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# Status of Perennial Estuarine Wetlands in the State of California

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# Status of Perennial Estuarine Wetlands in the State of California

Final Report to the

Surface Water Ambient Monitoring Program
State Water Resources Control Board


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# EXECUTIVE SUMMARY

Section 305(b) of the Federal Clean Water Act (CWA) requires each state submit biennial reports describing the health of its surface water, including wetlands, to the USEPA. This document reports on the health of California's perennial, saline estuarine wetlands.

Estuaries are partially enclosed bodies of water along the coast where freshwater runoff meets and mixes with salt water from the ocean. Based on the draft definition of wetlands for California, an estuarine wetland is an area within an estuary that is exposed at low tide and covered with rooted vegetation.

The health of the state's estuarine wetlands is estimated from a statewide survey of the distribution, abundance, and ambient condition of estuarine wetlands. The survey had three components: 1) landscape profile; 2) probability-based assessment of ambient condition; and 3) assessment of selected estuarine wetland restoration and mitigation projects. The results help answer four fundamental management questions: 1) where *are* the State's estuarine wetlands and how abundant are they; 2) what is the ambient condition of estuarine wetlands statewide and how does their condition vary by region; 3) what are the major stressors and how do they vary among coastal regions; and 4) what is the condition of permitted restoration projects relative to ambient condition. This fourth question demonstrates how data could be used to evaluate policies and programs affecting the distribution, abundance, and condition of estuarine wetlands.

The landscape profile described the distribution and abundance of the State's estuarine wetlands relative to other estuarine habitats and explored the underlying causes through a detailed examination of trends in San Francisco Estuary. A probability-based survey was used to assess the ambient condition of saline, perennial estuarine wetlands. The statewide ambient survey involved 120 sites allocated equally among four regions: North Coast, San Francisco Estuary, Central Coast, and South Coast. An additional 30 sites were allocated to South Coast to test for a difference between large and small estuaries. The field survey was conducted in the Fall of 2007. The statewide ambient survey in turn served as a regional frame of reference for project assessments.

Both the ambient survey and the project assessments utilized the California Rapid Assessment Method (CRAM; Version 5.0.2). CRAM is a field-based method to assess wetland condition based on visible indicators of four wetland attributes: Landscape Context, Hydrology, Physical Structure, and Biological Structure. Results were reported as the percent of the total area of estuarine wetland in California likely to fall within four categories equally-spaced categories of possible CRAM index or attribute scores, which range from 25-100: Scores greater than 82 = Category 1; scores between 63 and 82 = Category 2; scores between 44 and 63 = Category 3; and scores less than 44 = Category 4.

**Landscape Profile**. Approximately 91% of the historical amount acreage of California wetlands has been lost due to reclamation and land use. Accurate estimates of estuarine wetland loss in particular are only available for the San Francisco Estuary. In spite of losing approximately 85% of its saline wetlands and almost 92% of its freshwater tidal wetlands, the SF Estuary has almost 44,500 acres of estuarine wetlands at this time, about 77% of all the estuarine wetlands in the state. Although land use varies among the estuaries of California, it has affected the distribution, abundance, size, and shape of estuarine wetlands in consistently deleterious ways. It has decreased the amount of estuarine wetland and increased the number of small wetlands, thus increasing the distance between wetlands. In the more urbanized estuaries of the South Coast, Central Coast, and SF Estuary, many wetlands are embedded in intensive land uses and bounded by levees. These conditions diminish the hydrological and ecological connectivity among the wetlands, increase their susceptibility to invasion and local catastrophic events, and reduce their overall capacity to serve society.

**Ambient Survey**. An estimated 85% of the State's saline estuarine wetland scored within the top 50% of possible CRAM index scores. The statewide results are strongly influenced by the SF Estuary, which has most of the saline estuarine wetland. Landscape Context was the attribute for which the State's estuarine wetlands scored the highest. The CRAM Landscape Context consists of indicators of aquatic connectivity and natural buffer size and condition. With regard to Landscape Context, an estimated 64% of the total acreage of estuarine wetland was in the top category of CRAM scores. This is a reflection of the relatively large size of SF Estuary wetlands and their more rural context.

With regard to Hydrology and Biological Structure, an estimated 35% of the State's estuarine wetland acreage scored within the top category of CRAM scores. The CRAM Hydrology attribute is about freshwater source, hydrologic connectivity, and hydroperiod, while the Biological Structure attribute is about plant community composition, vertical vegetation structure, and horizontal zonation and interspersion of plant species or assemblages. Urbanized estuaries tend to have smaller wetlands with lower Hydrology and Biotic Structure health scores.

The State's estuarine wetlands scored lowest for the Physical Structure attribute, which is about the topographic complexity of a wetland and its diversity of physical patch types (e.g., pannes, pools, channels etc.). For this attribute, an estimated 62% of the acreage scored in the lower 50% of possible CRAM scores. Non-natural tidal and freshwater hydrology and excessive sediment supplies have reduced the physical complexity of wetlands in South and Central Coasts and San Francisco Estuary The presence of dikes, levees, and other water control structures that restrict tidal exchange is significantly correlated to poor wetland health.

CRAM index and attribute scores showed a general decrease from north to south. This difference was most pronounced for Hydrology and Physical Structure (25 - 30 point difference from North to South Coast) and least pronounced for Landscape Context (difference <10 point). This north-south gradient in condition tracks a similar gradient in density or extent of urbanization. While the general negative correlation between wetland condition and adjacent land use is clear, the corrective measures will vary with the particulars of local land use history and practice. Regional differences must be interpreted carefully because of inherent natural variability.

**Project Assessments**. Project assessments demonstrate how the condition of estuarine wetland projects can be assessed by comparing them to the ambient condition of comparable wetlands. The assessed projects include impact sites from development activities, mitigation sites resulting from compensatory mitigation, and non-regulatory wetland creation, restoration or enhancement sites. The project health scores tended to be 5 - 20% lower than the ambient scores for their regions, with the difference most pronounced for South Coast. The low scores for projects could be attributed to various factors: projects tend to be smaller, younger (less developed), and more closely associated with developed landscapes.

