HDR Inc. Contract 43A0304 (Task Order 18)
Project Name: California Rapid Assessment Method Statewide Study
San Francisco Estuary Institute, Richmond CA
April 25, 2016

Task 4:
Relationship between wetland condition, stress, and buffer

Introduction

The CRAM Manual explains that the condition of a wetland is the result of complex interrelationships among its natural formative processes, stress, disturbance, buffers, and wetland management. The condition of a wetland is defined as its capacity to provide high levels of its intrinsic ecological services. Wetland condition can be assessed based on observable indicators of its physical and biological form and structure in a landscape context. Stress is defined as an unnatural event or process that can negatively affect condition. A stressor is a source of stress. CRAM makes a clear distinction between stress and disturbance; stress is unnatural whereas disturbance is natural. Common stressors are industrial discharge, agricultural runoff, vegetation management, dredging, ditching, and the placement of fill. Common disturbances are floods, droughts, wildfire, and plant disease. CRAM includes a Stressor Checklist for identifying stressors that are likely to affect wetland condition. A buffer is defined as an area adjoining a wetland that can help protect it from outside stressors by mediating stress. CRAM includes specific metrics for assessing the extent and condition of buffers.

The possible negative impacts of stress on wetlands are many and varied. Most importantly, stress can reduce the extent of wetlands or negatively impact the natural processes and management practices that support their ecological services. In theory, the ability of a wetland to resist stress or recover from it depends on many factors including wetland type; wetland condition; stressor type; the number of stressors; the intensity, magnitude, frequency, and duration of stress; and the size and condition of the wetland buffer. Gradients of stress result from spatial variations in the diversity, magnitude, intensity, frequency, or duration of stress.

A key tenet of CRAM is that wetland managers can improve wetland condition by managing stress. Because most stress comes from outside the wetland, the presence of a buffer that surrounds the wetland can help reduce stress effects. Thus, in addition to directly managing the stressors, another way to reduce stress in a wetland is to manage its buffer. This puts a premium on being able to assess the interrelationships among wetland condition, stress, and buffer capacity.

Conceptual Models

As stated above, stressors are anthropogenic processes or events acting on a wetland that can diminish its condition, meaning the number and levels of its intrinsic ecological services. A buffer can help protect the condition of a wetland by mediating stress. The capacity of a buffer to mediate stress depends on its extent and structure.

These fundamental assumptions that underpin CRAM can be used to construct simple conceptual models of the interrelationships among wetland stress, buffer, and condition (see Figure 1 below). For the sake of simplicity, these models do not differentiate among the many important aspects of stress, such as its frequency, duration, intensity, extent, number of stressors involved, and the composition of the stressors. The intent of the models is to illustrate the alternative basic ways buffers can mediate the relationship between stress and condition.

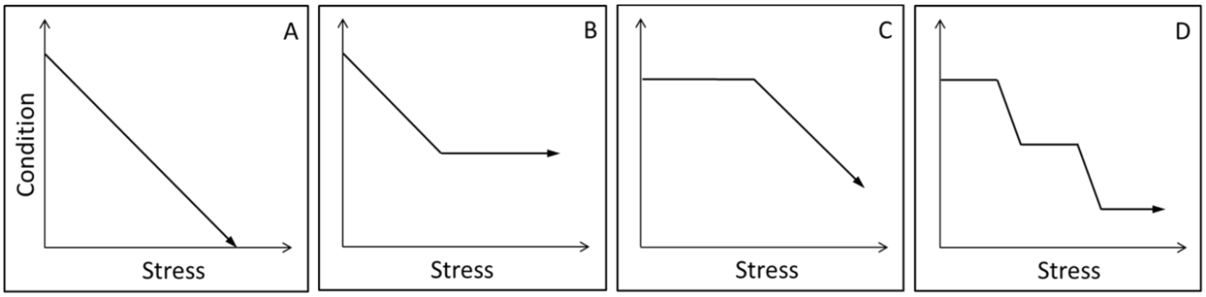


Figure 1. Conceptual models of the interrelationships among stress, condition, and buffer capacity showing (A) the neutral model featuring a constant, negative effect of stress on condition; (B) a variation of the neutral model featuring a minimum stress threshold that triggers mediation by the buffer; (C) an alternative to Model A and B whereby the buffer maintains condition up to a maximum threshold of buffer capacity or level of stress, at which point condition begins to decline; and (D) a variation of Model C showing multiple thresholds of buffer capacity or level of stress, whereby condition declines in a stepwise fashion.

The simplest model (Model A; see Figure 1A above) assumes that stress has a constant negative effect on condition; buffers have no effect on stress or condition when the level of stress is very low, but that buffers have a constant mediating effect on moderate to high levels of stress. The slope of the line relating condition to stress is a measure of the constant buffer effect. However, there are many reasons to expect that the relationship between stress and condition would not be constant. The capacity of buffers to mediate stress is likely to vary by stressor type and for different sets of stressors, resulting in non-linear relationships between stress and condition. There is abundant evidence, however, that in general, condition and stress are negatively correlated.

Three additional models of buffer effects have been developed (see Figures 1B-D above). A variation of the neutral model assumes that buffers have no measurable effect on condition until a lower threshold of stress is crossed, at which point the buffer begins to measurably mediate stress, and conditions are maintained (Figure 1B). This model presumably applies to stressors that trigger a buffer response. An example might be nutrient-rich runoff that triggers an increase in vegetation growth in the buffer that, in turn, increases the buffer's ability to sequester nutrients. An alternative model assumes that buffers measurably mediate condition until stress exceeds the mediating capacity of the buffer, at which point condition begins to decline (Figure 1C). The nutrient example is still illustrative, given that the ongoing load of nutrients might eventually saturate the buffer until it, too, becomes a source of excess nutrients. A variation of this model has multiple thresholds, each of which causes as a stepped decrease in condition (Figure 1D). The thresholds may be due to the level of stress exerted by one stressor or multiple stressors, or they may relate to buffer capacity, or a combination of these factors. There are many possible versions of these models representing different thresholds of stress and corresponding levels of wetland condition, different mediating capacities of the buffer, and non-linear effects of stress on buffer capacity or wetland condition.

Knowing which, if any, of these conceptual models reasonably represents the relationship between wetland stress, buffer capacity, and condition as measured by CRAM would help wetland managers adapt buffer designs and management practices to levels of stress. Ideally, CRAM would include independent scores for buffer capacity, stress, and wetland condition that could be used by managers to guide their efforts to manage wetland stress.

Buffer Capacity Index

Developing an index to assess the capacity of wetland buffers to mediate stress is complicated by many factors. The CRAM Condition Index is designed to assess the potential of a wetland to provide high levels of its intrinsic ecosystem services. For any wetland, the potential number and kinds and levels of service can be affected by wetland type, landscape or watershed position, environmental setting, climate, wetland age, and management practices. CRAM resolves this complexity into a simple measure of condition based on the fundamental assumption that the capacity of a wetland to provide its services is positively correlated to its biological and structural complexity in a landscape context.

How stressors influence these factors and how these influences are mediated by a buffer are also complex. According to the CRAM User's Manual, the capacity of a buffer to mediate stress is positively correlated to the percent of the wetland area that has buffer, the average width of the buffer, and its condition. The CRAM Buffer Metric score is a combination of scores for these three Sub-metrics.

As suggested above, efforts to analyze the interrelationships among stress, condition, and buffer capacity requires independent measures of stress, wetland condition, and buffer capacity. For this analysis, the Buffer Condition Sub-metric was excluded from measures of buffer capacity because it consists of field indicators of stress and is therefore likely to be auto-correlated with the Stress Index.

In Task 5, *The effects of aquatic area abundance, buffer, and hydrology on depressional wetland condition based on CRAM*, projects and non-project wetlands were compared based on the amount of buffer, calculated as the square root of the product of two Buffer Sub-metrics, the Percent of AA with Buffer and Average Buffer Width. For the purposes of analyzing the interrelationships among stress, condition, and buffer, the measure of buffer amount used in Task 5 is probably not an adequate measure of buffer capacity. An index based only on buffer amount disregards buffer structure. For example, in an instance where a large expanse of rangeland surrounds a depressional wetland, the buffer amount would be high, however the rangeland does not necessarily prevent the grazing stock from entering and severely impacting the wetland. The same area densely covered by shrubs would probably have greater buffer capacity with regard to grazing. Fencing cattle out of the wetland might provide even greater protection.

To more accurately capture the complexities of Buffer Capacity, we propose a Buffer Capacity Index (datasheet in Appendix 1), which consists of two Metrics, each with Sub-metrics (Table 1).

Table 1: Composition of the Buffer Capacity Index.

Composition of the Buffer Capacity Index	
Metric	**Sub-Metrics**
Buffer Amount	Percent of AA with Buffer (as per existing CRAM)
	Average Buffer Width (as per existing CRAM)
Buffer Structure	Average Topographic Slope (see Table 2)
	Groundcover Density (see Table 3)
	Buffer Management (see Table 4)

Buffer Amount Metric

The Buffer Amount Metric is comprised of two Sub-metrics, Percent of AA with Buffer and Average Buffer Width. These two Sub-metrics are scored as per existing CRAM.

Buffer Structure Metric

The Buffer Structure Metric is comprised of three Sub-metrics: Average Topographic Slope, Groundcover Density, and Buffer Management. These three Sub-metrics are scored using the following description.

An increase in topographic slope can increase the rate of surface runoff or vadose flow into a wetland and thus decrease the capacity of a buffer to mediate the rate of change in the wetland hydroperiod or to filter the runoff of nutrients, fine sediments, or other contaminants. For the purposes of this analysis, the following rules were adopted for scoring the Average Topographic Slope Sub-metric (Table 2).

Table 2: Mutually exclusive alternatives for scoring the Average Topographic Slope Sub-metric.

Topographic Slope within 10 m of the AA Boundary	Rating
Average slope within is < 5% (2.5 degrees)	A
Average slope is between 5% and 20% (2.5 to 11.5 degrees)	B
Average slope is between 20% and 50% (11.5 to 26.5 degrees)	C
Average slope is > 50% (26.5 degrees)	D

The density of ground cover can also affect rate of surface runoff while helping to shield the wetland from people, stock animals, and feral pets. For the purposes of this analysis, the following rules were adopted for scoring the Groundcover Density Sub-metric (Table 3).

Table 3: Mutually exclusive alternatives for scoring the Groundcover Density Sub-metric.

