Determining the Health of California's Coastal Salt Marshes Using Rapid Assessment

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Abstract
The integration of rapid assessment methods with probability-based regional survey designs provides a cost-effective means for making unbiased assessments of wetland condition over a relatively large area within a short period time. We demonstrated this synergy through a statewide probability-based survey of the condition of perennially tidal saline estuarine wetlands (salt marshes) in California using the California Rapid Assessment Method (CRAM). An estimated 85% of the State's salt marshes scored within the top 50% of possible CRAM index scores. Among the four CRAM attributes for salt marshes, Buffer and Landscape Context had the highest scores. Physical Structure was the attribute for which California's salt marshes scored the lowest. CRAM index and attribute scores showed a general decrease from northern to southern California. The presence of dikes, levees, and other water control structures that restrict tidal exchange was a severe stressor that is responsible for low physical structure scores. Urbanization of surrounding land uses was significantly correlated to poor wetland health statewide. Information on landscape and local stressors gathered via the CRAM assessment suggest possible management actions that could be used to improve wetland health. This study demonstrates how incorporation of a rapid assessment method into a regional, probability-based survey can be used as context for evaluating the condition of wetland restoration projects.

Keywords
wetland monitoring, ambient condition, CRAM, restoration effectiveness, probabilistic survey

Introduction

Considerable resources have been invested in wetland restoration and management in the United States, mostly to offset historical losses and mitigate current threats. Since 1990, it is estimated that public and private organizations have spent approximately $15 billion on over 30,000 river and wetland restoration projects (Malakoff 2004, Bernhardt et al. 2005). The National Coastal Wetlands Conservation Grant Program awards between 13 and 17 million dollars annually to acquire, restore, manage or enhance coastal wetlands (USFWS 2010). The need to account for the effectiveness of these investments and to track wetland status and trends has led to the proliferation of wetland monitoring and assessment programs across the country, such as the United States Environmental Protection Agency (USEPA) National Wetland Condition Assessment (http://water.epa.gov/type/wetlands/assessment/survey/index.cfm).

An important design element of many large-scale wetland monitoring programs is the use of probabilistic survey methods that allow scientists to assess the ambient (overall)condition of large areas based on data collected from a representative sample of locations (Stevens and Olsen 2004). Because probability-based surveys provide the ability to make unbiased assessments of wetland condition over a relatively large area, they have become the key basis for design of many state and regional monitoring programs (NAS 2001, USEPA 2010).

Implementing large regional wetland monitoring programs often requires that an accurate assessment of overall condition be made using standard tools and protocols during a single site visit within a relatively brief period of time. This has made the use of conventional, time-intensive assessment methods less tractable for these types of applications. As an alternative, rapid assessment methods (RAMs) are gaining popularity for use in a range of monitoring programs (Stapanian et al. 2004, Cohen et al. 2005, Fennessy et al. 2007, Scozzafava et al. 2011). RAMs are structured diagnostic tools that combine scientific understanding of process and function with best professional judgment in a consistent, systematic, and repeatable manner (Sutula et al. 2006). The basic assumptions of most RAMs is that ecological conditions vary predictably along stress gradients and that conditions can be evaluated based on a fixed set of observable field metrics. These metrics represent measures of a specific biological or physical attribute which reflects some element of ecological condition and can be related to key ecosystem functions (Stein et al. 2009a). RAMs can be used to extend the geographic application and understanding derived from expensive and geographically restrictive special studies and intensive assessments. In this way, RAMs can be the cornerstone of a comprehensive monitoring program and make basic assessment of wetland projects affordable (Sutula et al. 2006).

The application of RAMs as a tool for wetland condition assessment is not novel to the science of wetland monitoring. Over the past ten years, the USEPA has supported the development and implementation of RAMs to support national wetland assessment goals (USEPA 1998, 2006). RAMs have also been developed and applied in various state and regional wetland condition assessments (Fennessy et al. 2007), but rarely used as the foundation for a statewide assessment program. Skepticism of RAM results has limited their use in monitoring and regulatory programs. As a result, despite the stated preference of many wetland programs to consider overall function or condition in decision making processes, few do so in a rigorous manner (Stein et al. 2009b).

In this paper, we describe an application of the California Rapid Assessment Method for Wetlands (CRAM; Collins et al. 2007) in the context of the first statewide assessment of estuarine wetlands (salt marshes) in California. CRAM was developed as a diagnostic tool for the assessment of general wetland health and produces condition scores that are comparable and repeatable for all wetland types (using different "modules" for different wetland types) across regions in California (Collins et al.

2007). The objectives of this survey were to: 1) generate probability-based estimates of the condition and anthropogenic stressors affecting salt marshes within four coastal regions of California, and 2) use CRAM to assess the condition of a subset of estuarine restoration or mitigation projects located in salt marsh habitats throughout coastal California. By applying CRAM at the statewide, regional, and project scales, we demonstrate how probability-based surveys can provide context for interpretation of site-specific assessments.

Methods

Study Area and Assessment Target Population

This survey focused on the assessment of intertidal emergent wetlands (salt marshes) in those California estuaries that have a perennial surface water connection to the ocean (i.e., perennially tidal). In order to determine how salt marsh conditions vary regionally, four coastal regions were identified for the purposes of this study: North Coast; Central Coast; San Francisco Estuary, and South Coast (Figure 1). These regional delineations were based on a combination of the ecoregional boundaries developed by Hickman (1993) and California Regional Water Quality Control Board jurisdictions. The San Francisco Estuary and its attending watersheds were treated as a separate study region for this study because they contain 75% of the State's salt marsh acreage.