**Suggested Management Actions and Other Recommendations**. Within each region, CRAM scores and the stressor checklist suggest possible management actions to improve wetland health. The stressors affecting the condition of estuarine wetlands originate in their watersheds or adjoining uplands. In urbanized areas, decreases in water supplies due to upstream withdrawals or increases due to urban runoff have altered estuarine salinity regimes. In some estuaries, erosion control or impoundment of sediment has significantly reduced the amount needed to sustain estuarine wetlands. In other areas, such as the North Coast, timber harvesting activities upstream have led to excessive sedimentation. In all regions, conversion of floodplains to developed land use has reduced their abilities to filter runoff and buffer estuaries from upstream contaminants. Better management of urban and agriculture runoff through integration of Best Management Practices is necessary to reduce contaminant inputs to these systems, reduce toxicity of water and sediments and to improve flood control. Expansion of restoration within the upstream reaches of estuaries will reduce the stresses downstream.

Improving biological conditions in the North Coast region requires controlling the invasive cordgrass *Spartina densiflora*. Its intermediate dominance in many wetlands increases their structural complexity, but this will probably decrease as the dominance increases. Many North Coast estuarine wetlands are unlikely to attain higher conditions of species richness or biological structure unless this invasion is controlled.

Historical levees and dikes modify tidal circulation and thereby cause a general decline in estuarine wetland condition. Much of the infrastructure that adjoins estuaries, including operational and abandoned railroads and highways, occupies levees or other engineered fills that cross intertidal areas. Careful removal, realignment, or re-engineering of these crossings is required so that they no longer impede tidal circulation. Many of these crossings will need to be modified to accommodate rising sea levels and increased wave run-up; improved tidal exchange between estuarine wetlands and their estuaries should be linked to infrastructure repair and replacement as a design criterion.

Estuarine wetlands should be regarded as downstream extensions of local watersheds. Improving the overall condition of estuarine wetlands will ultimately require changes in watershed management to assure adequate supplies of clean water and sediment, improved tidal circulation between the wetlands and their estuaries, and adequate lands to accommodate estuarine transgression due to sea level rise.

One of the objectives of this assessment was to establish a baseline against which future landscape profiles could be compared. However, a comprehensive base map of one vintage and adequate precision and accuracy to meet local and state needs has proven to be very difficult to develop once, and is likely to be more difficult to replicate. For this reason, it is recommended that the state adopt the sampling approach used by the National Wetlands Inventory NWI Status and Trends (ST) assessments. For the national assessment being planned for 2011, 40-60 ST plots have been allocated to California estuarine habitat. This is likely to be an inadequate sample size to re-assess the distribution and abundance of estuarine wetlands within the State of California. The state should consider intensifying the proposed survey with additional ST plots. The existing comprehensive base map of estuarine wetlands produced for this report could be used to calculate the relationship between sample size and accuracy of the profile, as needed to identify the optimal number of ST plots.

Networks of reference sites that illustrate the full range of conditions for each CRAM attribute and metric should be established for each region of the state. Such networks are essential for refining CRAM, establishing quality assurance standards, and training CRAM users.

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# DISCLAIMER

The statewide estuarine ambient assessment is a component of the WDP project, which has been funded in part by the United States Environmental Protection Agency Assistance Agreement number CD-96956601 to the Resources Agency in the amount of $900,000. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The findings expressed in this report are the opinions of the assessment team members and do not necessarily reflect the positions of the organizations with which the assessment team members are affiliated.

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# INTRODUCTION

Estuaries are partially enclosed bodies of water along the coast where freshwater runoff meets and mixes with salt water from the ocean. They are among the most productive natural environments on earth, and support unique and diverse communities of plants and animals (Day *et al*. 1989). The human population is concentrated around estuaries because they provide abundant natural resources and access to the ocean.

One of the first steps in managing estuarine resources is to determine their current condition by answering the key question, “What is the status of California’s estuaries?” Often-raised questions relating to the condition of estuaries include, “Are the waters safe to swim?” “Are the fish safe to eat?” and “Is aquatic life healthy?” This document is focused on reporting on the last question “Is aquatic life healthy?” in estuarine wetlands, an important component of California estuaries.

Estuarine wetlands are the areas of an estuary exposed at low tide that are covered with rooted vegetation (Figure 1). They are commonly called salt marshes, although they can also be fresh or brackish depending on their location. They form along the quiet margins of estuaries, away from waves and where sediment deposited by floods and high tides tends to accumulate. The vegetation is uniquely adapted to variable soil salinity and the cycles of wetting and drying caused by the flood and ebb of tidal water. There are approximately four million acres of estuarine wetland in the coterminous United States, which is a small fraction of its historical extent (Dahl 2005). Estuarine wetlands are an integral component of the State’s coastal ecosystems.

Estuarine wetlands are highly valued for many reasons (Day *et al*. 1989, Mitsch and Gosselink 2000). They serve as nurseries for commercial fisheries, including salmon, crab, and shellfish. They shelter and feed millions of migratory shorebirds and waterfowl. They serve as critical habitat for most of the coastal threatened and endangered species. Estuarine wetlands filter contaminants from surface water, absorb flood waters, dissipate storm surges, and stabilize shorelines, and trap carbon (Chmura *et al*. 2003). They provide opportunities for boating, fishing, swimming, and other recreational activities that are central to local and regional economies. Estuarine wetlands are a major component of coastal open space and the intrinsic coastal aesthetic. Estuarine wetlands provide so many services that their overall value to society is very difficult to estimate (King 1998). In the San Francisco Estuary alone, the public has invested hundreds of millions of dollars to restore estuarine wetlands in the last decade.

The question of health of estuarine wetlands is restated by local wetland managers in this way: What is the condition of my wetland? Is my project working, how is it doing compared to other projects or to wetlands overall? Legislators and other policy makers ask the same question this way: Are the wetland protection policies and programs working? What is the public getting in return for its investment in wetlands? These questions are largely the same because they can be answered with the same basic information, comprehensive maps of wetlands and related projects, and standardized assessments of their overall condition.