Buffer Condition	Rating
Groundcover of Buffer, with or without tall trees, is mostly thatch, mulch, or leaf litter under dense brush, shrubs, or young trees. The groundcover serves as a filter for runoff whereas the brush etc. serves as a barrier that is difficult for people and stock animals to walk through, see through, or see over; area may be penetrated by game trails.	A
Groundcover of Buffer, with or without tall trees, is mostly thatch, mulch, leaf litter or abundant forbs and tall grasses mixed with brush, shrubs, or young trees that form a moderate barrier to people and stock animals and an effective filter for runoff (disregarding topographic slope); area may be penetrated by game trails.	B
Groundcover of Buffer, with or without tall trees, is mostly lacking thatch, mulch, leaf litter or abundant forbs, is largely dominated by short grasses, and probably serves as a poor barrier to people and stock animals, but can probably serve as a moderately effective filter for runoff (disregarding topographic slope).	C
Groundcover of Buffer, with or without tall trees, is mostly bare ground or sparse grasses lacking thatch, mulch, leaf litter or forbs and probably cannot effectively filter runoff.	D

In addition to the topographic slope of a buffer and its groundcover density, how the buffer is managed can also affect its capacity to buffer the wetland against stress. For example, a fence around a wetland can significantly mediate or even nullify stressors such as grazing, visitation by feral pets, and recreational overuse. In the case of some vernal pool systems and seasonal depressional wetlands, grazing is an important method to protect wetland flora and fauna. Wetland buffers in protected lands, such as parks, preserves, and wildlife refuges may lack the necessary structure for good buffer capacity but be very unlikely to ever be subject to moderate or high levels of stress. Without reflecting these kinds of management factors, the Buffer Capacity Index might falsely indicate lower capacity than what actually exists. This situation was encountered multiple times during the current analysis.

To prevent false assessments of buffer capacity due to the disregard of beneficial buffer management, a set of criteria were developed to determine when the Buffer Capacity ranking should be adjusted upward for favorable management practices (Table 4). The adjustment requires knowing the management regime for the wetland area and its buffer. The necessary knowledge can be garnered from online management reports and from field indicators such as fencing and signage.

Table 4. Criteria for scoring the Buffer Management Sub-metric. This Sub-metric adjusts the Buffer Structure Metric to reflect long-term favorable Buffer Management. These criteria should be used to determine whether or not the buffer is subject to long-term management practices that effectively increase buffer capacity. The practitioner will enter either a “3” or a “0” into the datasheet (Appendix 1), based upon these criteria.

Buffer Management	Metric Adjustment
First, the AA must have a score of 12 for the Buffer Amount Metric. If this condition is met, THEN The wetland buffer is entirely publicly owned and managed for the protection of the wetland, and the management practices and stressor regime is unlikely to change in the foreseeable future (the management practices can include vegetation control through grazing and other means if the Stress Index does not provide evidence that such stressors are causing wetland stress). OR The wetland is fenced at its perimeter, and the fence is not in disrepair, and is it constructed such that it prevents excessive grazing and recreational overuse, while allowing native wildlife, such as deer, elk, coyote, bobcat, etc. to access the wetland. OR The wetland buffer is not publicly owned and the wetland area is not adequately fenced as in the criteria immediately above, but the long-term buffer management regime is consistent with wetland protection, as evidenced by the condition of the wetland, and there is signage or posted information designed to protect the wetland (examples of this situation can include military lands, airports, golf courses, and municipal parks).	3 points (if the first criterion and any one of these other three criteria is met)
The AA has a score of <12 for the Buffer Amount Metric; OR The wetland buffer is not managed to protect the wetland from stress, regardless of its score for the Buffer Amount Metric.	0 points (if either of these criteria is met)

Buffer Capacity Index Calculation

A four-step procedure is used to calculate the Buffer Capacity Index, as outlined below (Table 5).

Table 5: Procedure to calculate the Buffer Capacity Index. The datasheet is included as Appendix 1.

Step 1	Buffer Amount Metric	a) Score the Percent of AA with Buffer Sub-metric. b) Score the Average Buffer Width Sub-metric. c) Calculate the Buffer Amount Metric as the square root of the product of the Percent of AA with Buffer and the Average Buffer Width Sub-metrics. The minimum score is 3, the maximum score is 12.
Step 2	Buffer Structure Metric	a) Score the Average Topographic Slope Sub-metric. b) Score the Groundcover Density Sub-metric. c) Score the Buffer Management Sub-metric. d) Calculate the Buffer Structure Metric as the square root of the product of the Average Topographic Slope and the Groundcover Density Sub-metric. Then add the Buffer Management Sub-metric score. The maximum score is 15.
Step 3	Buffer Capacity Index Score	a) Calculate the Buffer Capacity Index score as the sum of the scores for the Buffer Amount Metric and the Buffer Structure Metric divided by 27 (the maximum possible Buffer Capacity Index score) and convert the quotient to a percent. The minimum score is 22, the maximum score is 100.
Step 4	Rank the Buffer Capacity Index Score	Rank the Buffer Capacity Index score as poor, fair, or good, using the following tertiles: 22-48% is poor 49-74% is fair 75-100% is good

Condition Index

In Task 5, *The effects of aquatic area abundance, buffer, and hydrology on depressional wetland condition based on CRAM*, a rationale is presented for excluding the measures of condition outside a wetland from the assessment of its condition. It was noted that both the Hydrology Attribute and the Buffer and Landscape Context Attribute involve multiple Metrics that at least sometimes are used to assess the environmental setting of a wetland rather than the wetland itself. Here it is noted that the Hydrology Attribute consists entirely of indicators that assess departure from natural hydrology and therefore, to a large degree, individually and collectively represent stress. In order to assure that wetland condition is assessed independently of stress, the Hydrology Attribute was excluded from the Condition Index. As explained below, the indicators of the Hydrology Attribute were incorporated into the proposed Stress Index.

Given that the Aquatic Area Abundance Metric of the Buffer and Landscape Context Attribute pertains to conditions outside wetlands, it was excluded from the Condition Index used to analyze interrelationships among stress, wetland condition, and buffer. The usefulness of the Aquatic Area Abundance Metric for ambient surveys of wetland connectivity and for siting wetlands to improve their connectivity is acknowledged (see Task 5, *The effects of aquatic area abundance, buffer, and hydrology on depressional wetland condition based on CRAM*). However, this Metric can add variability to the assessment of wetland condition that can obscure its relationships to stress and buffer capacity.

For depressional wetlands, the Biotic Structure Attribute includes a Sub-metric of the Plant Community Composition Metric used to reduce the score for wetland condition based on the prevalence of non-native, invasive plant species. Because biological invasion is generally considered a stressor, this Sub-metric was excluded from the calculation of the Condition Index. As explained below, biological invasion was incorporated into the proposed Stress Index.

Based on these considerations, the Condition Index used to analyze interrelationships among stress, wetland condition, and buffer consists of the Physical Structure Attribute and the Biotic Structure Attribute, sans its Percent Invasion Sub-metric. To distinguish it from the Original Condition Index, it is referred to as the NoBLNoH Index (i.e., no Buffer and Landscape Context Attribute and no Hydrology Attribute – see discussion of NoBLNoH Index in the Task 5 memo).

Stress Index

Overview

The Stress Index is a proposed addition to CRAM. In combination with the proposed Buffer Capacity Index and the NoBLNoH Index, the Stress Index is intended to support analyses of the interrelationships among stress, wetland condition, and buffer capacity.

For a variety of reasons, the existing CRAM Stressor Checklist cannot meet the need for quantitative stress assessment. Past conversions of the Stressor Checklist into a Stress Index have not performed well. One large concern is inconsistent use of the Checklist among CRAM practitioners and their varying bias. For example, practitioners who are botanists tend to see more invasive plant species than other practitioners, and they tend to have a more sensitive set of criteria for assessing the severity of invasion. CRAM practitioners with rangeland management experience tend to evaluate the intensity of grazing differently than other practitioners. Practitioners who are professional wetland scientists can be especially discerning about the effects of wetland management practices. The purpose of an assessment can also influence the meaning of the Checklist. Surveys of ambient condition can be less focused on management effects than assessments of projects. The understanding and sense of priority of the stressors included in the Checklist can vary by region. And most importantly, the Checklist is not quantitative. While it can be used to identify the stressors most commonly evidenced in the field, and to identify stressors that might account for poor conditions, it cannot be used to assess levels of stress.

As described in the CRAM User's Manual, the existing Stressor Checklist is based on a number of assumptions. These assumptions have been used to guide development of a quantitative Stress Index.

- Most wetland stress originates outside wetlands.
- Deviation from the best achievable wetland condition can be explained by a single stressor or multiple stressors acting on the wetland.
- Increasing the number of stressors acting on the wetland will cause a decline in its condition.
- Increasing either the intensity or the proximity of a stressor will result in a greater decline in condition.
- Continuous or chronic stress will increase the decline in condition.
- The occurrence of stress can be assessed based on visible field indicators.

The purpose of the Stress Index is to help wetland managers identify and evaluate the relative importance and impact of different local stressors, and assist in buffer design and management to mediate the stress. Based on the purpose, the following criteria for a successful Stress Index have been drafted. Stress Index should be:

- Rapid;
- Quantitative;
- Scientifically sound;
- Unbiased and repeatable;
- Based on clear field indicators;
- Compatible with the CRAM Condition Index;
- Consistent with CRAM practitioner experience;
- Applicable across all wetland types and regions of California.

The primary sources of information used to develop the proposed Stress Index are experience with CRAM and especially the Stressor Checklist, plus experience developing and applying the USA-RAM Stress Index across multiple wetland types subject to a large array of stressors. To a large degree, the USA-RAM Stress Index has served as the model for the proposed CRAM Stress Index.

Stress Index Structure

Based on the assumptions and criteria listed above, and to assure compatibility between the CRAM Stress Index and the CRAM Condition Index, the following structure was adopted for the Stress Index.

- The Stress Index is comprised of Attributes, and each Attribute consists of separate Metrics.
- In order to prevent any one Metric from having an inordinate influence on Attribute scores, and to prevent their unintended weighting, each Attribute consists of four Metrics.
- Each Metric is assessed based on numerous field indicators of stress.

The selection of Attributes for the Stress Index depended mainly on USEPA guidance for evaluating environmental stress, the guiding assumptions and criteria listed above, and the following basic criteria for assuring that the Attributes have adequate information content. Each Attribute should:

- Be unique;
- Be assessable using at least three Metrics;
- Relate to a major, commonly recognized category of stressor;
- Be an integral part of a set of Attributes that represents all major, common stressors.

Based on all these considerations, five Attributes were defined: Land Use, Chemical, Hydrologic, Physical, and Biologic.

The selection of the four Metrics for each Stress Attribute was not guided by specific selection criteria. Instead, candidate Stress Indicators were identified from the CRAM Hydrology Attribute, Buffer Condition Sub-metric, Percent Invasion Sub-metric, Condition Stressor Checklist, and the USA-RAM Stressor Index lists. Each candidate Indicator was evaluated based on all the assumptions and criteria for a successful Stress Index, meaningful Attributes, plus the following Indicator section criteria. Each Stress Indicator should be:

- Commonly evident in California;
- Common to all CRAM (or CARI) wetland types;
- Consistent with lessons learned from the USA-RAM Stress Index;
- Consistent with lessons learned from the CRAM Stressor Checklist;
- Based on features or actions that are observable in the field or on aerial photographs and that are likely to affect wetland condition, as measured by the CRAM Condition Index.

