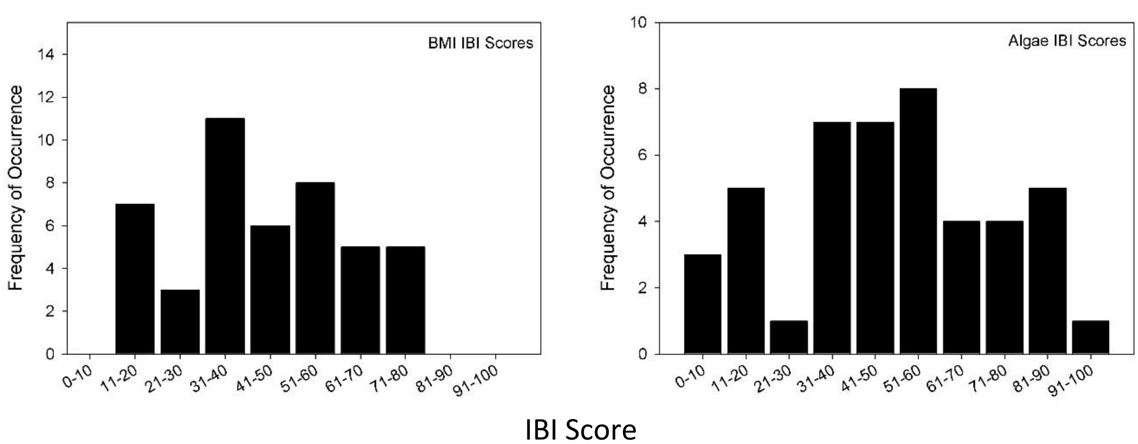

Figure 7. Histograms showing the distribution of data for the BMI and algae IBIs

The Level 3 indicators were found to have a similar wide range of IBI scores as found with CRAM (Figure 7).

The overall CRAM Index score and each Attribute score were tested for significant correlations with Level 3 data, including the BMI IBI, algae IBI, and water chemistry parameters.

Table 2 lists the results of all analyses with significant correlations' p-values shown in bold font (significant when compared to $\alpha = 0.05$). Interestingly, when a water quality parameter was significantly correlated, it tended to be significant across 3 CRAM Attributes: Buffer and Landscape Context, Hydrology, and Biotic Structure. Both the BMI IBI and the IBI D18 correlated significantly with the CRAM Index score as well as most Attributes. Water quality parameters of turbidity, pH, and dissolved oxygen did not significantly correlate with any Attributes, with the exception of pH, which correlated with the Biotic Structure. CRAM Physical Structure did not correlate significantly with any parameters, although it was marginally significantly correlated with the Algae IBI ($p = 0.1$).

Table 3. Spearman's rank correlations (ρ) and fdr-corrected p-values for all CRAM and CRAM metric comparisons to independent variables. P-values significant at the α = 0.05 level are printed in bold font.

	Overall CRAM	CRAM Buffer & Landscape Context	CRAM Hydrology	CRAM Biotic Structure	CRAM Physical Structure
BMI IBI	ρ= 0.42 **p = 0.01**	ρ = 0.34 **p = 0.03**	ρ = 0.47 **p = 0.005**	ρ = 0.29 p = 0.07	ρ = 0.11 p = 0.50
Algae IBI	ρ = 0.49 **p = 0.001**	ρ = 0.36 **p = 0.02**	ρ = 0.32 **p = 0.04**	ρ = 0.50 **p = 0.001**	ρ = 0.24 p = 0.10
Turbidity (NTU)	ρ = -0.19 p = 0.63	ρ = -0.04 p = 0.83	ρ = -0.05 p = 0.83	ρ = -0.30 p = 0.40	ρ = -0.15 p = 0.63
Water Temp (°C)	ρ = 0.23 p = 0.52	ρ = 0.05 p = 0.88	ρ = 0.13 p = 0.85	ρ = 0.03 p = 0.88	ρ = 0.37 p = 0.20
pH	ρ = -0.28 p = 0.10	ρ = -0.20 p = 0.10	ρ = -0.21 p = 0.24	ρ = -0.42 **p = 0.01**	ρ = -0.16 p = 0.30
Specific Conductance (µS/cm)	ρ = -0.38 **p = 0.02**	ρ = -0.36 **p = 0.02**	ρ = -0.33 **p = 0.04**	ρ = -0.39 **p = 0.02**	ρ = -0.09 p = 0.56
DO (mg/L)	ρ = -0.07 p = 0.85	ρ = -0.13 p = 0.85	ρ = -0.06 p = 0.85	ρ = -0.13 p = 0.85	ρ = 0.01 p = 0.96
Alkalinity ($CaCO_3$ average)	ρ = -0.32 **p = 0.05**	ρ = -0.34 **p = 0.05**	ρ = -0.34 **p = 0.05**	ρ = -0.25 p = 0.12	ρ = -0.07 p = 0.65