**Figure 1. Examples of estuarine wetlands from the South Coast, Central Coast, San Francisco Estuary, and North Coast of California.**

The purpose of this report is to present the findings of the state's initial effort to answer these questions with regard to estuarine wetlands. The statewide assessment of estuarine wetlands employed the state's "wetland monitoring and assessment toolkit" (Sutula et al. 2008). The toolkit is being developed by a consortium of wetland scientists and managers based on recent guidance provided by the United States Environmental Protection Agency (USEPA; 2006). The guidance recognizes three levels of assessment: inventories and landscape profiles (Level 1), rapid assessment of overall condition or functional capacity (Level 2), and assessment of wetland functions or specific aspects of condition (Level 3). In addition, the guidance calls for public access to assessment results and other information about wetlands. This estuarine assessment employed the Level 1 and Level 2 tools plus web-based information management capabilities currently available in the toolkit. Assessments based on Level 1 and Level 2 tools can be easily incorporated with Level 3 intensive indicators targeting specific management questions to provide a more complete assessment of estuarine wetland health. Likewise, estimates of estuarine wetland health can be incorporate with other assessments of estuarine habitat condition (e.g., sediment and water quality) to provide an integrated picture of health of estuarine aquatic life use.

This report provides broad statistical estimates of the condition of estuarine wetlands statewide and within four coastal regions. The assessment includes an analysis of the distribution and abundance of estuarine wetlands and related habitats based on the existing State Wetland

Inventory, plus a field survey of the overall condition of estuarine wetlands according to the California Rapid Assessment Method (CRAM; Collins *et al*. 2007). CRAM is a field-based tool for rapidly assessing the over condition and indentifying the major stressors of wetlands in California, based on visible indicators of landscape and buffer condition, hydrology, and physical and biological structure. CRAM has been peer reviewed (e.g., Ambrose *et al*. 2007) and validated for use in estuarine marsh (Stein *et al*. In press).

## Assessment Goals and Management Questions

The California Resources Agency received a Wetland Demonstration Pilot (WDP) grant through USEPA Region IX under Section 104b(3) of the US Clean Water Act in 2005 for the express purpose of demonstrating the State's capacity to evaluate the condition of wetlands. Under agreement with the USEPA, the Resources Agency chose to demonstrate application of the toolkit on estuarine wetlands statewide, and on wadeable streams and associated riparian areas (i.e., riverine wetlands) within three demonstration watersheds (Sutula et al., 2008). To define condition in practical terms, a set of fundamental management questions was assembled for the survey to answer:

- Where *are* the estuarine wetlands and how abundant are they?
- What is the ambient condition of estuarine wetlands statewide and how does their condition vary by region?
- What are the major stressors and how do they vary among coastal regions?
- What is the condition of permitted restoration projects relative to ambient condition? This question was included to show how these assessment data could be used to evaluate policies and programs affecting the distribution, abundance, and condition of estuarine wetlands.

These questions cut across the whole community of wetland managers, regulators, scientists, advocacy groups, affected private sector interests, and the concerned public at large. Clients for the assessment include: the Resources Agency and its daughter agencies (e.g., Coastal Conservancy, Coastal Commission, California Department of Fish and Game, etc), the State Water Resources Control Board (SWRCB) and Regional Water Quality Control Board (RWQCB) including the Surface Water Ambient Monitoring Program (SWAMP), US Fish and Wildlife Service (USFWS), National Marine Fisheries Service, USEPA, and the US Army Corps of Engineers, and various regional and local coastal zone managers such as the Southern California Wetland Recovery Project (www.scwrp.org), the San Francisco Bay Wetlands Regional Monitoring Program (www.wrmp.org), the Humboldt Bay Harbor Recreation and Conservation District (http://www.humboldtbay.org) among others.

# METHODS

## General Approach

The statewide ambient assessment of estuarine wetlands consists of three major components:

- Landscape profile of the extent and geographic distribution of estuarine wetlands and related habitats;
- Probability-based survey of the ambient condition of saline perennial estuarine wetlands using CRAM; and
- Assessment of completed estuarine wetland restoration projects, relative to the statewide ambient condition of estuarine wetlands.

The “landscape profile” of estuarine wetlands and related habitat was based on the existing US Fish and Wildlife Service National Wetland Inventory (NWI) updated by the regional teams. The landscape profile describes the distribution and abundance of estuarine wetlands relative to other estuarine habitats (Gwin *et al*. 1999) and explores some of the underlying causes for the observed patterns. This landscape profile and the wetland inventory data help to establish a baseline from which future assessments of net change in acreage can be assessed.

The probability-based survey of ambient condition and a targeted assessment of a population of restoration projects utilized the California Rapid Assessment Method (CRAM) for wetlands (Version 5.0.2[1]; Collins *et al*. 2007), developed through a series of Wetland Program Development grants funded by USEPA Region IX under Section 104b(3) of the US Clean Water Act. CRAM is a field-based method to assess overall wetland condition or functional capacity based on visible indicators of landscape and buffer condition, hydrological characteristics, and physical and biological structure (Sutula *et al*. 2006, Stein *et al*. in press). The ambient survey results were used as a regional frame of reference against which results of the project assessments were compared.

## Assessment Target Population

As indicated by the brief definition given in the introduction, all estuaries are primarily characterized by a longitudinal gradient in water salinity between marine and riverine environments. However, the gradient can range from saline or hypersaline to non-saline, and it is much steeper for some estuaries than others. The freshwater zone can be very narrow for small estuaries in arid areas, and very broad for large estuaries in areas with abundant rainfall. Sources of non-saline water include rivers, streams, overflow from depressional wetlands, lakes, groundwater, point discharges (e.g., effluent from sewage treatment facilities), and storm drains. Some are much smaller than others. There are estuaries associated with large and small coastal embayments, coastal lagoons, major rivers, and small streams. California has a great diversity of estuaries due to its large range in coastal climate, physiography, and land use.

Due to time and funding constraints, it was not possible to comparably survey the conditions of wetlands in all kinds of California estuaries. To select a target population, the estuarine wetlands were first grouped according to their dominant salinity and hydrological regime, given the scientific consensus that these factors affect condition more than any others, then a subset

[1] Field survey activities were conducted using Version 4.6. An adjustment was made to the method which affects how the number of physical patch types were scaled after field work was completed. This adjustment does not affect how the data were collected. This adjustment is captured in Version 5.0.2.

of these groups was selected as the target assessment population based on their prevalence and importance to coastal zone managers. The following groups of estuarine wetlands were considered.