Estuarine Habitat Inventory

The sample frame for the ambient survey was created by overlaying the current National Wetland Inventory (NWI; USFWS 2011) onto National Agricultural Imagery Program (NAIP) imagery (NAIP 2005). From among the wetland categories, the sample frame was established to include areas identified as intertidal emergent wetlands. Whenever possible, regional maps were revised based on local knowledge.

Study Design

A stratified generalized random tessellation (GRTS) design (Stevens and Olsen 1999, 2004; Stevens and Jensen 2007) was used to probabilistically select 150 assessment sites (Figure 1) from the revised estuarine habitat maps, with 30 sites allocated to Central Coast, San Francisco Estuary, North Coast, and South Coast, respectively. Additional funding permitted the allocation of 30 additional sites in the South Coast, for a total of 60 sites in this region. South Coast sites were evenly divided between large (>500 acres) and small (<500 acres) estuaries. Probability-based estimators were area-weighted (based on percent of salt marsh acreage) to account the number of sites selected by the GRTS design within a given salt marsh and the total salt marsh area represented by each site. Sutula et al. (2008a) provide a detailed explanation of the GRTS design as it was applied in this study.

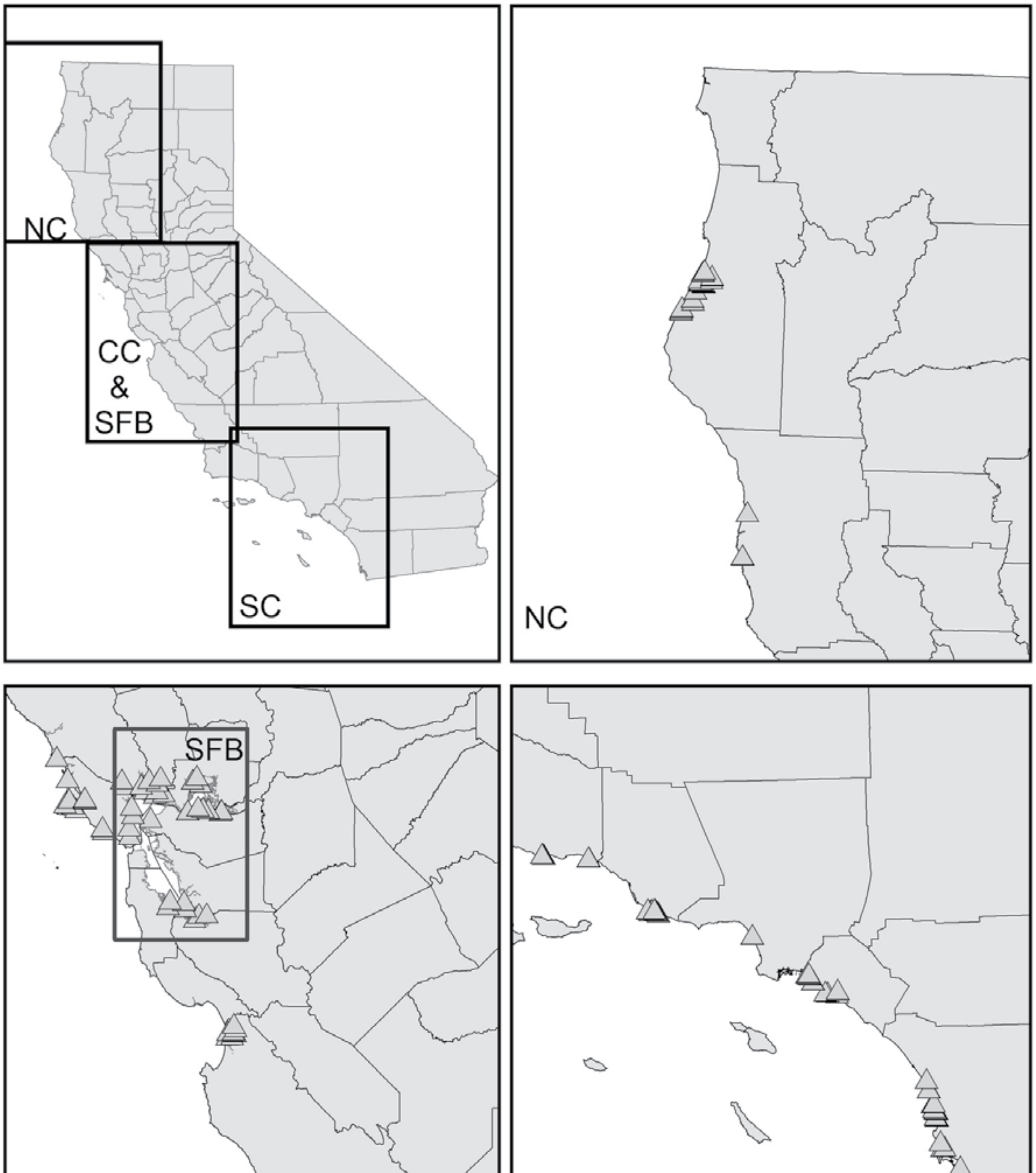

Figure 1: California coastline showing approximate boundaries of the four coastal regions and the location of the 150 probabilistic sites included in the statewide assessment of estuarine wetland condition.

Field Survey of Ambient Condition

From August through November 2007, field assessments were conducted at the 150 probabilistically selected sites using the CRAM perennial estuarine module. CRAM assesses four overarching attributes of wetland condition: Buffer and Landscape Context, Hydrologic Regime, Physical Structure, and Biotic Structure (Collins et al. 2007). Each attribute is related to several attribute-specific metrics and submetrics that are evaluated in the field for a prescribed assessment area (Table 1). Assessment Area (AA) sizes and delineation adhered to the guidelines in Collins et al. 2007. Wetlands less than 0.1 ha were excluded from the sample frame for this study.