The significant correlations between the CRAM Index score and the level 3 indicators are of particular interest. The CRAM Index score was significantly correlated with both of the selected independent assessment protocols (BMI IBI and the Algae IBI) as well as expected water quality parameters (specific conductance) (Figures 8-11).

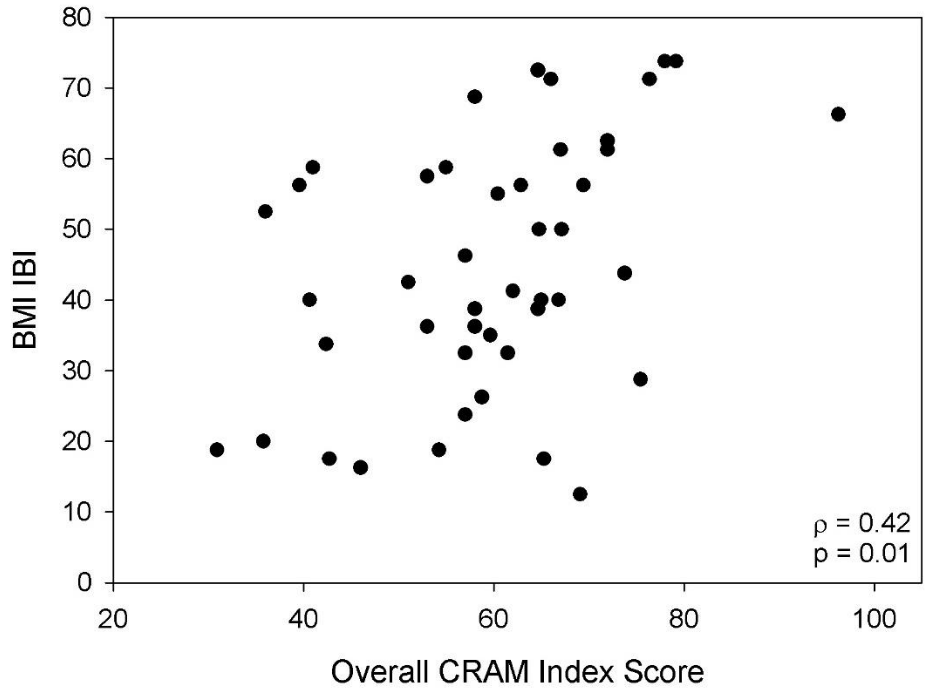

Figure 8. Correlation plot of CRAM Index score vs. BMI IBI

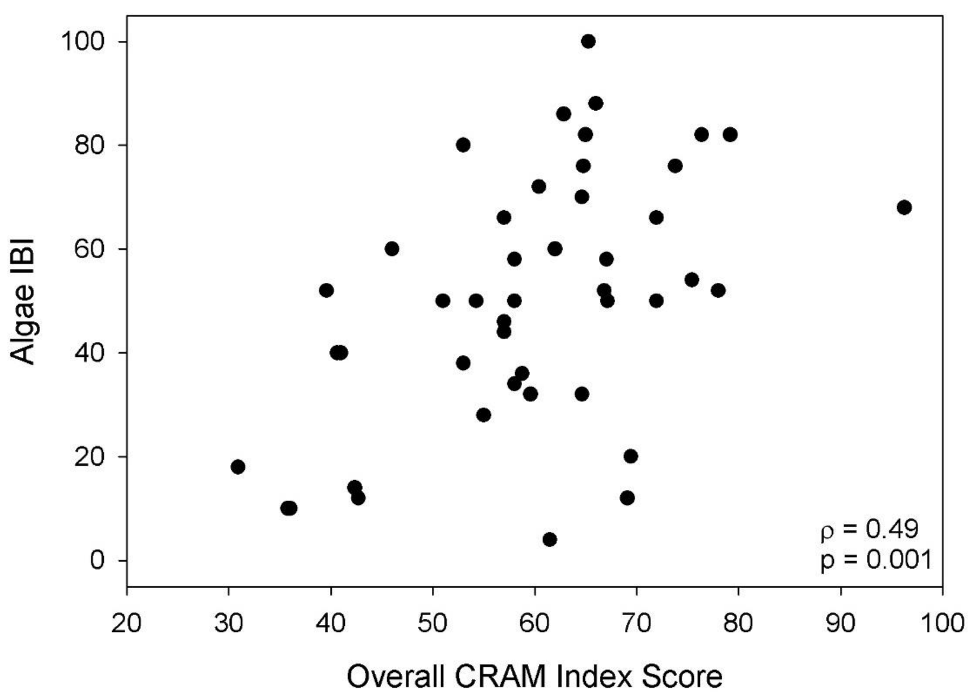

Figure 9. Correlation plot of CRAM Index score vs. Algae IBI

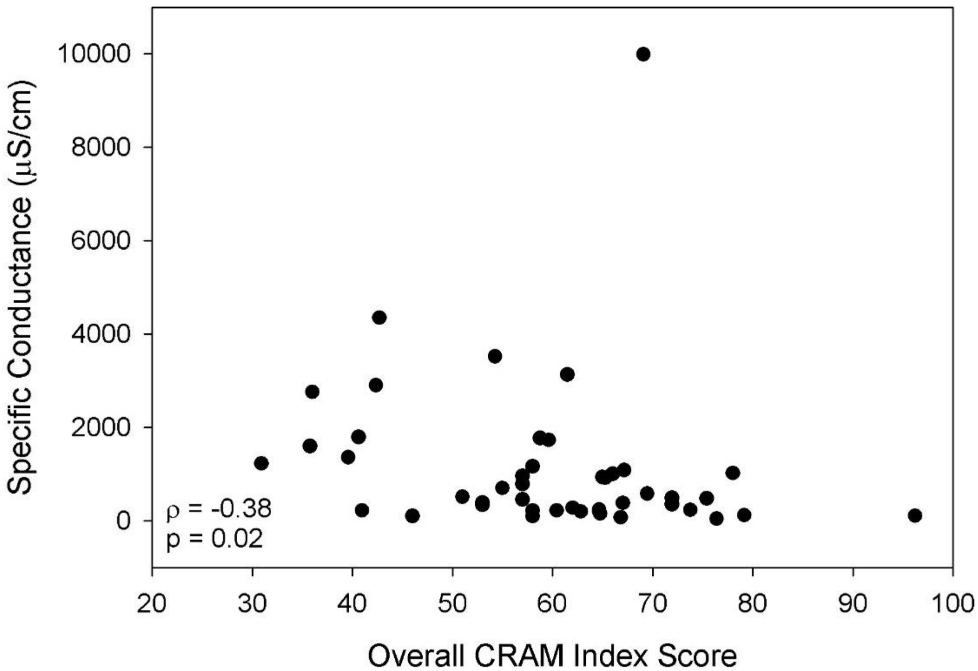

Figure 10. Correlation plot of CRAM Index score vs. Specific Conductance

The individual CRAM Attributes were also tested for correlation with the IBIs. The BMI IBI was significantly correlated with the Buffer and Landscape Context Attribute and the Hydrology Attribute (Figure 12). It was not significantly correlated with Physical Structure or Biotic Structure. The Algae IBI was significantly correlated with the Buffer and Landscape Context, Hydrology, and Biotic Structure Attributes, but not the Physical Structure Attribute (Figure 13).