> ***Saline vs. Non-saline.*** *A saline estuarine wetland is distinguished from a non-saline estuarine wetland by having a dominance of salt-tolerant vascular vegetation along the shoreline, including the banks of larger tidal creeks and sloughs. Non-saline estuarine wetlands are not dominated by salt-tolerant vegetation along their shorelines. In the brackish area of an estuary, the estuarine wetlands can shift annually from saline to non-saline conditions due to changes in freshwater inputs. Very large estuarine wetlands with multiple drainage networks can be saline in some areas and non-saline in other areas. The classification of an estuarine wetland as saline or non-saline can therefore require local knowledge or field reconnaissance.*
>
> ***Perennial vs. Seasonal.*** *An estuarine wetland is perennial if its estuary is perennial, and it is seasonal if its estuary is seasonal. A perennial estuary is distinguished from a seasonal estuary by having a tidal inlet that is continuously open for more than eleven months during most years. A seasonal estuary has a tidal inlet that is closed for at least one month during most years. In either case, the inlet can be natural or artificial, and its closure or opening can be natural or managed. While the inlet is open, the estuary is subject to daily fluctuations in water height due to oceanic tides, although the fluctuations within the estuary may be muted relative to the fluctuations in the adjoining ocean environment.*

A preliminary reconnaissance indicated that almost all estuarine wetlands in California are perennial, that saline conditions dominate most perennial estuaries, and that most restoration projects are saline. Therefore, given their prevalence statewide, and the desire to assess projects relative to ambient condition, the decision was made to focus on saline wetlands of perennial estuaries.

Many coastal zone managers are also interested in knowing how estuarine wetland condition varies among regions. To address this interest, the statewide assessment was subdivided into four regions (Figure 2) based on the eco-regional boundaries developed by Hickman (1993). The regions are listed below.

- North Coast (extending north-south from the northern limits of the Russian River Watershed to the Oregon state border)
- Central Coast (extending south from the northern limits of the Russian River Watershed to Point Conception)
- San Francisco Estuary (SF Estuary; extending inland from the Golden Gate to the historical limits of the tides before European contact in the region)
- South Coast (extending south from Point Conception to the Mexico international border)

The San Francisco Estuary and its attending watersheds were treated as a separate region because they have much more estuarine wetland than the other regions combined.


**Figure 2. California coastline showing boundaries of the four coastal regions of the statewide assessment of estuarine wetland condition.**

### *Landscape Assessment*

Wetland maps were used to produce a landscape profile. A wetland landscape profile describes the geographic distribution and abundance of wetlands within and among watersheds, regions, or larger areas (Kentula *et al*. 1992). The perennial estuarine landscape profile for California describes the distribution and abundance of estuarine wetlands relative to all other estuarine habitats and explores some of the underlying causes for the observed patterns. It was also designed to support future assessments of net change in estuarine habitat acreage and to help explain the field-based assessment of estuarine wetland condition.

The landscape profile is based on the most recent USFWS National Wetland Inventory (NWI). For the purposes of this assessment, the inventory was updated and revised by the regional teams. All estuarine subtidal and estuarine intertidal polygons were selected from the NWI dataset for California. These polygons were overlaid onto the National Agricultural Imagery Program (NAIP) imagery from 2005, and also converted to KDL files and overlaid onto the aerial imagery in Google Earth. Each regional team examined these files to identify any needed updates in polygon boundaries or classifications. Any required updates were then made based on the 2005 NAIP imagery, which was also used to assign the habitat polygons to their estuaries. Each estuary, and all of its component habitats, was then classified as either seasonal or perennial, based on estuarine morphology and the local knowledge of the regional teams. Time and budget constraints prevented comprehensive field-based verification of the revised inventory. However, the regional teams in charge of the revisions included experts familiar with local field conditions.

The updated inventory was used to assess the relative abundance of all perennial estuarine habitats. It was also used to calculate the size and shape of estuarine wetlands as basic parameters of their distribution and abundance. To determine how wetland size and shape varies among regions, standard methods for mapping individual wetlands should be applied statewide, a set of rules were created to distinguish one wetland from another or from non-wetland areas based on professional judgment about landcover types and landforms that inhibit the movements of estuarine wetland wildlife, especially species of non-migratory small mammals and birds that reside in estuarine wetlands. In short, the rules are as follows.

An area of estuarine wetland is a unique area unto itself if:

- it is completely separated from any other estuarine wetland by one or more of the following barriers or a combination of them: developed or non-developed upland of any width (including levees and dikes), or subtidal or non-vegetated intertidal habitat at least 50 m wide; or
- it is hydrologically connected to another area of estuarine wetland by drains or pipes, no matter how short, but is otherwise completely disconnected from that estuarine wetland and any other estuarine wetland by the barriers listed above.

The shape of each estuarine wetland thus defined was quantified using the shoreline development index, which evaluates the regularity of a shoreline (Hutchinson 1957). For a wetland that is a perfect circle, the index value is 1.0. Elongate wetlands tend to have values between 2 and 4. Values greater than 4 represent complex branching forms. The following formula was used to calculate the shoreline development index for each estuarine wetland:

$$SLD = SL \div 2 \cdot \mathrm{sqrt}(\pi \cdot A)$$

where SL is the length of shoreline and A is wetland area.

The initial landscape profiles suggested that the distribution and abundance of estuarine wetlands might be related to watershed size and land use history. To explore these relationships, each perennial estuary was assigned to its respective watershed. This was generally straightforward because most estuaries have one watershed to which all of their wetlands can be assigned. In the case of complex estuaries, such as the San Francisco Estuary, wetlands were assigned to local watersheds based on proximity and available data on sediment sources. For example, the contiguous wetlands joining the mouths of the Napa River and the Sonoma Creek in the San Francisco (SF) Estuary were assigned to an amalgamated Napa-Sonoma Watershed since both component watersheds provide essential sediment to these wetlands. Most of the wetlands of the Suisun subregion of the SF Estuary, as well as the nearby delta wetlands, were assigned to the amalgamated Sacramento-San Joaquin Watershed because it provides most the sediment upon which these wetlands rely. The watershed boundaries were derived from the map of “planning watersheds” of CalWater 2.2.1. Some of these watersheds had to be combined to contain large estuaries. The watersheds of some very small estuaries had to be mapped directly from the NAIP imagery. The land use associated with each estuarine wetland was quantified using the 2001 National Land Cover Dataset (NLDC) provided by the United States Geological Survey (USGS). For SF Estuary, the NLCD maps of developed lands were combined with the regional maps of reclaimed but non-developed historical estuarine habitats to provide a comprehensive map of lands bound by levees.