Attribute	Metric and Submetrics
Buffer and Landscape Context	Landscape Connectivity (m)
	Buffer (m):
	Percent of AA with Buffer (s)
	Average Buffer Width (s)
	Buffer Condition (s)
Hydrologic Regime	Water Source (m)
	Hydroperiod (m)
	Hydrologic Connectivity (m)
Physical Structure	Structural Patch Richness (m)
	Topographic Complexity (m)
Biological Structure	Plant Community (m)
	Number of Plant Layers Present (s)
	Number of Co-dominant Plant Species (s)
	Percent of Invasion (s)
	Horizontal Interspersion and Zonation (m)
	Vertical Biotic Structure (m)

Table 1:Relationship between CRAM attributes, metrics (m), and submetrics (s).

Each CRAM metric or submetric is evaluated using a standardized set of narrative descriptions, schematic diagrams, or simple quantitative measures. Choosing the alternative that best describes each metric in an attribute generates a score for that attribute. The attribute scores are averaged to produce an overall index score. Attribute and index scores are expressed as percent possible; scores range from 25 (lowest possible) to a maximum of 100. In the context of CRAM, wetland condition is evaluated based on observations made at the time of the assessment. Higher scores represent better condition and infer a higher potential to provide the functions and services expected for the wetland site being assessed (Collins et al. 2007). The estuarine module of CRAM has been validated against independent, more intensive measures of condition including benthic invertebrates, riparian birds, and estuarine

plant richness and diversity (Stein et al. 2009). This has resulted in refinement of the metrics for this wetland type and provides an increased level of confidence that higher CRAM condition scores equate to a higher level of function.

Extensive inter-team calibration exercises were conducted prior to this research, with field personnel from all four regions jointly applying the methodology at field sites within each of the four regions. The intercalibration training documented an average error rate among field teams of ±6 points for attribute scores and ±9 points for index scores (Sutula et al. 2008a,b). The variability in condition as measured by the standard error of the mean for index and attribute scores was generally much less (approximately 3%). Thus, differences in CRAM index and attribute scores of 10 points or more among regions were considered to be significant.

In addition to producing condition scores, CRAM also includes a list of 52 anthropogenic stressors within a wetland or its setting that are likely to negatively impact the functional capacity of the CRAM assessment area. Each CRAM attribute has its corresponding stressor checklist. Stressors for each attribute are represented as categorical variables ranging from “0”, indicating no stressor is present; “1”, indicating that the stressor is present; and “2”, indicating that the stressor is severe and likely to cause a significant negative impact. The CRAM stressor checklist does not affect the calculation of the CRAM scores, but relationships between CRAM scores and the checklist tallies can help to explain the CRAM scores and to identify possible management actions to improve condition.

Assessment of Projects Using CRAM

Ten estuarine restoration projects were selected in the San Francisco Bay, Central Coast, and South Coast regions of the State, respectively (n= 30), and assessed using CRAM. The North Coast region was not included in this phase of the survey. The lack of comprehensive project inventories for all regions except the Central Coast prevented the use of a probabilistic approach for selecting the projects, thus the projects included in this survey were not considered representative of the population of projects as a whole and were considered as case studies to demonstrate how project and ambient assessment can be used in concert. Furthermore, because the survey included sites of special interest to regional coastal zone managers, sites were not standardized by size, type, and age since restoration. Projects larger than two CRAM assessment areas (larger than 2.0 ha) required multiple assessments, based on the guidance for project assessment (Collins et al. 2007). In these cases, attribute scores were averaged to generate an overall project index score.

Data Analysis

Area-weighted estimates of condition were analyzed using cumulative frequency distribution (CFDs) plotted from distributions of statewide and regional CRAM index and attribute scores. The CFD plots allow one to estimate what percent of the wetland area of that wetland type is less than or equal to a particular score, based on the number of sites per score expressed as a percentage of the total number of sites. The total range in possible index scores (25 - 100) was separated into four equal score quartiles: (1) Quartile 1 (> 82); (2) Quartile 2 (64-82); (3) Quartile 3 (44-63); and (4) Quartile 4 (< 44). These four ranges of CRAM scores represent a theoretical continuum of condition along various stressor gradients, with 100 and 25 representing the highest and lowest possible scores possible, respectively, on each gradient (Sutula et al. 2006). These bins were then overlaid onto the CFDs to estimate the percentage of wetland area within a particular range of scores for each region and statewide. The mean scores, as well as the percent of area within each of the quartiles, represent statistical estimates derived from a probability-based selection of sites. Measures of confidence or standard errors used a local variance estimator that utilizes distances between sites to increase precision (Stevens and Olsen 2004).

Non-parametric Spearman's rank correlation coefficients were calculated to explore relationships between CRAM index scores and sources of stress. The Stressor Severity Index for a site was calculated as the percent maximum possible score for all stressors combined. Kruskal-Wallis one-way analysis of variance (ANOVA) by ranks was used to test differences in median CRAM Index scores between regions and for the major individual stressors identified statewide and regionally. Where CRAM Index scores could be transformed to address unequal variance, parametric ANOVAs were used to generate Tukey's pairwise comparisons for the absent, present, and severe categories.

Results

Summary of Extent and Geographic Distribution of California Salt Marshes

A total of 154,128 ha of perennially-tidal subtidal and intertidal estuarine habitat were identified in California based on the NWI database. Salt marsh comprises 12% of this area (17,990 ha), distributed among the four coastal regions depicted in Figure 2. The San Francisco Estuary is the largest estuary in the state, and contains three-quarters of the estuarine habitat, including most of the salt marsh acreage. Outside of this region, the acreage of estuarine habitat is fairly equally distributed among the North Coast, Central Coast and South Coast. However, the estuaries of the Central Coast and South Coast each have approximately three times as much area of salt marsh than the North Coast estuaries (Figure 2).