More than 100 Stress Indicators were selected based on these criteria. Each of these Indicators was assigned to one of the five Stress Attributes based on their likely causative stressors. For example, land use Indicators were assigned to the Land Use Attribute; chemical indicators were assigned to the Chemical Attribute, and so forth. The indicators currently included in the Hydrology Attribute, Buffer Condition Sub-metric, and Percent Invasion Sub-metric were incorporated into the Stress Index.

Each Stress Indicator of each Attribute was assigned to one of four groups of Indicators according to similarities in their usual landscape setting or mode of stress. For example, all the Land Use Stress Indicators relating to vehicular transportation as a stressor, (such as highways, arterial roads, rural roads, parking lots, railroads, air traffic lanes), were grouped apart from Land Use Stress Indicators relating to agriculture, (such as truck crops, vineyards, orchards, hay fields, dairies, feed lots, pasture, rangeland). The four obvious groupings of Indicators for each Attribute comprise its four Metrics. The Stressor Attributes, Metrics, and Indicators are presented in the Stress Index Field Book (Appendix 1).

Unlike the Condition Index, which uses different modules to account for the natural differences in form and structure among different types of wetlands, there are no modules of the proposed Stress Index. It is expected to be equally applicable to all wetland types. This expectation is based on the basic tenet of the USA-RAM Stress Index, affirmed by its national application, that all types of wetlands are subject to the same kinds of stressors to varying degrees, and that their effects can be evidenced by one set of field indicators for all wetland types.

Stress Index Calculation

To assure compatibility with the CRAM Condition Index, the process used in its calculation was adopted for calculating the CRAM Stress Index.

- The raw score for each Stress Attribute is the sum of its four Stress Metric Scores.
- The final score for each Stress Attribute is its raw score stated as a percent of the maximum possible raw score.
- The Stress Index score is the average of all the final Stress Attribute scores.

The same procedure is used to score each Metric of each Stress Attribute. The procedure is based on assumptions outlined in the documentation of the USA-RAM Stress Index. These assumptions indicate the level of impacts caused by stress should be positively correlated to the number of effective stressors, negatively correlated to the distance between the stressors and the wetland, and positively correlated to the frequency of stress, its extent, and its intensity within the wetland (i.e., the severity or magnitude of the stress).

All the Stress Metrics are scored according to the same procedure, as guided by the Stress Index Field Book (Appendix 2). The CRAM practitioner determines the presence or absence of each Stress Indicator within a standard Stress Assessment Area (SAA). The SAA includes the Condition Assessment Area (AA) plus an area extending 250m from the AA perimeter. For AAs that have the maximum amount of buffer, the portion of the SAA outside the AA and the buffer area are the same. For each observed Indicator, the practitioner assesses the proximity of its stressor to the AA, and then assesses the severity of the associated stress. Severity is scored based on separate assessments of stress extent, which is equated to the percentage of the AA in which the indicator is evident, and the magnitude or intensity of the stress, which is based on the obviousness and spatial density of the indicator. The severity score is based on the scores for stress extent and intensity. The Metric score is the product of the proximity score and the severity score. As stated above, the raw Stress Attribute score is the sum of its four Metric scores, and the final Attribute score is the raw score divided by maximum possible raw score, converted to a percent. The final Stress Index score is the average of the five final Attribute scores. Based on the assumptions that underpin CRAM, and given the conceptual models presented above, higher Stress Index scores indicate greater stress, and lower scores indicate lesser stress.

Management Questions

Existing CRAM assessments can be used to compute independent scores for the Buffer Capacity Index, revised Condition Index, and Stress Index described above. The scores can be used to address the following questions that frame the interrelationships among these indices. The answers to these questions can help protect wetlands by informing efforts to manage their stress.

1. Is there a relationship between wetland stress and wetland condition?
2. Is there a relationship between buffer capacity and wetland condition?
3. Is there a relationship between buffer capacity and stress?
4. Does buffer capacity mediate stress?

Dataset

The dataset used to develop the Stress Index was derived from the depressional wetland assessments of 2007 to 2015 (n= 393) accessed from the statewide CRAM database (www.cramwetlands.org). A total of 38 of these assessments were selected based on the following criteria:

- They were assessed by the Stress Index development team;
- In aggregate they represent a broad range in condition and stress.
- They are supported by abundant field notes and field photographs not available in the statewide dataset;
- They represent wetlands where the relationship between condition, stress, and buffer is unlikely to have been substantially altered by management practices. Application of this criterion required expert knowledge of the selected wetlands and their assessments.

To calculate the Stress Index scores for the 38 selected wetlands, a desktop version of the Stressor Index was implemented, using high resolution aerial imagery, original field notes and photographs of each of the 38 selected wetlands, and personal memories of the field assessments. Scores for the Buffer Index and revised Condition Index were calculated from the original field data. For these same 38 wetlands, a desktop version of the Buffer Capacity Index was also implemented using the same resources.

Results

Question 1: *Is there a relationship between wetland stress and wetland condition?*

Null Hypothesis: There is no relationship between stress and wetland condition.

Summary of Findings: The null hypothesis is rejected. Stress and condition are negatively correlated.

To address this question, Condition Index scores were regressed on Stress Index scores separately for two versions of the Condition Index. The initial regression involved the Original CRAM Condition Index based on all the Metrics of all the Condition Attributes (Figure 2). This regression tested for correlation between the proposed Stress Index and the existing version of the Condition Index that might continue to be used for the foreseeable future. A subsequent regression involved a version of the Condition Index that is based only on the Physical Structure Attribute and the Biologic Structure Attribute sans its Percent Invasion Sub-metric. This version of the Condition Index also excludes the Hydrology Attribute and the Buffer and landscape Context Attribute. It is referred to as the NoBLNoH Index in Task 5 (Figure 3). As explained below, the purpose of this regression was to test for correlation between the proposed Stress Index and a version of the Condition Index excluding autocorrelation.

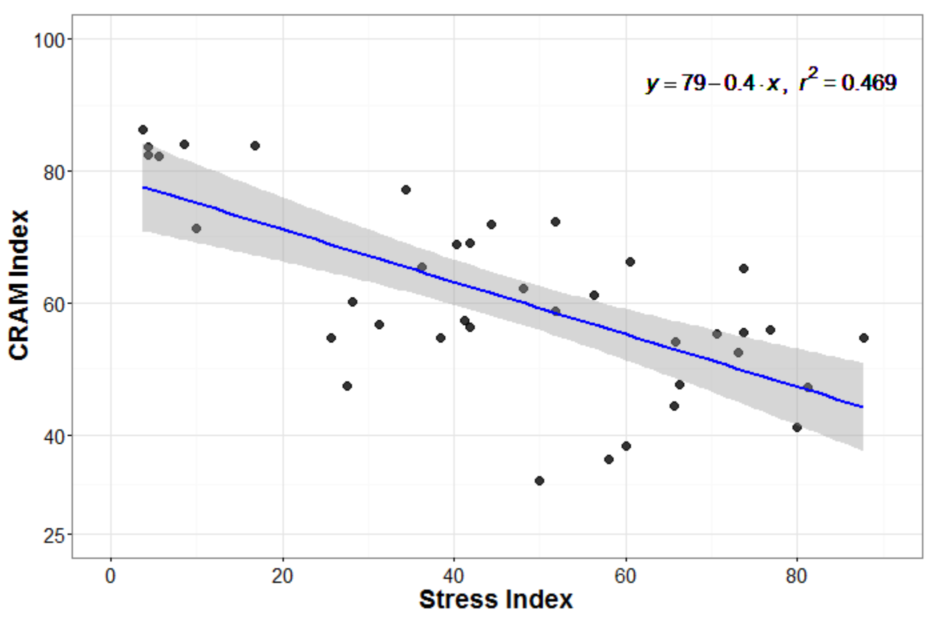


Figure 2. Results of regressing the Original CRAM Condition Index on the proposed Stress Index, showing a significant negative correlation.

As expected, the Original CRAM Condition Index is negatively correlated to the Stress Index (Figure 2). To help understand this correlation, regression analysis was used to explore relationships between the Stress Index and the Attributes of the Original Condition Index (see Figure 3 below). Each of the four correlations is negative, and the strongest correlations are for the Hydrology Attribute and the Buffer and Landscape Context Attribute (See Figures 3A and 3B). This undoubtedly represents some degree of autocorrelation, given that these two Attributes include Stress Metrics. One obvious inference is that the autocorrelation between the Stress Index and these two Condition Attributes accounts for much of the correlation between the Stress Index and the Original CRAM Condition Index.

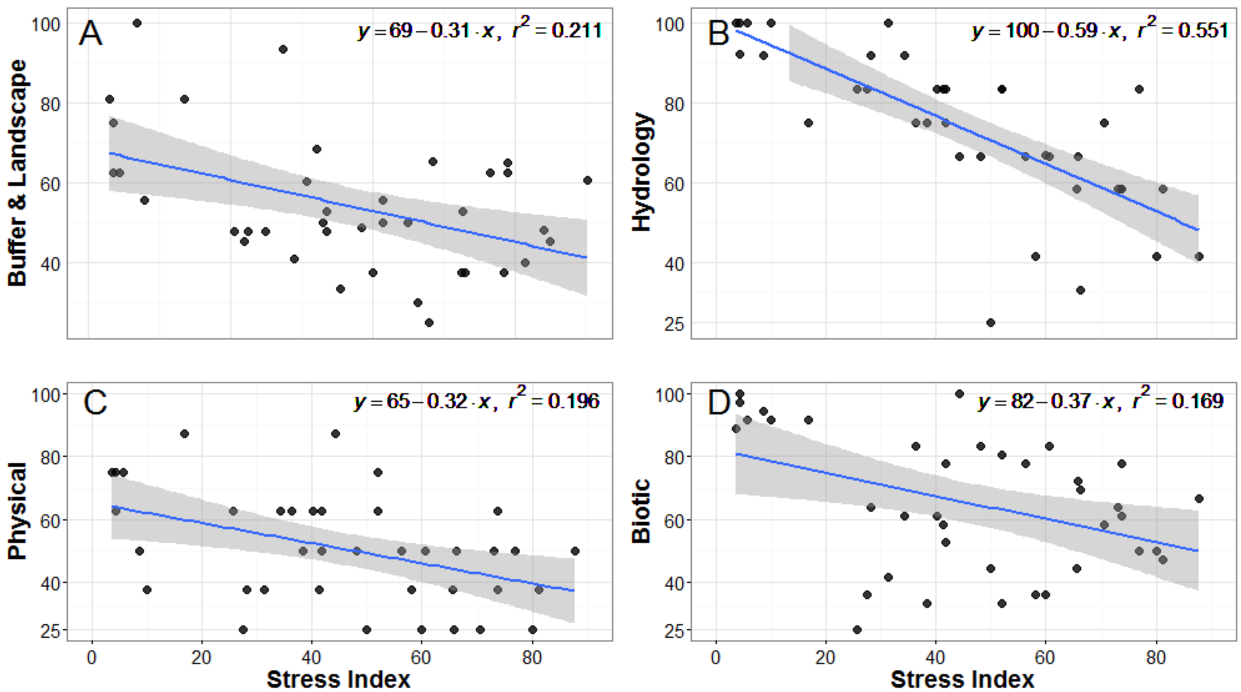


Figure 3. Results of regressing Attribute scores from the Original Condition Index on Stress Index scores for (A) Buffer and Landscape Context, (B) Hydrology, (C) Physical Structure, and (D) Biotic Structure.