### *Field Survey of Ambient Condition*

The field survey of ambient estuarine wetland condition was based on the inventory of saline wetlands of perennial estuaries developed by the regional teams. The survey was designed and site selection was conducted in consultation with USEPA Environmental Monitoring and Assessment Program (EMAP; Anthony Olsen, USEPA, Western Ecology Division, Corvallis). The design features an unequal probability-based allocation of sites by percent of estuarine wetland acreage, with 30 sites allocated to Central Coast, SF Estuary, and North Coast. South Coast was allocated 60 sites evenly divided between wetlands of large and small perennial estuaries, where small estuaries have less than 500 total acres of subtidal and intertidal habitats.

A generalized random tessellation stratified (GRTS) design (Stevens and Olsen 1999, 2004) was used to select the 150 assessment sites from the inventory. The GRTS design results in a spatially balanced sample with the points ordered so that the sequential use of the points as study sites maintains spatial balance. This design is intended to provide good spatial coverage across the entire inventory while allowing for increased sampling or intensification in regions or for subsets of the inventory, such as wetland in small estuaries. In this way, a better allocation of resources is achieved to ensure robust assessments of condition within each region while maintaining an unbiased estimate of condition statewide.

The regional teams were deployed from August through November 2007 to conduct the field-based assessments using the estuarine wetland module of CRAM, version 5.0.2 (Collins *et al*. 2007). CRAM can be used to assess the overall condition of estuarine wetlands and to identify stressors likely to affect their condition. The method separates condition into four attributes with multiple metrics (Table 1). Each metric has a standardized set of mutually exclusive descriptions representing a full range of possible condition. Each description has a numerical value representing its potential to support a suite of wetland functions. Choosing the best-fit description for each metric generates a score for each attribute. The attribute scores can be averaged as an overall index score. Attribute and index scores are expressed as percent possible, ranging from 25 (lowest possible) to a maximum of 100.

**Table 1. Schematic of CRAM attributes and metrics.**

| Attribute | Metric |
|---|---|
| Buffer and Landscape Contex | Landscape Connectivity |
| | Buffer |
| | Percent of AA with Buffer |
| | Average Buffer Width |
| | Buffer Condition |
| Hydrology | Water Source |
| | Hydroperiod |
| | Hydrologic Connectivity |
| Physical Structure | Structural Patch Richness |
| | Topopgraphic Complexity |
| Biological Structure | Plant Community |
| | Number of Plant Layers Presents |
| | Number of Co-dominants |
| | Percent Invasion |
| | Horizontal Interspersion and Zonation |
| | Vertical Biotic Structure |

CRAM also provides a stressor check list to help explain the assessments and to identify possible management actions to improve condition. Stressors are represented as categorical scores ranging from “0”, indicating no stressor was present; “1”, indicating that the stressor is present but unlikely to cause significant impact; and “2”, indicating that the stressor is present and likely to cause a significant impact. The Stressor Severity Index for a site is the percent maximum possible score for all stressors combined.

To maintain the integrity of the spatially balanced survey design, each CRAM score must represent the same amount of wetland area. To meet this requirement, each assessment is restricted to a 1-ha circle of estuarine wetland. If the wetland is smaller than 1 ha but larger than 0.1 ha, the entire wetland is assessed.

The precision of an assessment is an important aspect of its quality assurance and control. CRAM precision was assessed as the difference in attribute and index scores among the regional teams for the same assessment areas. Four one-day field exercises were conducted in each of the four regions, with two to three sites assessed per region by each team. The precision target was ±10% for attribute scores and index scores. Detailed procedures guiding the quality assurance and quality control procedures governing field assessments and data management were prepared in the Quality Assurance Project Plan (QAPP; Sutula *et al*. 2008).

## Project Assessment

The goal of restoration project assessments in this survey is to demonstrate how to assess the ambient condition of a project using CRAM and how to use ambient probability-based survey data to provide context for these scores.

The restoration projects selected were drawn from an initial list of projects assembled for three regions (North Coast was not included in this phase of the project). A comprehensive inventory of projects existed for the SF Estuary, but not for the other regions although a process to inventory projects coast-wide is now being implemented.

The lack of comprehensive project inventories prevented the use of a randomized approach for selecting projects to assess. Instead, each regional team chose ten projects (the most sites that every regions could assess) representing a large range in project size and including sites of special interest to regional coastal zone managers. The selected projects are not considered representative of the whole population of projects in any region except Central Coast, where no more than ten candidate projects total were found. Projects larger than two assessment areas (larger than 2.0 ha) required multiple assessments, based on the guidance document for project assessment (Collins *et al*. 2007). In these cases, the attribute scores were averaged to generate an overall project index score.

## Data Analysis

Analysis of the CRAM survey data relied on a probability-based statistical approach to produce unbiased estimates estuarine condition regionally and statewide. Using information provided by the sample design, these probability-based estimators take into account the number of sites selected by the design within a given area, as well as the total area represented by each site; together these are called also called “area weights”. Area-weighted estimates of estuarine condition included cumulative distribution functions (CDFs), which give the percent area of the resource below a particular attribute value as a function of that value, as well as means, standard errors, and 95% confidence intervals. CDFs were calculated for CRAM Index and the four component attribute scores, as their scores approximate continuous data. Measures of confidence or standard errors used a local variance estimator (Stevens and Olsen, 2004) that utilizes distances between sites to increase precision. Prior to any statistical computation, area weights were adjusted to account for missing data, either due to inability to access sites or failure to meet quality controls, as well as minor inaccuracies in the initial sample frame. For a complete description of the statistical tools used in this analysis, as well as a free download of scripts for probability-based estimation, go to http://www.epa.gov/nheerl/arm.