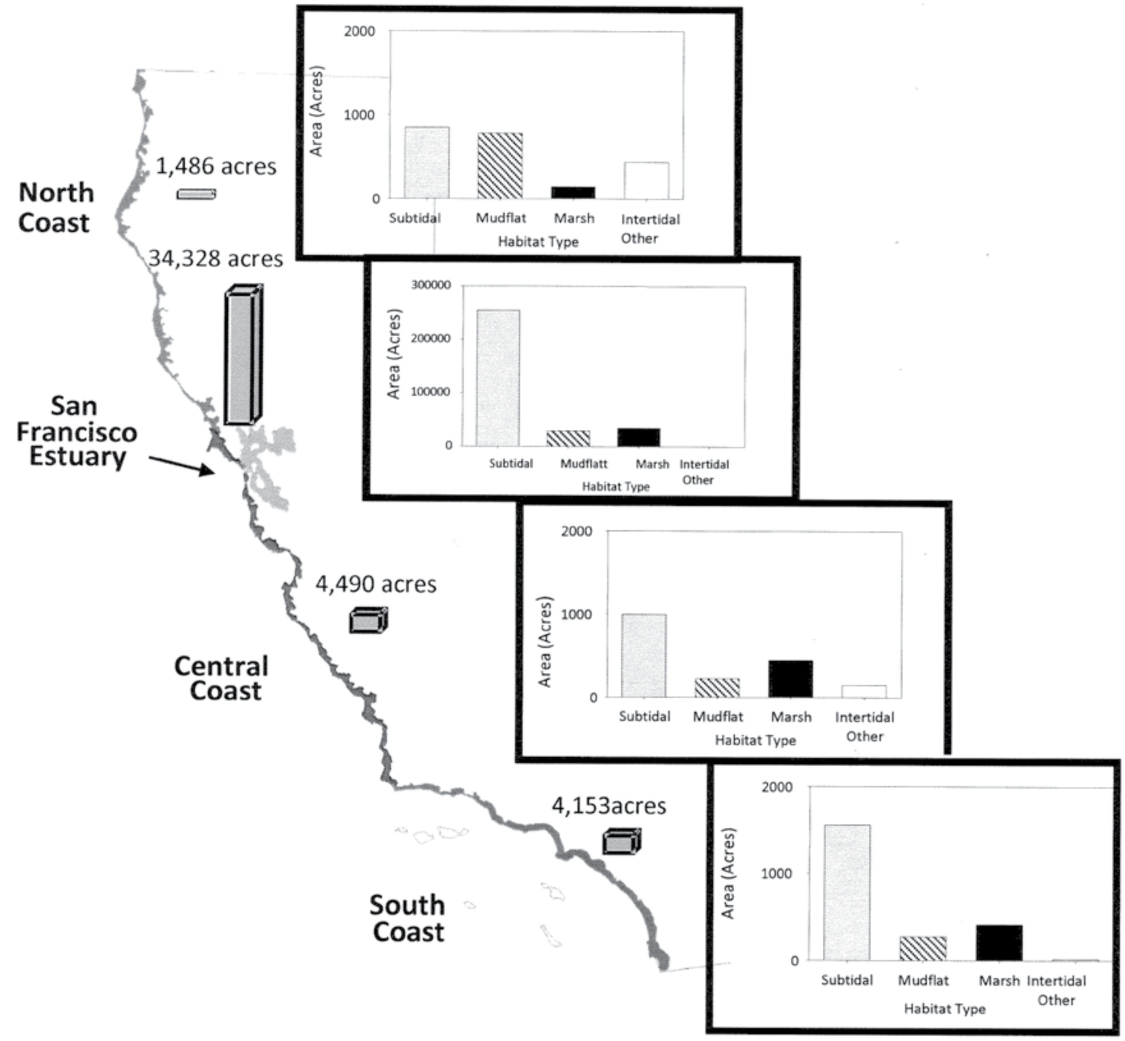

Figure 2: California coastline showing boundaries of the four coastal regions of the statewide assessment of salt marsh condition and the relative distribution of salt marsh habitat within each region. Inset graphs show relative importance of salt marsh versus other habitat types in the perennially tidal estuaries of each region.

Statewide Estimates of Salt Marsh Condition

Approximately 16% of California salt marshes received CRAM index scores in the top quartile (score > 82; Table 2). The majority of salt marsh acreage (69%) scored in the second quartile of CRAM index scores (63-82) statewide. Less than 1% of the state's estuarine marsh acreage scored in the lowest quartile (<44). Among the four CRAM attributes, salt marshes achieved their highest scores for Buffer and Landscape Context, with an estimated 64% of the total acreage scoring in the top quartile, and 96% in the top two quartiles. The Hydrologic Regime attribute and Biotic Structure attribute scores included 80% and 75%, respectively, within the top 50% of scores. The Physical Structure attribute produced the lowest scores, with 62% of the salt marsh acreage scoring in the bottom 50% of possible scores.

Score Type	Mean Score	Percent of Salt Marsh Area in Four Score Bins			
		Quartile 1 (>82)	*Quartile 2 (63-82)*	*Quartile 3 (44-63)*	*Quartile 4 (<44)*
CRAM Index	76 (1)	16	69	14	1
Landscape Context	88 (2)	64	32	4	0
Hydrologic Regime	80 (2)	36	44	18	2
Physical Structure	59 (2)	10	28	31	31
Biotic Structure	76 (2)	35	40	23	2

Table 2: Summary of Statewide CRAM index and attribute scores. The first column contains the mean and standard error (in parentheses) of CRAM index and attribute scores statewide. The last four columns present the estimated percentage of salt marsh area to score within each quartile of CRAM scores. Higher scores equate to higher condition.