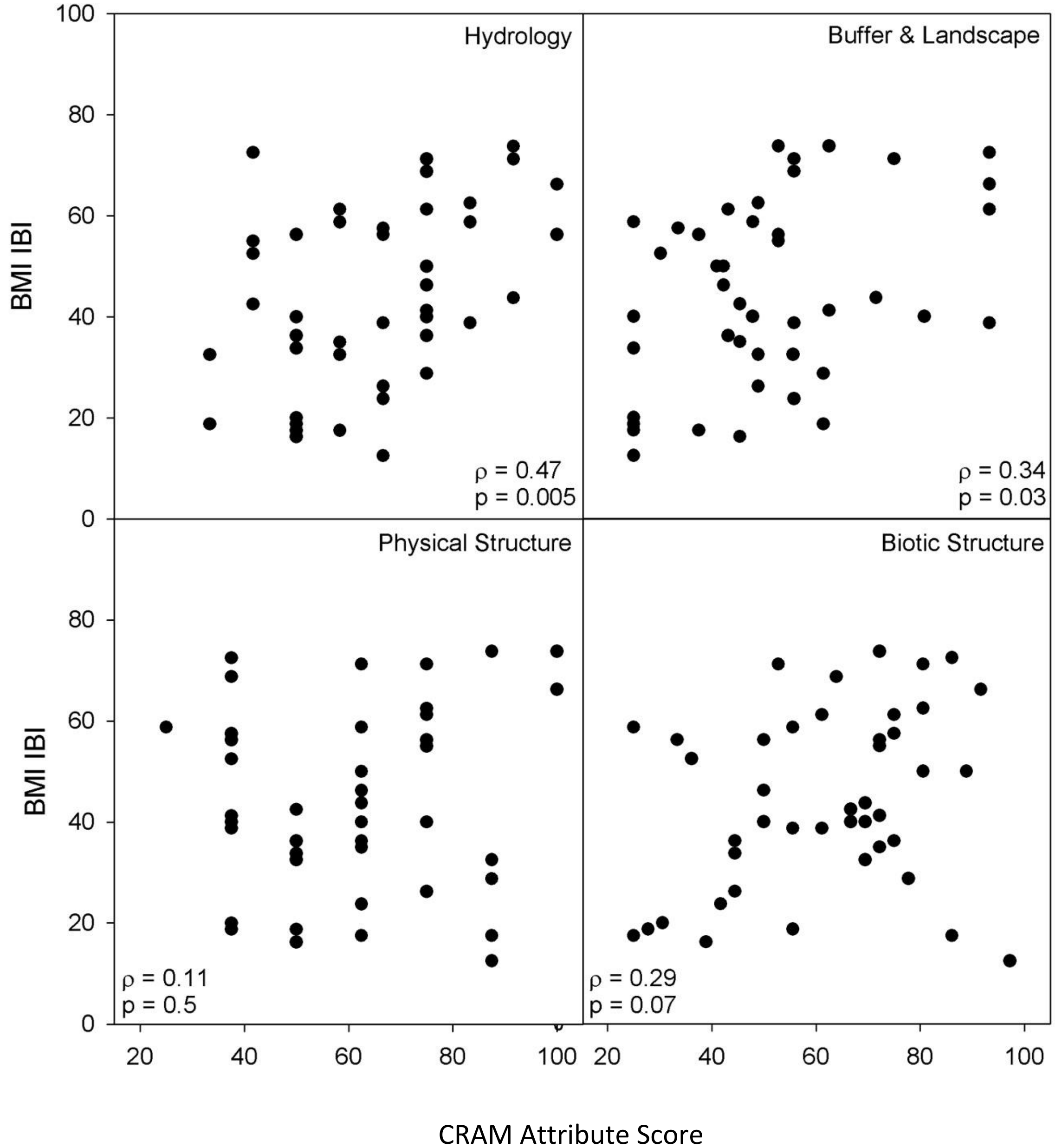

Figure 11. Correlation plots of the BMI IBI versus CRAM Attribute scores

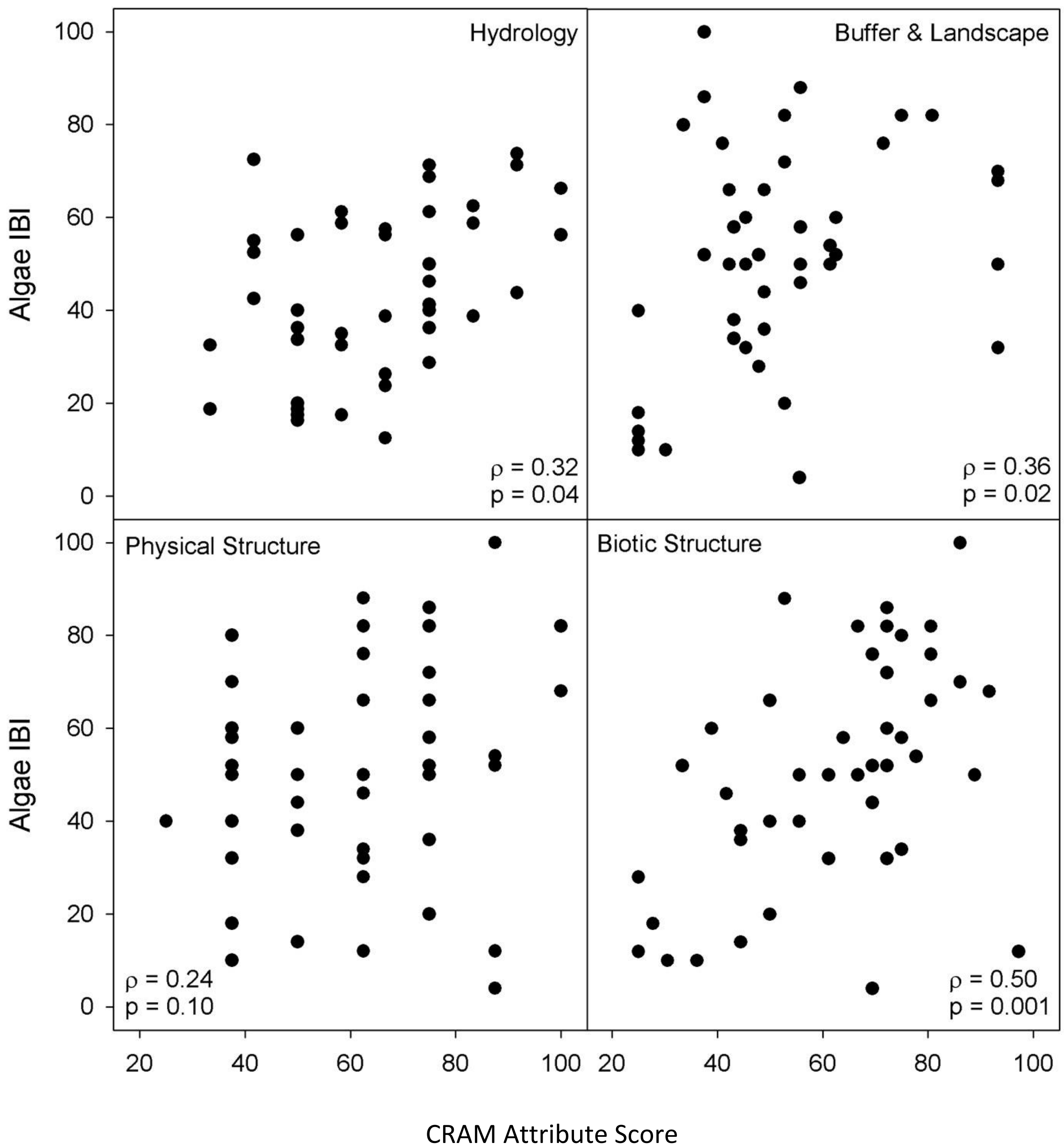

Figure 12. Correlation plots of the Algae IBI versus CRAM Attribute scores

Discussion

The goal of this project was to validate the CRAM module for Depressional 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 depressional 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. By partnering with wetland scientists throughout the state with extensive experience in California depressional wetlands, we have developed a tool that can be used successfully by most 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 depressional Attribute, with the exception of Physical Habitat, although its relationship to Algae IBI scores was nearly significant ($\rho = 0.24$, $p = 0.10$). Our analysis found that site CRAM Index scores were significantly correlated with the benthic invertebrate index (BMI IBI), the algae index (Algae IBI), and several water quality parameters (specific conductance and alkalinity). The CRAM Attributes Buffer and Landscape Context and Hydrology were significantly correlated with the same Level 3 parameters. Since the algae and macroinvertebrate indexes were developed to respond to disturbance and stress in the wetland, CRAM attributes that evaluate similar functions and areas of condition should reflect a similar gradient of impacts. Both the overall Index score and several