Non-parametric Spearman's rank correlation coefficients were calculated to explore relationships between CRAM index scores and stressor indices. Kruskal-Wallis one-way analysis of variance (ANOVA) by ranks was used to test differences in median CRAM Index scores for the major individual stressors identified statewide and by region. 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 present/severe categories.

# RESULTS

## Summary of Extent and Geographic Distribution

380,860 acres of subtidal and intertidal estuarine habitat exist in California. Perennially tidal estuarine wetlands comprise 12% of this habitat, or 44,456 acres. Figure 3 illustrates how the total acreage of estuarine habitats and the acreage of estuarine wetlands are distributed among the four coastal regions. The SF Estuary is the largest in the state. It has three-quarters of the perennial estuarine habitat, including most of the estuarine wetland. Outside of this region, the acreage of estuarine habitats is fairly equally distributed among the North Coast, Central Coast and South Coast. However, the Central Coast and South Coast have roughly three times more area of estuarine wetland than the North Coast.

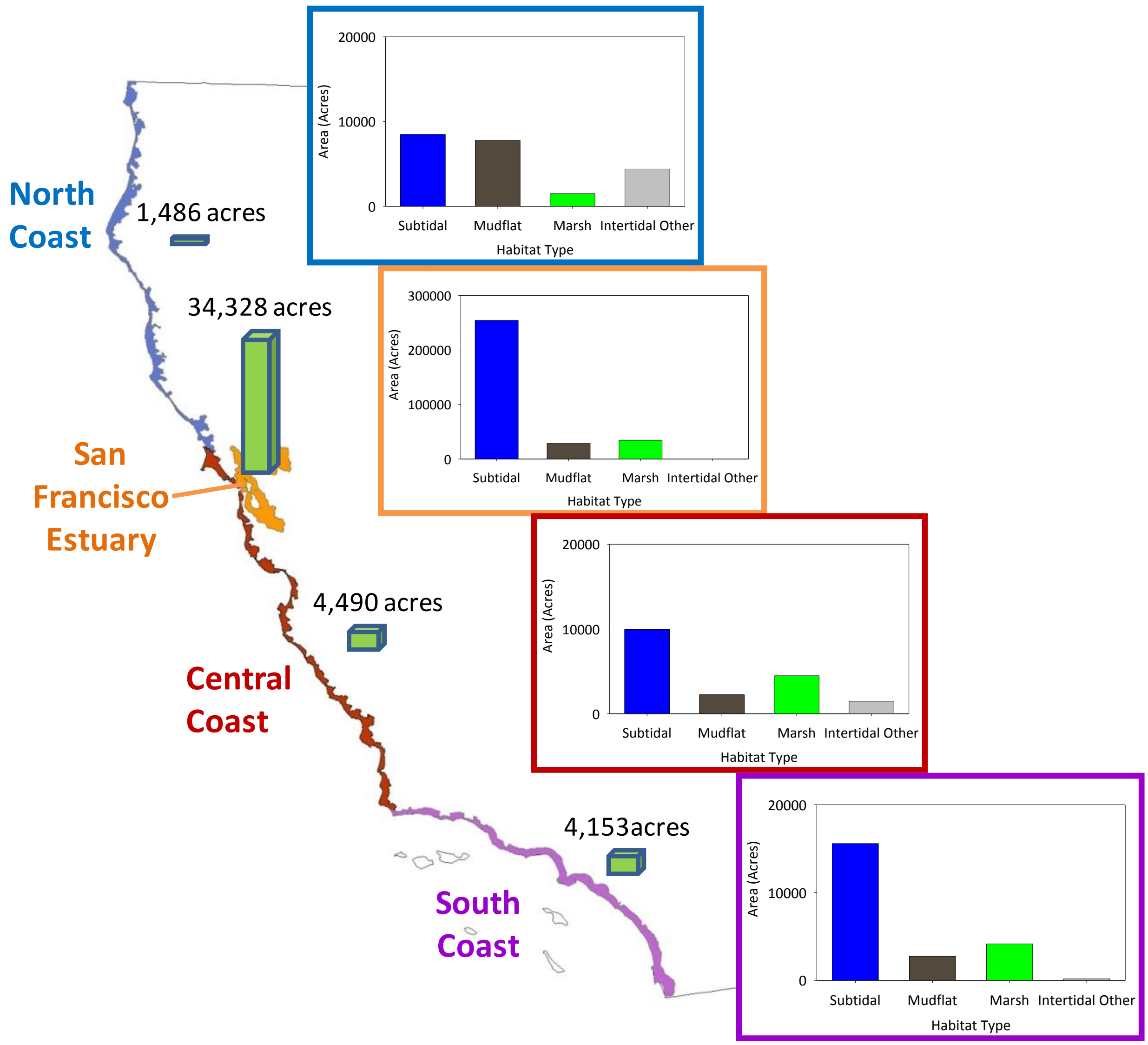


**Figure 3. Graphic depicting the relative abundance of estuarine wetland habitat among the four coastal regions (dark green bars along the coastline) and its abundance relative to the other estuarine habitat types within each region (inset graphs). Mudflats and wetlands are intertidal habitats. "Intertidal other" represents reefs, aquatic beds, and rocky shorelines. Note unique y-axis scale for SF Estuary.**

The inset graphs of Figure 3 show the distribution of each of the major estuarine habitat types within each region. In all regions, estuaries are dominated by subtidal habitat, though to a much greater extent in SF Estuary. In the North Coast region, the area of mudflat is about six times that of estuarine marsh; in combination with other intertidal habitats (e.g., intertidal aquatic beds), estuarine marsh is only approximately 10% of the total intertidal estuarine habitat. In both South Coast and Central Coast, estuarine marsh represents 54% of total intertidal habitat.

## Historical Estuarine Landscape Change: Evidence for San Francisco Estuary

Historical extent of estuarine wetlands has not been well documented for California. However, historical analysis of the SF Estuary provides evidence of how land use can affect the size and shape of wetlands as well as their distribution and overall amount. The evidence stems from intensive analyses of the historical (Pre-European contact) and current distribution and abundance of wetlands (Figures 4 and 5). Although changes in all estuarine habitat types have been studied, (Goals Project 1999, Collins *et al*. 2007), only the changes in estuarine wetlands are presented here. Historical change in wetland habitats is better documented for the SF Estuary than for any other region in California. An estimated 15% of the nearly 190,000 acres of historical saline wetland remain (Goals Project 1999).