Regional Estimates of Salt Marsh Condition

Regional differences in CRAM index scores were highly significant (p-value < 0.0001). A comparison of regional distribution of CRAM index scores (Figure 3) indicates that the condition of salt marshes generally decreases from the North Coast to the South Coast in California. North Coast wetlands had the highest mean index scores (82 ±1), followed by the San Francisco Bay region (78 ±1), and Central Coast (71 ±2). The mean index scores for the South Coast were the lowest of the four regions (67 ±1). Mean scores for Central and South Coast were 11- 15 % lower than North Coast, while that of San Francisco Estuary was 5% lower. The attribute scores generally followed the same trends as the index scores.

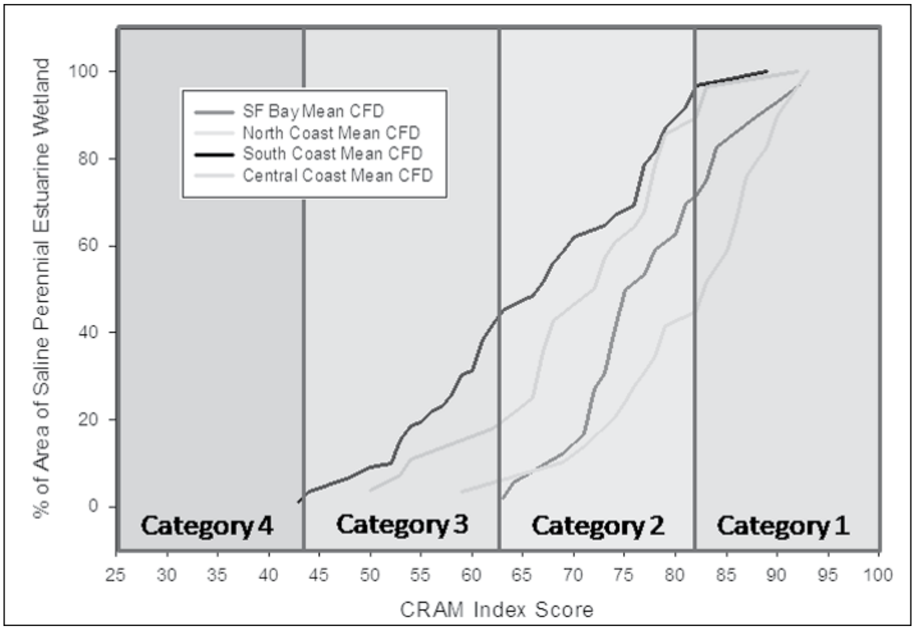

Figure 3: Cumulative frequency distribution (CFD) of CRAM Index scores as a function of percent of area of perennially tidal estuarine marsh by region.

There were regional differences at the CRAM attribute level as well. All regions scored high (81-90) for Buffer and Landscape Context. Physical Structure; however, this attribute was the lowest-scoring among all regions except the North Coast. The North Coast received the highest scores for the Hydrologic Regime and Physical Structure attributes, while the San Francisco Estuary achieved the highest scores for Buffer and Landscape Context and Biotic Structure attributes. Differences among regions were most significant with respect to the Hydrologic Regime and Physical Structure attributes, with the North Coast estuaries scoring from 21-28 points higher for these attributes in comparison with the other regions (Table 3).

CRAM Index or Attribute	North Coast Mean	SF Estuary Mean	Central Coast Mean	South Coast Mean
Index Score	82 (1)	78 (1)	71 (2)	87 (1)
Landscape Context	83 (1)	90 (2)	81 (2)	82 (2)
Hydrologic Regime	89 (2)	82 (2)	82 (2)	61 (1)
Physical Structure	84 (2)	59 (3)	57 (3)	59 (3)
Biotic Structure	72 (2)	78 (2)	63 (2)	87 (2)

Table 3: Mean and standard error (SE) CRAM index and attribute scores statewide and by region. Scores range from 25 to 100 with the standard error given in parenthesis. Differences of ±10 points or more between regions are considered to represent substantial distinctions.

Along the southern California coast, approximately 75% of salt marsh area (3,070 acres) is located in large estuaries (>500 acres). Wetlands in large estuaries had significantly higher CRAM index scores, primarily due to higher attribute scores for Hydrologic Regime and Biotic Structure, than small estuaries (p-value >0.05; Figure 4). This difference was greatest for Biotic Structure, which was 13 % higher.

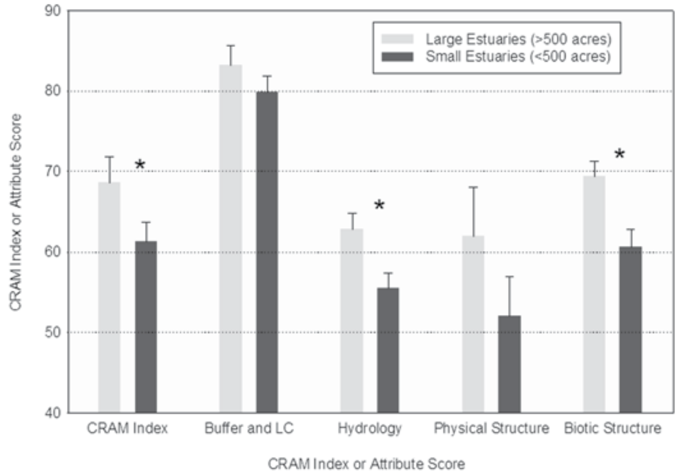

Figure 4: Plots of mean and upper 95% confidence interval for CRAM index and attribute scores for large and small estuaries in the South Coast. The size threshold of 500 acres includes both subtidal and intertidal acreage. An asterisk (*) indicates significant difference between large and small estuaries (p-value<0.05). LC = Landscape Context.