Based on the results presented in Figure 3, the auto-correlation between the Stress Index and the Condition Index can be removed by replacing the Original Condition Index with the NoBLNoH Index (i.e., excluding the Hydrology Attribute, the Buffer and Landscape Context Attribute, and the Percent Invasion Sub-metric of the Biotic Attribute). Excluding the autocorrelation weakens the regression between condition and stress. However, it is still significantly negative (Figure 4), consistent with the first conceptual model (see Figure 1A).

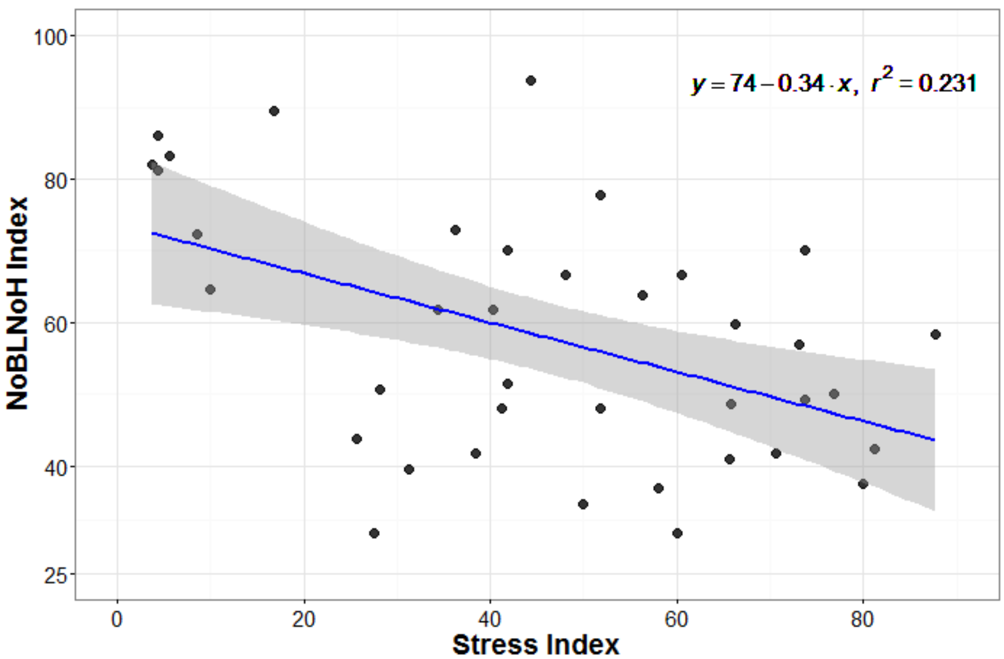


Figure 4. Results of regressing the modified Condition Index on the proposed Stress Index excluding autocorrelation, showing a negative correlation.

Question 2: *Is there a relationship between buffer capacity and wetland condition?*

Null Hypothesis: There is no relationship between buffer capacity and wetland condition.

Summary of Findings: The hypothesis is rejected. There is a positive correlation between buffer capacity and wetland condition.

This question is based on the CRAM assumption that buffers can mediate stress and thus reduce its effects on wetland condition. To test this assumption, the Buffer Capacity Index was regressed on the NoBLNoH Index. A positive correlation is clearly evident (see Figure 5 below) that supports the assumption.

Although the data are scant, the results suggest that moderate or better conditions require at least moderate buffer capacity. That is, there are no high condition scores associated with low buffer capacity scores. This is consistent with the assumption that wetland buffers can mediate the effects of stress on wetland condition.

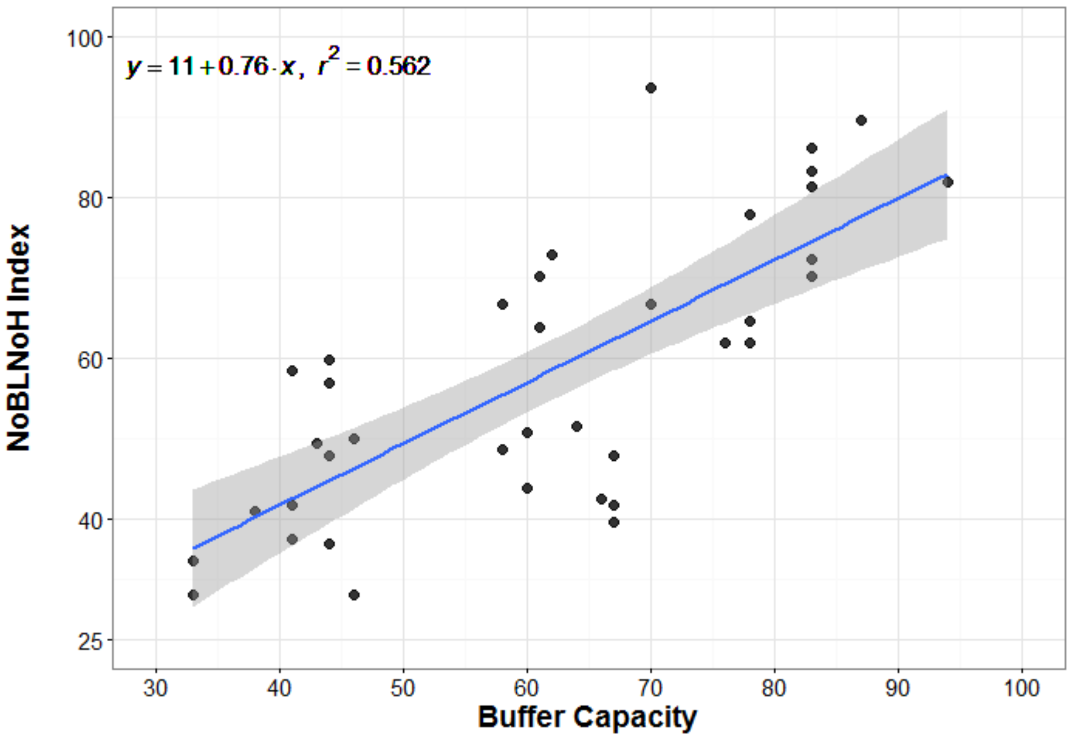


Figure 5. Results of regressing Condition on Buffer Capacity, where condition is measured as the NoBLNoH Index that excludes condition Attributes and Metrics autocorrelated with the Stress Index.

Question 3: *Is there a relationship between buffer capacity and stress?*

<u>Null Hypothesis:</u> There is no relationship between buffer capacity and stress.

<u>Summary of Findings:</u> The null hypothesis is rejected. There is a significant negative correlation between stress and buffer capacity.

This question is based on the logical assumption that, since condition is negatively correlated to stress (see Figure 4 above), and positively correlated to buffer capacity (see Figure 5 above), then stress should be negatively correlated to buffer capacity. In other words, since condition decreases as stress increases, and since condition increases as buffer capacity increases, then stress should decrease as buffer capacity increases.

To test this assumption, the Stress Index was regressed on the Buffer Capacity Index. A strong negative correlation is evident (Figure 6) that supports the assumption. Simply stated, wetlands with more buffer capacity tend to show less signs of stress.
However, it is clearly possible for a wetland to show signs of moderate levels of stress despite having abundant buffer capacity. As explained above, the Buffer Capacity Index may falsely indicate moderate to high buffer capacity for some stressors.

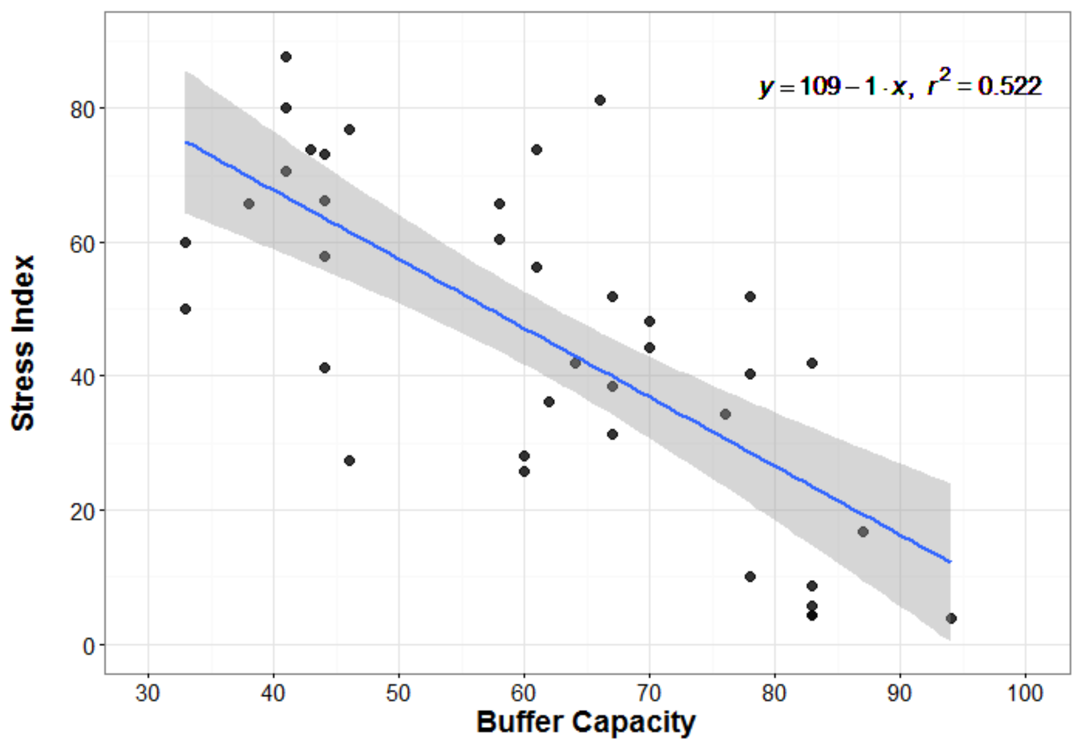


Figure 6. Results of regressing the Stress Index on Buffer Capacity.

Question 4: Does buffer capacity mediate stress?