In the SF Estuary, wetlands were historically distributed fairly evenly among the geometric size classes shown in Figure 6. Following almost two centuries of land development in this region, there are only a few wetlands smaller than 0.5 acres, and these are not the same as the wetlands of similar size that existed historically. Those wetlands no longer exist; however, there has been a great increase in the number of wetlands between 0.5 and 200 acres in size. About 25% of these wetlands are restoration or mitigation projects. The rest have either evolved along levees, or they are remnants of historically larger wetlands that have been encroached upon and subdivided by development. The number of wetlands between 200 and 2,000 acres in size has been decreased by about 20%, despite a few completed restoration projects involving hundreds of acres large. The number of wetlands between 2,000 and 4,000 acres has also decreased by about 20%. No existing wetlands are as large as any of the 14 historical wetlands that were larger than 4,000 acres. The largest remnant is the nearly 3,000 acre Petaluma Marsh in Sonoma County, the largest estuarine wetland in California.

A stronger correlation existed between watershed size and wetland area for the historical landscape that the modern, more urbanized landscape in SF Estuary (Figure 6A). Among modern habitats statewide, the strength of these correlations ranged from high in SF Estuary and North Coast ($R^2$ from 0.83 – 0.80) and decrease southward, with a low $R^2$ of 0.12 in South Coast (Figure 6B – 6D). These data suggest that the regional variation in strength in the correlation between watershed size and wetland area among estuarine wetlands statewide is likely associated with wetland loss stemming from urbanization.


**Figure 4. Historical and present distribution of wetlands in the SF Estuary downstream of its inland Delta (top panel), with a close up of the Suisun sub-region of SF Estuary (bottom panel).**

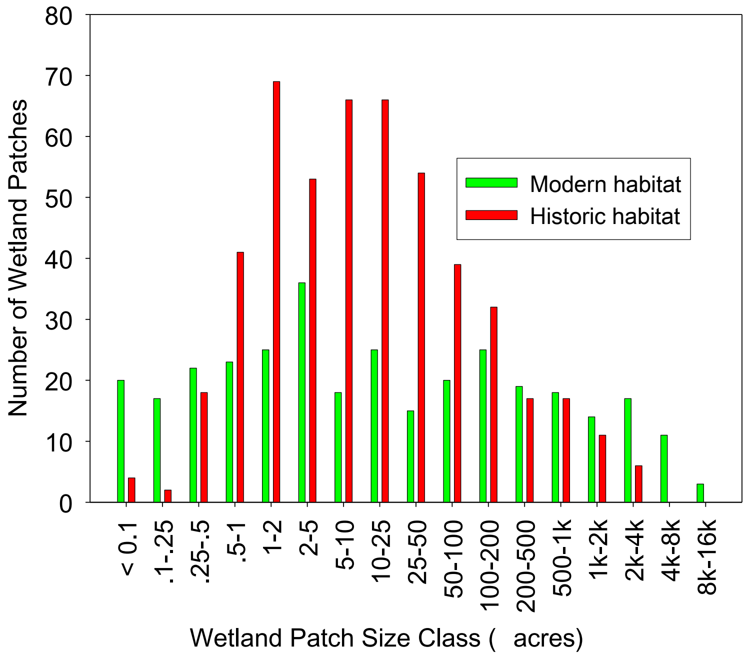


**Figure 5. Distribution of wetlands among size classes for historical and modern landscapes of the SF Estuary.**

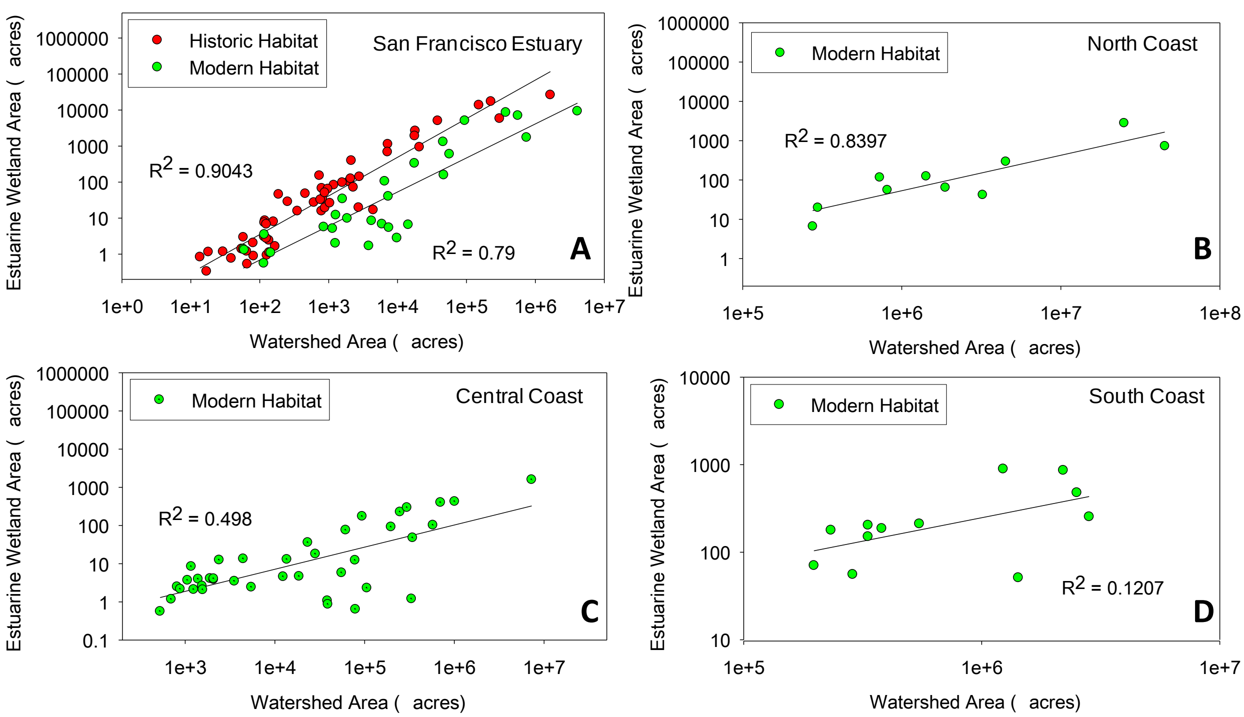


**Figure 6. Correlation between estuarine wetland area and watershed area for historical and present SF Estuary (A) and correlation between the total wetland area within estuaries and the size of their watersheds for other regions (B-D).**