Analysis of Common Stressors

CRAM index scores were significantly negatively correlated with the total number of stressors found at each site (non-parametric spearman's rank correlation r = -0.44; p-value <0.0001). Dikes/levees were the most common stressor on wetlands statewide, impacting 43% of the sites visited (Table 4). The degree of impoundment due to dikes and levees was judged to be severe at 34% of the sites visited. The lack of treatment of invasive plants, nonpoint source (NPS) discharges, and contaminant pollution due to bacteria, pathogens, and heavy metals were among the other most frequently cited severe stressors statewide. Dikes/levees, excessive sedimentation (from watershed), and flow obstructions, such as culverts, were highly significant statewide (Table 5).

Stressor Name	**State (n=150)**	**NC (n=30)**	**SF (n=30)**	**CC (n=30)**	**SC (n=60)**
Dike/levees (h)	43	30	50	23	70
Non-point Source (NPS) discharge (h)	38	47	7	57	43
Lack of treatment of invasive plants adjacent to AA/ buffer (b)	34	80	7	17	33
Heavy metal impaired (p)	28	7	33	23	48
Bacteria and pathogens impaired (p)	25	13	17	27	43
Pesticides or trace organics impaired (p)	25	17	30	27	28
Nutrient impaired (p)	20	3	0	30	45
Predation & habitat destruction by non-native vertebrates (b)	20	0	53	3	23
Trash or refuse (p)	18	17	3	30	22
Excessive sediment or organic debris from watershed (p)	20	67	7	3	3
Ditches (borrow, agricultural drainage, mosquito control) (h)	16	23	33	0	7
Excessive runoff from watershed (p)	11	7	10	7	20
Grading/ compaction (p)	7	7	0	0	22
Flow obstructions (culverts, paved stream crossings) (h)	8	3	0	13	13
Excessive human visitation (b)	8	7	3	13	10
Flow diversions or unnatural inflows (h)	5	0	0	3	18
Pesticide application or vector control (b)	6	0	10	3	12
Mowing, grazing, excessive herbivory (b)	6	7	3	13	0

Table 4: Continued on page 19

Stressor Name	State (n=150)	NC (n=30)	SF (n=30)	CC (n=30)	SC (n=60)
Engineered channel (riprap, armored channel bank, bed) (h)	3	0	3	3	7
Dredged inlet/channel (h)	3	7	0	0	7
Lack of vegetation management to conserve natural resources (b)	4	0	0	10	5
Actively managed hydrologic regime (h)	3	3	0	7	3
Weir/drop structure, tide gates (h)	3	0	0	10	3
Filling or dumping of sediment/soils (p)	2	3	0	0	5
Point Source discharges (h)	2	3	0	0	5
Plowing/disking (p)	3	0	10	0	2
Dams (reservoirs, detention basins, recharge basins) (h)	3	0	0	10	2
Vegetation management (p)	3	0	3	7	0
Median Number of Stressors Per Site	10	6	9	9	15
n = number of sampling sites/region; h= hydrological stressor, p= physical stressor, b=biological stressor					

Table 4: Statewide and regional prioritization of stressors based on their frequency of occurrence among sites, regardless of severity. Statewide frequencies are based on regional means to account for regional differences in sample size (n). CC = Central Coast, NC = North Coast, SC = South Coast, SF = SF Estuary.

Although sites with a high number of stressors had significantly lower CRAM scores statewide, the predominance of individual stressors varied by region (Table 4). In the North Coast, the lack of treatment of invasive plant species (the dominant invasive species was identified as Spartina densiflora, a non-native cordgrass) was the most frequently occurring stressor (88% of sites) and the most severe stressor (70% of sites) at all sites. North Coast CRAM index scores were significantly lower for sites where this stressor was severe (p = 0.046; Table 5). For the San Francisco Estuary salt marshes, dikes and levees were among the most frequently stressors (50% of sites) and the most severe stressors (37% of sites) to occur. In the Central Coast, non-point source pollution was identified as the most frequently occurring stressor (56% of sites) and the most severe stressor (23% of sites). In the South Coast, dikes and levees were the most frequent stressor (70% of sites) and the most prevalent severe stressor (63% of sites). Non-parametric ANOVA tests showed that the number of stressors and number of severe stressors did not significantly differ between large and small estuaries in the South Coast (p-value = 0.98 and 0.78, respectively).

Stressor Type	Kruskal-Wallis Test (p-value)				
	Statewide	North Coast	SF Bay	Central Coast	South Coast
Dikes/Levees	0.0001 (n=76,14,59)	0.14 (n=30,3,6)	0.19 (n=17,4,11)	0.21 (n=31,3,4)	0.006 (n=18,4,38)
Lack of Treatment of Invasive Plants in Buffer	0.39 (n=100,33,16)	0.046 (n=5,3,21)	0.78 (n=30,2,0)	0.046 (n=25,1,2)	0.015 (n=40,10,10)
Excessive sediment from watershed	0.0001 (n=124,17,8)	0.35 (n=9,14,6)	0.019 (n=30,2,0)	0.49 (n=27,1,0)	0.43 (n=58,0,2)
Ditches	0.26	0.19	0.45	0.11	0.11
Flow obstructions	0.0005 (n=135,2,12)	0.18 (n=28,0,2)	NA	0.11 (n=23,0,5)	0.0012 (n=52,2,6)

Table 5: Summary of results of non-parametric ANOVAs examining the relationship of median CRAM index scores relative to the five major stressor types observed statewide and by region. The values in parentheses are the numbers of sites in which the stressor was absent, present but not severe, and severe, respectively. Note that flow obstructions were not an observed stressor type in the SF Bay.