Null Hypothesis: Buffer capacity has no effect on the relationship between wetland stress and condition.

Summary of Findings: The null hypothesis is rejected. There is evidence that buffer capacity affects the relationship between stress and condition. The effects are complex, however, and probably involve threshold levels of stress and buffer capacity that vary among different stressors.

To visualize the interactions among stress, condition, and buffer capacity, the NoBLNoH Index was regressed on the Stress Index (see Figure 4), and each assessment in the regression was colored coded as either good, fair, or poor, based on its Buffer Capacity Index score (using neutral tertiles). The three groups of assessments are not randomly distributed across the regression plot. Wetlands that had the lowest Stress Index scores and the highest Condition Index scores also had good scores for Buffer Capacity (see green cases in the upper left quadrat of Figure 7). Conversely, wetlands that had the highest Stress Index scores and the lowest Condition Index scores tended to have poor scores for Buffer Capacity (see red cases in the lower right quadrat of Figure 7). Wetlands with fair Buffer Capacity (see the yellow dots in Figure 7) are broadly distributed across the middle of the range of condition, but are mostly associated with moderate to high Stress Index scores.

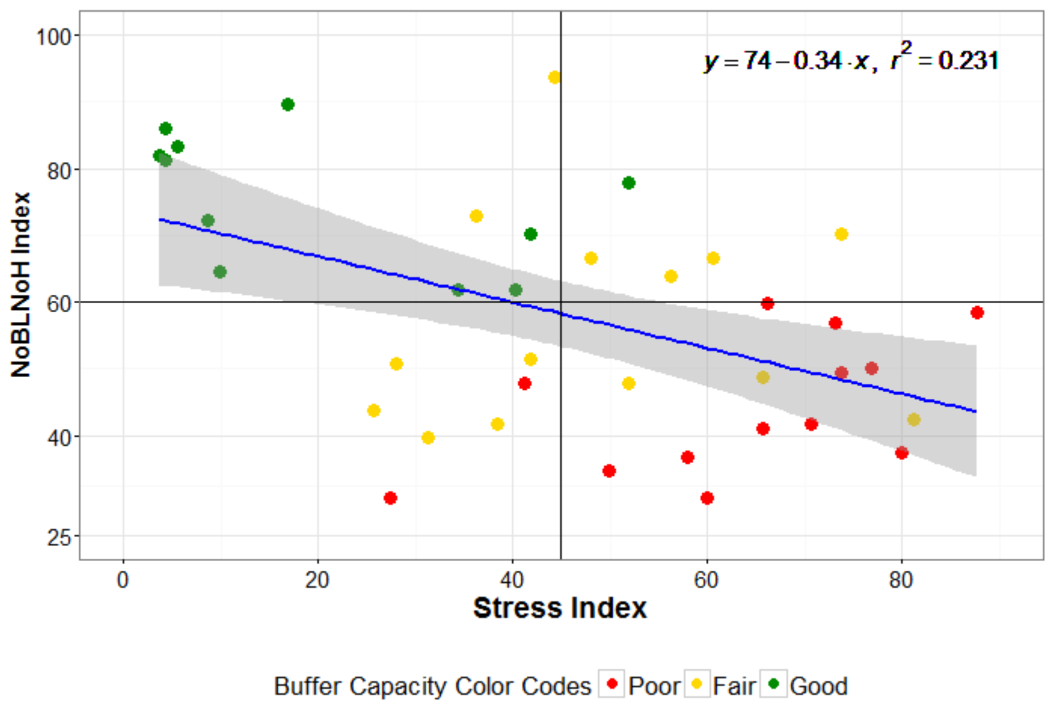


Figure 7. Results of regressing Condition on Buffer Capacity, where condition is measured as the NoBLNoH Index that excludes condition Attributes and Metrics autocorrelated with the Stress Index, and showing the Buffer Capacity of each wetland as good (green), fair (yellow), or poor (red).

Further interpretation of these results is guided by the conceptual models (see Figure 1). To enhance the comparison between the models and the results, trend lines are added for the groups of good, fair, and poor buffer capacity (see Figure 8 below).

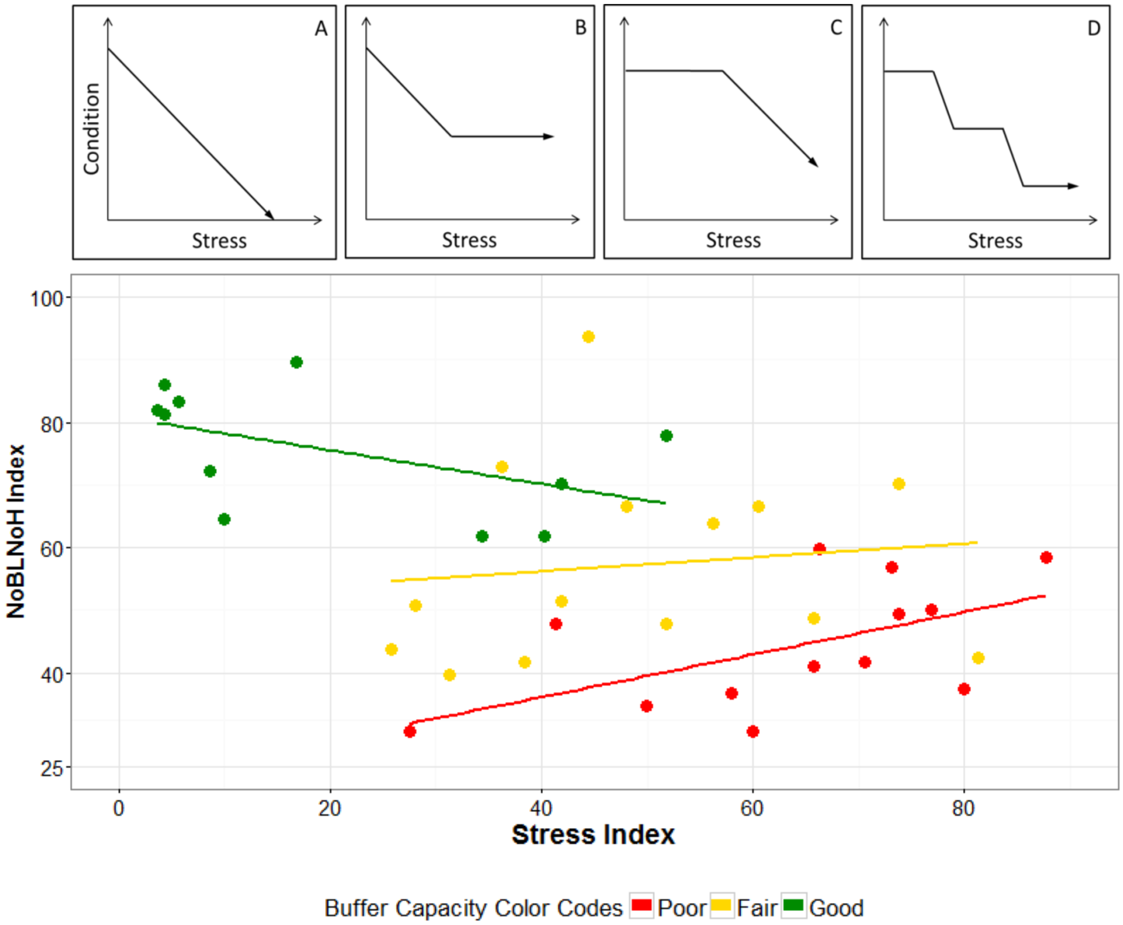


Figure 8. Results of regressing condition on buffer capacity, where condition is measured as the NoBLNoH Index that excludes condition Attributes and Metrics autocorrelated with the Stress Index, and showing the trend lines for the data representing good buffer capacity (green trend line), fair buffer capacity (yellow trend line) and poor buffer capacity (red trend line), as well as four alternative conceptual models of the interrelationships among stress, condition, and buffer capacity (from Figure 1).

The data do not neatly fit Model A. The broad spread of fair and poor buffer capacity assessments along the stressor gradient (x-axis) does not support the concepts that stress has a constant negative effect on condition, or that buffers have a constant mediating effect on stress. The data also do not support Model B; there is no evidence that stress reduces condition until a threshold level of stress triggers mediation by the buffer. There is some suggestion that Model C is applicable. That is, good buffer capacity allows fair to good wetland conditions to persist at low to moderate levels of stress. The data may also support Model D as an elaboration of Model C. That is, more than one threshold level of stress or buffer capacity is evident. At moderately high to very high levels of stress, fair condition is more likely if buffer capacity is also fair. If the buffer capacity is reduced further, so is wetland condition. Wetlands subject to high levels of stress with poor buffer capacity have poor conditions.

Conclusions

This analysis of the interrelationships among wetland condition, stress and buffer capacity supports the following conclusions.

- There is a strong negative correlation between stress and condition. However, the relationship is weaker when the Condition Index excludes the Buffer and Landscape Context Attribute, the Hydrology Attribute, and the Percent Invasion Sub-metric of the Biotic Structure Attribute, each of which involves indicators of stress and therefore is autocorrelated to the Stress Index.

- The strong negative correlation between stress and condition, plus the positive correlation between condition and buffer capacity, plus a strong negative correlation between buffer capacity and stress supports the finding that condition increases as buffer capacity increases and stress decreases. Wetlands with the least stress and greatest buffer capacity tend to have the best condition. Conversely, wetlands with the most stress and least buffer capacity tend to have the worst condition.

- Buffer capacity affects the relationship between stress and condition, although the effects are complex and involve threshold levels of stress and buffer capacity. At low to moderate stress levels, wetlands must have good buffer capacity to have good condition. At moderately high to very high levels of stress, fair condition is more likely if the buffer capacity is also fair. If the buffer capacity is reduced further, so is wetland condition. Wetlands subject to high levels of stress with poor buffer capacity have poor conditions.

- To assess the interrelationships among wetland condition, stress, and buffer capacity, independent indices of condition, buffer capacity, and stress are needed. The basis of these indices exists as the CRAM Condition Index, Buffer Metric, and Stressor Checklist. The necessary adaptations of these existing components of CRAM are described in the sections above, and outlined again below in the section on recommendations.

Discussion

The analysis of interrelationships among stress, condition, and buffer indicate that CRAM has the potential to inform basic decisions about the design and management of wetland buffers as well as wetlands. The interrelationships described by this analysis are consistent with the fundamental assumptions that underpin CRAM.

There is no reason to expect that these analytical results for depressional wetlands will not pertain to other wetland types. The concepts and assumptions underlying the analyses are not particular to depressional wetlands. This does not preclude the need to conduct similar analyses for other types of wetlands, but it does suggest that the same analyses are broadly applicable across wetland types, and that similar results can be expected.