predicted CRAM Attribute scores were correlated with the IBI scores. The Buffer and Landscape Context Attribute measures anthropogenic impacts from surrounding land use. Similarly, the macroinvertebrates and algae indexes are sensitive to those same impacts. The Hydrology Attribute evaluates the sources of water and potential contamination, the artificial manipulation of water flow, and the connection to adjacent transitional habitat. These factors similarly affect the composition of the algae and macroinvertebrate communities.

The water quality parameters that were most strongly correlated with CRAM scores were specific conductance and alkalinity. In addition, pH was correlated with the Biotic Structure Attribute. In the absence of marine sources, higher levels of conductivity often indicate an increase in human disturbance, which results in runoff high in salts and dissolved solids (EPA 2017). The significant correlation between CRAM and these parameters shows that CRAM is able to detect adjacent land uses which lead to impaired water quality.

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 Spearmans' Rho 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.

A number of the water chemistry measurements didn't correlate with CRAM, including turbidity, temperature, and dissolved oxygen, while pH only correlated with one CRAM Attribute (Biotic Structure). We expected a negative correlation between CRAM Attributes and turbidity and temperature measurements, because both indicate upland disturbances. Turbidity and temperature were expected to correlate negatively with CRAM Index scores, as a reduction in riparian cover can lead to higher temperatures, increased erosion (turbidity) and lower CRAM Index scores. Similar to findings by CRAM validation efforts for other modules, other factors appear to be affecting the quality of water flowing into the sampled wetlands, such as specific upstream land uses, local climate and geography (Sutula et al. 2006).

Most of the sites with high water temperatures were in the Central Valley, but had a range of CRAM Index scores reflecting site conditions. Other water quality parameters including dissolved oxygen also seems to be influenced by factors that don't relate to the overall condition of the wetland. Dissolved oxygen can vary widely at a single wetland in response to dynamic factors such as daily respiration fluctuations, so it may not be the best indicator of wetland condition. The pH of a system is more influenced by local geology and rainfall than overall wetland health.

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 Depressional CRAM module at the October, 2017 meeting.

The Depressional 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 Depressional CRAM module provides a meaningful, repeatable, and accurate assessment of wetland condition across the state of California.

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