Assessment of Projects with CRAM

For the restoration projects evaluated, overall CRAM index scores were lower than the median ambient condition scores in every region of the State; however, specific results varied by attribute (Table 6). The upper range of attribute scores for Landscape Context and Hydrologic Regime for projects were 15 - 18% lower than the statewide ambient scores for these attributes (Table 6). Project sites had higher scores than ambient sites for Physical Structure in the San Francisco Estuary and Central Coast regions. Physical Structure scores were essentially the same between projects and ambient sites in South Coast. Statewide, the scores for the Biotic Structure attribute were 6 - 13% higher for ambient sites than project related sites.

CRAM Index or Attribute Scores	SF Estuary		Central Coast		South Coast	
	Ambient	Project	Ambient	Project	Ambient	Project
Index Score	78	67	71	63	67	59
Landscape Context	90	72	81	64	82	65
Hydrologic Regime	82	65	82	67	61	55
Physical Structure	59	68	57	66	59	56
Biotic Structure	78	65	63	57	67	59

Table 6: Comparison of statewide (Ambient) and project related (Project) mean CRAM index and attribute scores for San Francisco Estuary, Central Coast, and South Coast.

Discussion

Condition assessments are an important aspect of wetland monitoring as they provide a means to measure the relative ability of a wetland to support and maintain its complexity and capacity for self-organization with respect to species composition, physico-chemical characteristics and functional processes as compared to wetlands of a similar type without human alterations (USEPA 2004). Methods best suited to assess condition reflect this by providing a quantitative measure describing where a wetland lies on the continuum ranging from least impacted condition to highly impaired. Because a primary goal of monitoring and assessment programs is to report on the ambient (overall) condition of the wetland resource, methods that evaluate condition directly can effectively serve programmatic needs. The information derived from condition assessments can also be used to develop and support aquatic life use designations for the implementation of wetland water quality standards (USEPA 2003).

Use of rapid assessment methods, which provide a more holistic assessment of wetland condition, in conjunction with probabilistic survey designs allows for a broader perspective on wetland condition. Probability-based surveys are becoming a commonly used monitoring tool within state and federal ambient monitoring programs (Fennessy et al. 2007, Kentula 2007, Scozzafava et al. 2011). A key advantage of the probability-based ambient survey is that it produces an unbiased, statistically representative estimate of condition at the state or regional scales, thus helping to inform program evaluation and restoration funding decisions at a broader scale. Although there are numerous examples of coastal wetland or estuarine monitoring programs in the United States that have utilized probability-based sampling designs, these applications have been primarily focused on contaminant-related management issues (Lamberson and Nelson 2002), or have sampled specific indicators (Fetscher et al. 2010). Assessments that focus only on individual measures of wetland quality or function (e.g. water quality, endangered species) provide a limited view of the condition of the resource as a whole. More inclusive assessment of ecological health that factor in multiple aspects of the system's ecology, hydrologic regime, and physical structure allow for a better representation of all ecological links e.g. water/sediment interactions and provide the ability to make more informed management decisions (Fairweather 1999).

Condition of California's Salt Marshes and Relationship to Major Stressors

This study generated important baseline information on condition of California's salt marshes throughout the state. Buffer and Landscape Context, Hydrologic Regime and Biotic Structure were the attributes for which the State's salt marshes scored the highest. This result was driven by two factors. There is a strong correlation between both Landscape Context and Biotic Structures scores with size, reflecting decreases in percent developed lands adjacent to wetlands as well as a well-established relationship between habitat area and plant species richness (Rosenzweig 1995). Second, a statistical design that reports on area percentages will most likely select sites from larger wetlands, even if that design is spatially balanced (Stevens and Olsen 1999). Central and South Coast regions have small lagoons and river mouth estuaries that are more fragmented (by roads, railroads, levees, and developed areas). These sites tend to have muted tidal hydrologic regimes which typically results in lower species richness (Noss and Csuti 1994). This is reflected in the lower Buffer and Landscape Context, Hydrologic Regime, and Biotic Structure scores for Central Coast and South Coast compared to the San Francisco Bay and North Coast regions.

Relationships between RAM scores and stressor data can suggest possible management actions to increase the overall condition of wetlands. Physical Structure was the attribute for which the State's estuarine marshes scored the lowest. A wetland's physical structure can be affected by anthropogenic modifications to the tidal and freshwater hydrologic regime, sediment transport, and geomorphology of the marsh, which results in reduced integrity of marsh physical structure (Day et al. 1989). Not surprisingly, dikes/levees were the most frequent and most severe stressor identified statewide. Dikes and levees can act to impound the wetland, restricting tidal exchange and extending the retention time of water on the wetland (Brockmeyer et al. 1997). This can lead to decreased topographic complexity, decreased plant diversity, increased retention of contaminants (Zedler and Callaway 2000, Fell et al. 1991, Fetscher et al. 2010). Sites bounded by levees or other water control structures that reduce the wetland tidal action can be expected to have a lower rating for almost all metrics relative to other sites. For example, South Coast sites where levees were present had, on average, 15 point lower CRAM index scores than sites where this stressor was absent.