The observed variability in the interrelationships among condition, stress, and buffer capacity was greater than anticipated and reduces the strength of the correlations. There are many possible causes for this variability. However, the inclusion of many different kinds of stressors, and the great diversity of wetland form and structure represented by depressional wetlands probably accounts for much of this variability. Depressional wetlands are not only highly varied in form and structure statewide, but they are also very sensitive to inter-annual variations in rainfall and evapotranspiration. The inclusion of

CRAM assessments from multiple years in the analysis of interrelationships among stress, condition, and buffer capacity also contributed to their apparent variability.

Significant improvements are warranted for each of the three indices employed in this analysis. The Condition Index must not involve any indicators of stress. Including them in the assessment of condition confounds the analysis of stress and buffer effects. The Buffer Capacity Index must include indicators of buffer structure that relate to the ability of a buffer to effectively filter and exclude important kinds of wetland stress. For example, it should include a Sub-metric for upslope topographic steepness, since it controls the rate of runoff to a wetland, and for plant cover density, since it affects the runoff rates and the ability of people and stock animals to access a wetland. The Buffer Capacity Index should also recognize specific management practices, such as fencing, and management programs that eliminate stressors regardless of buffer conditions or that adequately shield wetlands from existing stressors. The ability of the Stress Index to discern effective levels of stress might be improved by recognizing the relative differences in importance among the stress indicators. As currently configured, the Stress Index assumes that all stressors have equal effect on wetland condition. Therefore, Stress Index scores may be more influenced by the number of stressors evidenced than by the levels of stress they cause. This ignores the observation that for many wetlands a single stressor, such as biological invasion, grazing, or ditching, can account for most of the assessed decline in condition. The calculation of the Stress Index score may need to include numerically weighting indicators of especially important stressors.

Despite the shortcomings of the dataset and the indices of condition, stress, and buffer capacity used to analyze their interrelationships, the results of the analysis support some basic, albeit preliminary, guidance for managing the interrelationships to improve wetland protection. This preliminary guidance is summarized in Table 6 below.

Table 6. Preliminary guidance on buffer and stressor management to achieve or maintain good wetland condition. Stressor management can mean eliminating stressors or curtailing their impacts through changes in land use or management practices. Buffer management can mean increasing the percent of the wetland that has buffer, increasing average buffer width, or improving the structure of the buffer. Monitoring means application of CRAM plus specific quantitative methods to assess individual stressors.

Examples of Likely Wetland Status			**Recommended Action**
Buffer Capacity	*Stress*	*Condition*	
Poor	Low	Fair to Good	Monitor every 2 years
Poor	Low to Fair	Fair to Good	Monitor every 2 years
Poor	Low to Fair	Poor to Fair	Manage buffer; Monitor annually
Fair to Good	Low	Fair to Good	Monitor every 2 years
Fair to Good	Low to Fair	Fair to Good	Monitor every 2 years
Fair to Good	Fair to High	Poor to Good	Manage stressors; Monitor annually
Poor to Fair	Fair to High	Poor to Good	Manage stressors and buffer; Monitor annually

Recommendations

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

1. Develop a CRAM Buffer Capacity Index.

   a. Remove the Buffer Metric from the Buffer and Landscape Context Attribute of the Condition Index.

   b. Construct a Buffer Amount Metric, which is scored as the square root of the product of the Percent of AA with Buffer Sub-Metric and Average Buffer Width Sub-metric of the existing Buffer Metric.

   c. Construct a Buffer Structure Metric based on field indicators of topographic slope in relation to upland runoff to a wetland, and indicators of ground cover density in relation to hydrologic roughness and protection from excessive uses by people and animal stock. Include assessment of addition protection for the wetland, such as fencing or signage/management to protect wildlife habitat.

2. Revise the CRAM Condition Index. The CRAM Condition Index should be modified to eliminate any autocorrelation between it and the CRAM Stress Index or the Buffer Capacity Index.

   a. Exclude the Buffer Metric.

   b. Exclude the Hydrology Attribute.

   c. Exclude the Percent Invasion Sub-metric of the Biotic Structure Attribute.

   d. Assure that the Physical Structure and Biotic Structure Attributes consist of at least three independent Metrics that do not involve any indicators of stress.

3. Develop a CRAM Stress Index, based on the methodology proposed in this memorandum.

   a. Consider numerically weighting the values of relatively more important stressors or groups of stressors.

   b. Develop and implement a workplan to validate the CRAM Stress Index for multiple wetland types statewide, and to revise the Stress Index based on the validation effort.

4. Develop and implement a workplan to further analyze the interrelationships among condition, stress, and buffer capacity using the three recommended CRAM indices.

   a. Focus the plan on individual stress gradients for individual wetland types.

   b. Design the plan to elucidate threshold levels of stress and buffer capacity associated with categorical changes in wetland condition.

   c. Design the plan to elucidate the relative importance of buffer amount and buffer structure in mediating stress.

5. Based on the findings from recommendations 3 and 4 above, develop guidance for managing the interrelationships among wetland condition, stress, and buffer capacity.

   a. Identify optimal combinations of buffer amount and structure for different stressors.

   b. Identify threshold levels of wetland condition to trigger stress or buffer capacity management actions.

   c. Prepare and distribute the guidance document.

Appendix 1

Buffer Capacity Index Datasheet

Scoring Sheet: Buffer Capacity Index

AA Name:	**Date:**
eCRAM ID:	**Wetland Type:**
Assessment Team Members:	

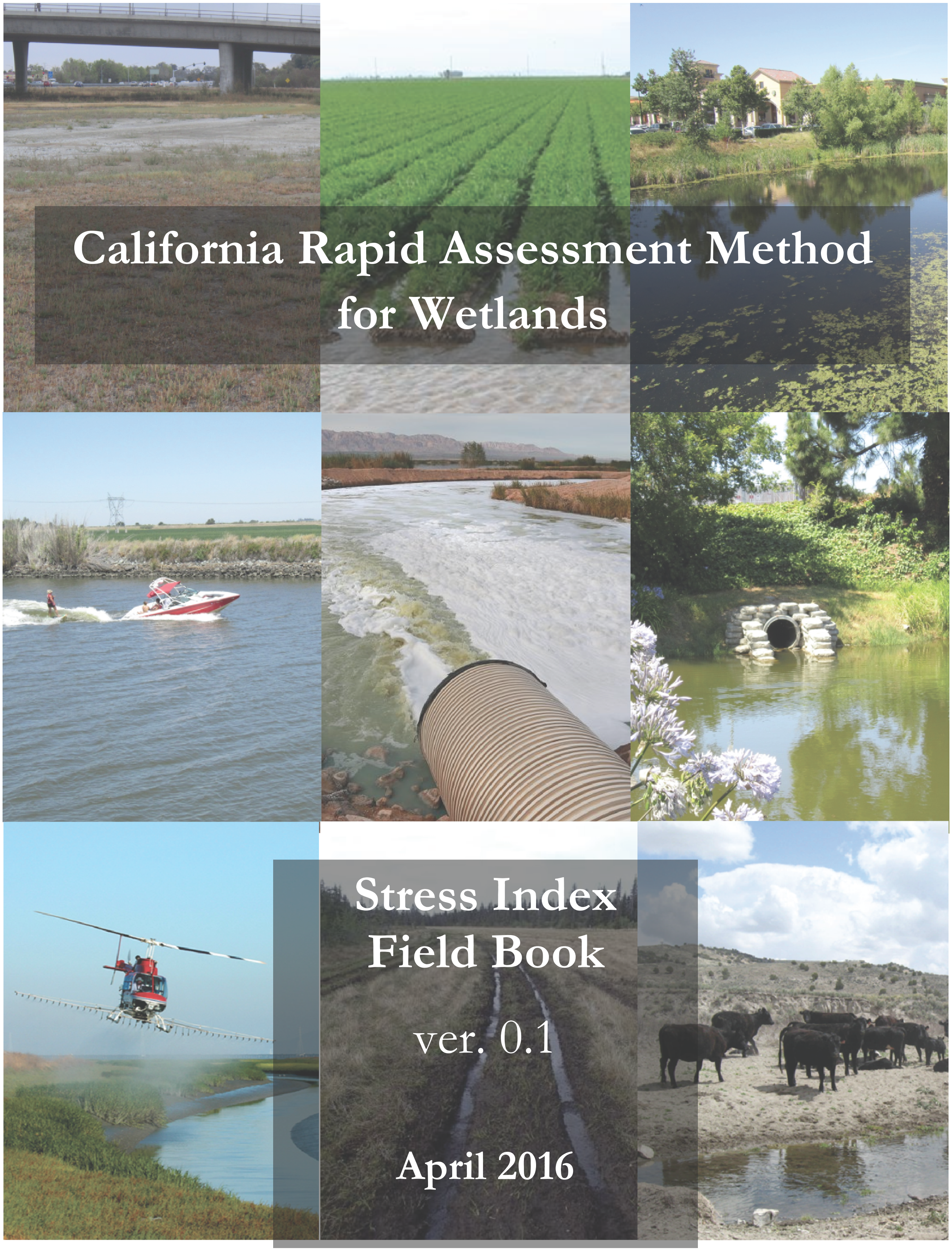
Metric 1				**Comments**
Buffer Amount:				
	Alpha.	Numeric		
Buffer Amount submetric A: Percent of AA with Buffer				
Buffer Amount submetric B: Average Buffer Width				
Metric Score = (A x B)^{½}				

Metric 2				**Comments**
Buffer Structure:				
	Alpha.	Numeric		
Buffer Structure submetric A: Average Topographic Slope				
Buffer Structure submetric B: Groundcover Density				
Buffer Structure submetric C: Buffer Management				
Metric Score = (A x B)^{½} + C				

Buffer Capacity Index Score = (Sum of two Metrics/27) x 100	
Buffer Capacity Index Ranking 22-48% is poor 49-74% is fair 75-100% is good	

Appendix 2

Stress Index Field Book



California Rapid Assessment Method for Wetlands

Stress Index Field Book

ver. 0.1

April 2016

This Stress Index Field book, version 0.1, dated April 2016 represents Phase 3 “Test Verification Version” of this module in the CRAM development process. Select users will conduct abundant field testing using this version in the spring and summer of 2016. This version will be used alongside the Condition Index during ambient surveys of wetland condition and during assessments of wetland projects. The verification data will be used to identify potential methodological bias, or to update the content and/or design of this Field Book. The findings will be presented to the California Wetland Monitoring Group, which will continue to guide the Stress Index development and potential future implementation, possibly replacing the Stressor Checklist.

Scoring Sheet: Stress Index

AA Name:		**Date:**
eCRAM ID:	**Wetland Type:**	
Assessment Team Members:		

Land Use Stressor Attribute

Metrics	**Examples** (circle present stressors)	**A: Proximity Score**	**B1: Extent**	**B2: Intensity**	**B: Severity Score**	**Score (AxB)**
Industrial land uses	Industrial, landfill, mining, timber harvest, military land	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Urban land uses	Urban commercial, urban residential, suburban residential, rural residential, golf course, park, lawn, sports fields, active/passive recreation, excessive human visitation	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Agricultural land uses	Crops (irrigated, non-irrigated, row), vineyards, orchards, hay, fallow fields, dairies, confined animal feeding operations, dairies, pasture, rangeland	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Transportation land uses	Highway, road (paved, 2 lanes or larger), road (1 lane or unpaved), parking lot/pavement, railroad, air traffic	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
					Raw Stressor Attribute Score (sum of all scores)	
					Final Stressor Attribute Score ((raw score / 576) x 100)	
Comments						

Chemical Stressor Attribute

Metrics	**Examples** (circle present stressors)	A: Proximity Score	B1: Extent	B2: Intensity	B: Severity Score	Score (AxB)
Industrial water quality effects	Point source discharges (POTW, factories), industrial or domestic spills or discharges, acid mine drainage, high concentration of dissolved salts, noxious chemical odors	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Urban water quality effects	Non-point source discharge (stormwater), trash or dumping, vector control, urban pesticide or fertilizer use	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Agricultural water quality effects	Agricultural runoff, direct application of fertilizer, chemical vegetation control, pesticide use	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Nutrient related water quality effects	Formation of algal or Lemna sp. surface mats or benthic algal growth, direct discharges from septic or sewage systems, manure pits, or feedlots, excess animal waste	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
					Raw Stressor Attribute Score (sum of all scores)	
					Final Stressor Attribute Score ((raw score / 576) x 100)	
Comments						

Hydrologic Stressor Attribute

Metrics	**Examples** (circle present stressors)	A: Proximity Score	B1: Extent	B2: Intensity	B: Severity Score	Score (AxB)
Water control actions	Actively managed hydrology (including filling and drying), flow diversions, groundwater extraction, unnatural inflows	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Within the wetland water control features	Dike/levee, ditches, dam, weirs, flashboards, slide gates, tide gates, pumps, spring boxes, canals	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Outside the wetland water control features	Dike/levee, ditches, dams (reservoirs, detention or recharge basins), weirs, flashboards, slide gates, tide gates, pumps, spring boxes, canals	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Hydro-modification	Increased or altered runoff patterns (e.g. timing or amount) within the watershed (up to 2 km) due to development or impervious surfaces	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
					Raw Stressor Attribute Score (sum of all scores)	
					Final Stressor Attribute Score ((raw score / 576) x 100)	

Comments

Physical Stressor Attribute

Metrics	**Examples** (circle present stressors)	A: Proximity Score	B1: Extent	B2: Intensity	B: Severity Score	Score (AxB)
Non-wetland sediment disturbance	Substrate disturbance (ATVs, mountain biking), excavation, grading/compaction, plowing/discing, feral pig disturbance	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Wetland sediment disturbance	Wetland sediment removal, dredged inlet or channel, substrate disturbance (ATVs, mountain biking), excavation, grading/compaction, plowing/discing, wet soil/waterfowl management, feral pig disturbance	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Excess sediment input	Wetland fill, passive sediment input (construction, erosion), turbidity, debris lines or silt-laden vegetation, sedimentation (fans, deposits, plumes)	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Hardened features	Engineered channel (riprap, armored channel bed or bank), flow obstructions (culverts, paved stream crossings), drop structures	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
					Raw Stressor Attribute Score (sum of all scores)	
					Final Stressor Attribute Score ((raw score / 576) x 100)	
Comments						

Biologic Stressor Attribute

Metrics	**Examples** (circle present stressors)	A: Proximity Score	B1: Extent	B2: Intensity	B: Severity Score	Score (AxB)
Vegetation management	Fire breaks, mowing or cutting, mechanical plant removal, removal of large woody debris, prescribed burns, habitat destruction	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Predation	Excessive predation (feral pigs, pets, wild turkeys, other non-native vertebrates), excessive hunting, biological resource extraction	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Herbivory	Excessive unmanaged herbivory	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
Invasive plants	Presence of invasive species, lack of control/treatment of invasion	0 3 6 9 12	1 2 3	1 2 3	0 3 6 9 12	
					Raw Stressor Attribute Score (sum of all scores)	
					Final Stressor Attribute Score ((raw score / 576) x 100)	

Comments

Overall Stress Index Score

Land Use Stressor Final Attribute Score	
Chemical Stressor Final Attribute Score	
Hydrologic Stressor Final Attribute Score	
Physical Stressor Final Attribute Score	
Biologic Stressor Final Attribute Score	
Overall Stress Index Score (sum / 5) x 2	

Stress Index

The CRAM User's Manual explains that the condition of a wetland is the result of complex interrelationships among its natural formative processes, stress, disturbance, buffers, and purposeful management. The condition of a wetland is defined as its capacity to provide high levels of its intrinsic ecological services. Condition is assessed using the CRAM Condition Index. Stress is defined as unnatural actions or processes operating inside or outside a wetland that can negatively impact its condition. Stressors are the immediate sources of stress. For example, the discharge of chemical pollutants into a wetland can negatively impact the condition of a wetland by causing its chemistry to exceed the tolerances of some native plant and animal species. The stress is the change in chemistry and the stressor is the discharge of pollutants.

The ability of a wetland to resist stress or recover from that stress depends on many factors including wetland type; wetland condition; stressor type; the number of stressors; the intensity, magnitude, frequency, and duration of stress; and the size, condition, structure and management of the wetland buffer. Gradients of stress result from spatial variations in the diversity, magnitude, intensity, frequency, or duration of the stress.

The possible negative impacts of stressors on wetlands are many and varied. Most importantly, stressors can reduce the extent of wetlands or negatively impact the natural processes and management practices that support the ecological services of wetlands.

A key tenet of CRAM is that wetland managers can improve wetland condition by managing stressors. The purpose of the Stress Index is to help wetland managers identify and evaluate the relative importance and impact of different local stressors, based on field indicators of stress. Furthermore, independent assessments of wetland condition, buffer capacity, and wetland stress can be used to understand their interrelationships and thus improve buffer design and management, with the aim of mediating the stress to the wetland. Without the Stress Index, this understanding cannot be achieved.

Stress Index Construction

The Stress Index is constructed in parallel to the Condition Index. That is, the Index is comprised of Attributes and Metrics. Five categories of stressors are referred to as Attributes: Land Use Stressors, Chemical Stressors, Hydrologic Stressors, Physical Stressors, and Biologic Stressors. The Attributes were selected based mainly on USEPA guidance for evaluating environmental stress. In addition, each Attribute was selected because it has adequate information content, is unique, is assessable using at least three Metrics, relates to a major and commonly recognized category of stressor, and is an integral part of a set of Attributes that represents all major and common stressors.

Each Attribute is comprised of four Metrics. Each Metric is comprised of numerous indicators of stress, grouped in obvious associations. The selected stress indicators are: commonly evident in California, common to all CRAM wetland types, based on features or actions that are observable in the field or on aerial photographs, likely affect wetland condition as measured by CRAM, and are consistent with lessons learned in previous efforts by CRAM and USA-RAM to assess stress.

These indicators were assigned to each Metric based upon similarities in their usual landscape setting or mode of stress. For example, all the Land Use Stress Indicators relating to vehicular transportation as a stressor, (such as highways, arterial roads, rural roads, parking lots, railroads, air traffic lanes), were grouped apart from Land Use Stress Indicators relating to agriculture, (such as truck crops, vineyards, orchards, hay fields, dairies, feed lots, pasture, rangeland).

The Stress Index Score is a simple average of the Stressor Attribute Scores, which is then scaled to more closely match the Condition Index scores. However, unlike the Condition Index, which uses different modules to account for the natural differences in form and structure among different wetland types, stress can be assessed for all wetland types using a single module of the Stress Index. This is because all wetland types are subject to the same stressors and there is a universal set of field indicators of stress for all wetland types.

Completing the Stress Index

The Stress Index is currently in the Verification Phase of development, intended to be used for ample data collection during the 2016 field season. It is a companion to the CRAM Condition Index (currently version 6.1) and as such, should be completed by trained CRAM practitioners that have successfully completed an approved training course. Training courses and trained practitioners are listed on the CRAM website at www.cramwetlands.org/training.

The Stress Index is intended to be completed alongside the Condition Index, using the existing CRAM modules; it is not intended for use without a companion Condition Assessment Area (AA). Also, in this current Verification Version, the Stress Index does not replace the existing Stressor Checklist. Instead, it should be completed in addition to the Condition Index and the Stressor Checklist.

CRAM field teams should complete the Stress Index immediately after the condition assessment (using the Condition Index and the Stressor Checklist). Application of the Stress Index should take an expert team approximately 15-20 minutes to complete.

Establish the Stress Assessment Area (SAA)

The Stress Assessment Area (SAA) is based on the Assessment Area (AA) that is established for the condition assessment. The SAA is an area that a) includes the AA, and b) extends 250 m out from the perimeter of the AA in all directions. The outer portion of the SAA is therefore approximately the same as the area used in the Condition Index to assess the Buffer Metric.

Aerial photographs needed:

1) An image showing an area 250 m in all directions extending outward from the AA perimeter.

2) An image showing the contributing watershed area, up to 2 km upstream.

Step 1: On an aerial photograph, sketch the boundary of the AA.

Step 2: From the AA boundary, outline the area that extends 250 m in all directions from the AA. Carefully measure and sketch the area on the photograph; remember that the intent is to rapidly sketch an area for consideration, rather than exactly mirror the shape of the AA. This step should take no more than 1-2 minutes. See Figure 1 for example SAAs.

Step 3: Use this aerial photograph in scoring the Stress Index.

One Metric in the Hydrologic Stressor Attribute, the Hydromodification Metric, requires looking upstream no more than 2 km within the watershed that drains to the AA. This requires having the aerial imagery that shows this upstream area. A topographic map can also be helpful in estimating the boundaries of the upstream drainage area.