Results from rapid assessments can help to prioritize restoration activity and help identify pristine areas for conservation. CRAM index and attribute scores showed a general decrease from north to south. This pattern is partially explained by an overall north-south gradient in condition relating to urbanization along the coastline. This relationship was supported by the strong negative correlation between CRAM Index scores and percent of adjacent developed land and the presence of infrastructure, such as dikes and levees (the stressor types most directly linked to urbanization). Previous studies have also found that indices of urbanization of surrounding land uses are correlated with indicators of wetland condition (e.g., Brown and Vivas 2005, Mack 2006, Fennessy et al. 2007, Wardrop et al. 2007, Sutula et al. 2008a,b, Johnston et al. 2009).

Utility of Probability-Based Surveys in Providing Context for Project Assessments

Evaluation of the overall ecological benefit associated with restoration activities requires application of standard approaches and tools that allow compilation and synthesis of findings across many wetlands and broad geographic areas. The use of rapid assessment in both probability-based surveys and as an element of individual restoration project monitoring provides a cost-effective mechanism to report on restoration effectiveness at a regional or statewide level. In California, CRAM Index scores of estuarine projects were lower than ambient scores for their respective region, with the gap most pronounced for the South Coast. In addition, the scores for the Buffer and Landscape Context and Hydrologic Regime attributes for projects were 15-18% lower than ambient scores in all regions. Differences can be attributed to a number of factors: size of project versus ambient wetland patches, landscape context, and project age/ maturation. For example, the fact that restoration projects tended to be smaller and more completely embedded in urbanized landscapes than ambient sites, could have lowered the Buffer and Landscape Context scores for projects. True differences are difficult to tease out without control of these confounding factors and well as a pre- and post-restoration baseline assessment. However, this study demonstrates the concept of how the use of low-cost rapid assessments, when incorporated into both regional and project assessments, becomes a mechanism to evaluate restoration program effectiveness. Future incorporation of rapid assessment into pre and post project monitoring at both impact and restoration sites, along with monitoring over time through the restoration trajectory will provide greater insight into the net effect of restoration actions relative to permitted wetland losses.

Importance of Reference in Probability-Based Surveys

Patterns in estuarine wetland condition based on ambient surveys and rapid assessment data must be interpreted with care, because gradients in latitude, geomorphology, hydrologic regime, and ecology among estuaries will control, to some extent, the best attainable (or reference) condition. Each CRAM module incorporates an internal standard for wetlands assessed with the module, based on established relationships among wetland conditions and related ecological processes (Stein et al. 2009a), and all assessed wetlands are evaluated against this internal model of the "best" wetlands in the class (Collins et al. 2007). Differences among regions must nonetheless be interpreted with an awareness of the existing natural variability among wetlands in those regions. In order to address questions of natural variability, there is a critical need to establish regional networks of reference sites that illustrate the full range of conditions for each CRAM metric, including the best attainable condition (Brinson and Rheinhardt 1996).

Although the ambient survey provides opportunities for identifying and selecting sites to comprise regional reference networks of estuarine wetlands, the internal CRAM standard for salt marshes should continue to be evaluated in the light of this first-time statewide ambient survey. Evaluation of internal standards will assure that the methodology appropriately identifies the best attainable condition for estuarine wetlands in the State of California as a whole, without respect to region. As reference sites are identified statewide, CRAM metrics can be adjusted to account for natural variability (e.g. latitudinal gradients) and regional differences in any wetland type. Further, identification of reference sites would assist in the development of performance thresholds for CRAM scores to differentiate between impaired from non-impaired conditions. While these thresholds may be subjective, a priori selected reference sites will ultimately verify the appropriateness of the threshold for the various CRAM metrics (Barbour et al. 1999).

Utility of RAMs in Probability-Based Surveys

The data obtained from our study indicate that a rapid method like CRAM was able to capture a variety of important regional differences in the condition of salt marshes in California. An assessment of salt marsh vegetation community structure in southern California and the San Francisco Bay estuaries found similar regional patterns in the condition of salt marsh vegetation in California (Fetscher et al. 2010). Regional differences in condition can have implications from a management perspective. For example, while the general negative correlation between estuarine wetland condition and intensity of adjacent land use is clear from this study, the management actions needed to address the issue at the regional scale will vary with the particulars of local land use history and practice.

Thus our study provides an example of how rapid assessment can provide similar insight into the general patterns of overall wetland condition comparable to the data collected through more intensive methods. Although rapid methods like CRAM provide a cost-effective means for basic assessment of overall ecosystem health, they are just one element of a comprehensive regional monitoring program. In most cases, RAMs will need to be used in conjunction with more intensive methods, rather than as stand-alone tools, to support management decisions. Intensive methods are essential to answer more precise management questions about particular plant and animal species, water quality parameters, or other condition aspects that are not individually assessed using RAMs. However, addition of rapid assessment to more intensive protocols has an advantage in that the CRAM data is available at the completion each assessment. . Although the addition of rapid assessment typically add 1-2 hours to the length of time the field crew is on site, the time required to process and obtain the assessment results is relatively minimal compared to methods that require the analysis of laboratory samples. In addition, RAM results can be used to help focus and prioritize the need and location for more intensive assessments. Thus, the low cost of RAM makes them ideal for addition for all state-sponsored assessments and becomes the mechanism through which state wetland management and restoration program effectiveness can be evaluated (Kentula 2007).

Although the inherent limitations of RAMs must be recognized, their integration with probabilistic survey designs provide a means to make unbiased estimates of wetland condition and can substantially reduce the amount of field time and kinds of data needed to monitor wetlands across large areas. Because estuaries throughout the world are recognized as important transitional habitats in larger wetland matrices, with few global examples of holistic survey approaches for determining their condition, RAM applications provide vital information to inform the management of these unique wetland resources.

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