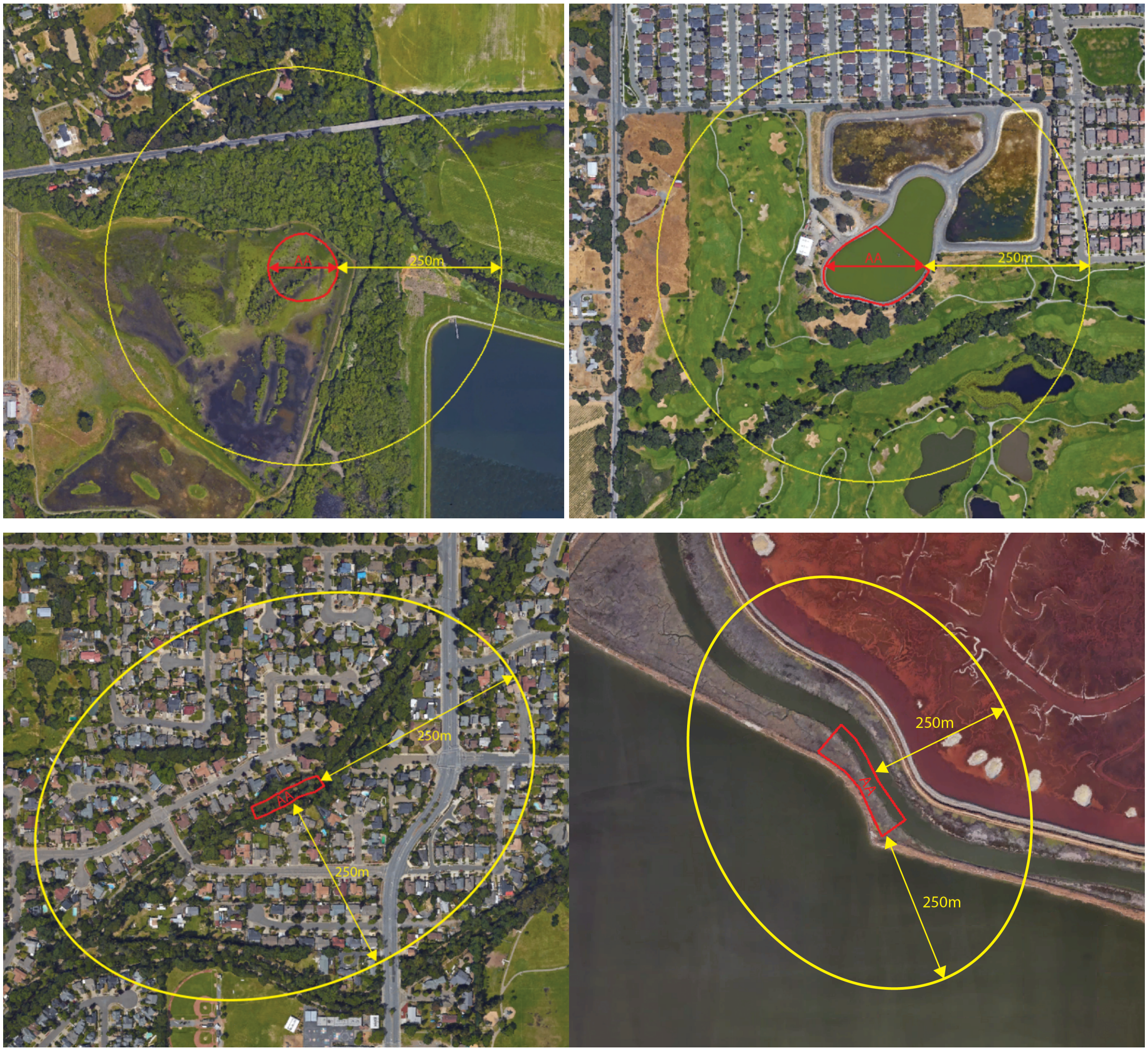


Figure 1. Examples showing sketches of Stress Assessment Areas (SAAs). In each figure, the red polygon represents the AA boundary. Extending 250 m outward from the AA boundary is the SAA shown in yellow. The SAA includes the entire area shown in yellow and the area inside the AA polygon. Note that the yellow area has a smooth boundary and does not reflect the exact shape of the AA.

Scoring Procedure

The following steps must be completed to derive a Stress Index score. For all Metrics, except Hydromodification, only consider Stressors within the Stress Assessment Area.

Step 1: Score Proximity for each Metric.

For each Metric consider the proximity of that stressor to the AA, using Table 1 to determine a score. Choose the appropriate score based upon the *minimum* instance of that stressor to the AA boundary, where it physically exists. If the stressor is not present within the SAA, enter a score of zero.

Table 1. Rating table for stressor proximity, where zero distance is the perimeter of the AA.

Proximity (m)	Score
< 0 (within the AA)	12
0-50 m	9
50-100 m	6
100 – 250 m	3
Not Present	0

Step 2: Score Severity for each Metric that received a zero for Proximity.

Each Metric that received a zero for Proximity automatically receives a zero for Severity. In other words, stressors that do not exist within the SAA cannot have an associated Severity of stress.

Step 3: Score Severity for each Metric that did not receive a zero for Proximity.

Score Severity for each Metric that did not receive a zero for Proximity (i.e. was present at some distance within the SAA). The Severity of a stressor is comprised of both its Extent and Intensity. Use Table 2 to evaluate the Extent and Intensity of each stressor. To be clear, the Severity is to be scored only considering impacts within the area of the AA; defining the SAA allows the practitioner to place an outer limit on the practices, processes, and land uses that contribute stress to the AA. However, it is how that stress (that primarily originates in the SAA) actually impacts the AA proper that should be considered and scored.

Extent: What proportion of the Assessment Area is impacted by the stressor?

Intensity: What is the concentration or magnitude of the stress?

Table 2. Stressor Severity rating table. The severity score has two parts: an evaluation of the likely spatial extent of the impacts of the stressor(s) within the AA that are represented by the indicator, and an evaluation of the likely intensity of the impacts. For each part, choose the most appropriate condition based upon observation of the AA and the SAA.

Aspect of Severity	Condition	Corresponding Numerical Code
Extent	Stressor likely impacts >75% of the AA	3
	Stressor likely impacts 25-75% of the AA	2
	Stressor likely impacts <25% of the AA	1
Intensity	Stressor has a high concentration or magnitude	3
	Stressor has a moderate concentration or magnitude	2
	Stressor has a low concentration or magnitude	1
	Sum of circled codes	

Rating Table	
Sum of circled codes	**Corresponding Severity Score**
2	3
3	6
4	9
5-6	12

Stressors can impact most, a portion, or very little of any given AA; this spatial impact is considered when scoring the Extent. For example, an AA that has actively managed hydrology (e.g. affecting the timing and amount of filling and drying) is likely affected by this stressor across the entire AA, or as stated in Table 2, more than 75% of the AA. Alternatively, an AA that is experiencing excess sedimentation (as evidenced by a small sediment plume or fan) may only be impacted by this stressor for a small portion of the AA, or less than 25% of the AA.

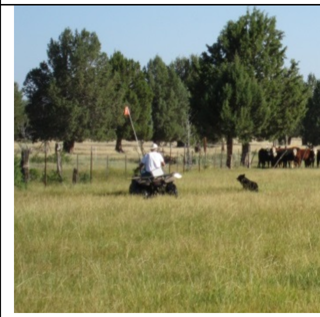
The strength of a stressor is considered when scoring Intensity. The rating table uses the qualitative terms of "high, moderate or low" when describing concentration or magnitude. The practitioner is asked, using best professional judgment, to evaluate the intensity of the impact, based upon tertiles of potential impact for each stress indicator. In other words, for any given indicator, are the impacts observed in the upper, middle, or lower third of concentration or magnitude for what is possible for that indicator. Because of the large, and widely varied list of indicators in the Stress Index, specific guidance cannot be given for each, however examples listed below (Tables 3 and 4) are intended to guide the practitioner in thinking about various levels of impact.

Table 3. Examples of High, Moderate, and Low concentration or magnitude of impact for scoring the Intensity aspect of Severity.

Indicator	High concentration or magnitude	Moderate concentration or magnitude	Low concentration or magnitude
Industrial point source discharge	Obvious water quality effects (noxious odor, sheen, coloration) or effects upon flora or fauna	Some effects on water quality or flora/fauna, but none significant	No obvious effects on water quality, flora or fauna
Trash	Solid mat of trash, or hazardous trash (batteries, 55 gallon drums, etc) clearly affecting water quality or wildlife	Noticeable trash likely affecting water quality or wildlife (e.g. 5-15 pieces in the AA)	Minor, scattered pieces of trash, not likely affecting water quality or wildlife (e.g. <5 pieces in the AA)
Golf course	Turf slopes in; swales direct water into wetland; mowed turf to the edge; golfers entering the wetland	Some drainage from turf into wetland, occasional golfers in wetland	Turf slopes away from wetland; almost no drainage routed in, a significant buffer prevents access
Roads	Significant traffic, constant noise, drainage routed into wetland, clear hazard for wildlife	Regular traffic, some drainage routed into wetland, likely hazard for wildlife	Light traffic, low noise, little to no drainage routed into wetland, not a hazard for wildlife
Hydromodification	Significant increased scour or incision, change in hydrologic regime, support of new species due to altered regime	Some scour or incision, some evidence of altered hydrologic regime	Only minor scour or incision, no observable change in hydrologic regime
Wetland sediment disturbance	Significant removal or addition of sediment that also causes wholesale vegetation removal/burial, affects soil properties, causes turbidity, causes new erosion pathways	Some sediment disturbance that has minor or short-lived effects on vegetation, water quality, or erosion	Minor sediment disturbance that does not affect vegetation, water quality, or cause new erosion pathways
Invasive plants	The wetland supports many invasive species that are co-dominant, clearly out-competing native species, are affecting vegetation patterns and structure, and are causing changes in processes (water movement or filtration) or wildlife use	Some invasive species are supported, they may or may not be co-dominant, and are having some impact on vegetation pattern or structure, or slightly affecting processes or wildlife use	Only a few invasive species are supported, they are not likely co-dominant, they have not had an effect on vegetation structure or are affecting wildlife use

Table 4. Photographic examples of High, Moderate, and Low concentration or magnitude of impact for scoring the Intensity aspect of Severity.

Indicator	High concentration or magnitude	Moderate concentration or magnitude	Low concentration or magnitude
Industrial point source discharge			
Trash			
Golf course			
Roads			

Indicator	High concentration or magnitude	Moderate concentration or magnitude	Low concentration or magnitude
Hydro-modification			
Wetland sediment disturbance			
Invasive plants			

The Severity Score is calculated using the rating table in Table 2. The practitioner adds the number of circled codes for Extent and Intensity, and uses the rating table to convert from the 3-point scale used in the narrative to the Severity Score in the standard 4-point scale.

After completing the Severity Score, for each Metric, multiply the Proximity Score by the Severity Score, filling in the score on the right-hand side of the datasheet.

Step 4: Calculate the Raw and Final Attribute Scores.

For each Stressor Attribute, sum the scores of all the Metrics to calculate the Raw Attribute Score, and divide by the total possible score, then convert the product into a percentage, to calculate the Final Attribute Score.

Step 5: Calculate the Stress Index Score.

Transfer each Final Attribute Score to the end of the datasheet. The Stress Index Score is simply the average of the five Final Attribute Scores, multiplied by two.

Low Stress Index scores represent sites with low stress, while high Stress Index scores represent sites with high stress.

Step 6: Enter the Stress Index data into eCRAM.

After completing the data entry for the Condition Index of the Assessment Area (AA) in eCRAM, next enter the Stress Index data. The Stress Index data entry portion of eCRAM will only be available to select users. Data are linked to the Condition Index AA using the eCRAM ID number. Fill this number in at the top of the hardcopy Stress Index datasheet.