Urbanization has clear impacts on the shape and edge of estuarine wetlands. Figure 7 shows the distribution of the shape index among historical versus modern day habitats in SF Estuary. The shape index denotes wetlands that are generally round (x-axis values = 1), much longer than wide (values between 1 and 2), complexly branching (values between 2 and 4), or very complex (values greater than 4). SF Estuary wetlands naturally vary in shape but tend to be round, as indicated by the greater proportion of historical wetlands having very low shape index values and the lack of any historical wetlands having very large values (Figure 7A). Some wetlands remain round while getting smaller due to encroaching development all around them. Others get carved into elongate and complexly branching shapes. Both scenarios are clearly evident in Figure 7A. However, even the most complexly shaped wetlands appear to eventually become one or more round remnants with repeated encroachment and subdivision.

Patterns in the shape of SF Estuary wetlands can help interpret those of wetlands statewide. Figure 7B shows the relative abundance of different shape wetlands in all estuaries statewide. The distributions are generally similar among the regions. Most wetlands in each region are roundish and few have very complex shapes. However, estuarine wetlands tend to be rounder in North Coast and Central Coast than in South Coast or SF Estuary. Only in SF Estuary and South Coast do wetlands have very complex shapes.

The repeated encroachment of urban land uses on SF Estuary wetlands is evident in the percentage of wetland edge developed (Figure 8). Every wetland in SF Estuary is bounded by development to some extent. Most wetlands have at least 60% of their margins adjoining developed lands. This includes developed fill, salt ponds, developed uplands, and agricultural lands separated from the wetlands by levees, dikes, or other tidal control structures. The effect of agricultural development is evident in the SF Estuary's Suisun sub-region, where historical reclamation eliminated many large wetland areas and reduced others to small, isolated remnants. (Figure 4, bottom panel). The long, narrow wetlands have since developed along the outboard margins of the reclamation levees. Many of the remaining wetlands have complex shapes.

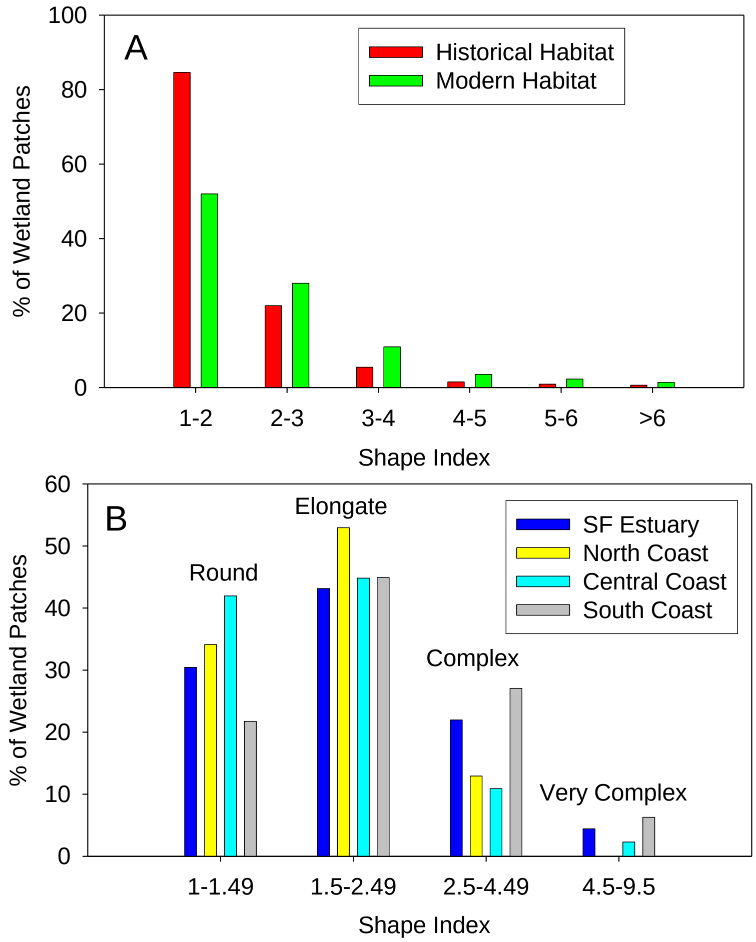


**Figure 7. Relative abundance of wetland shapes in SF Estuary (A); Distribution of modern wetland patches relative to the index of wetland shape statewide (B).**

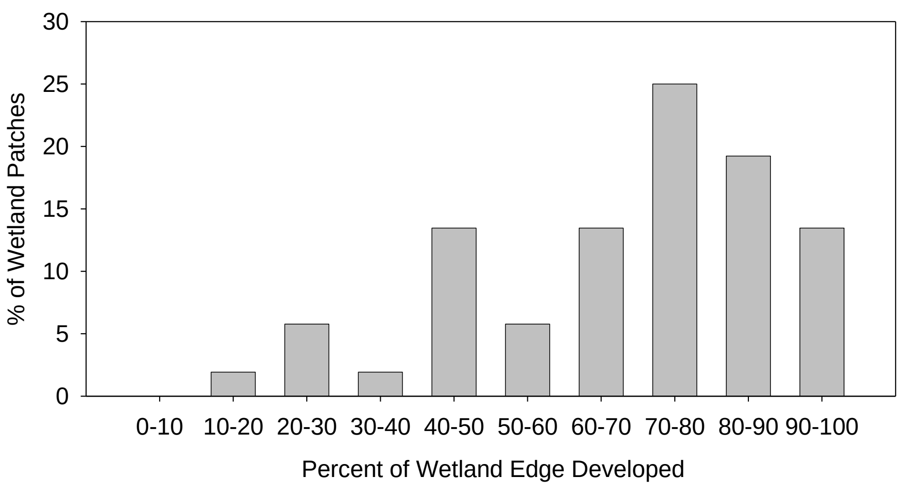


**Figure 8. Amount of development adjoining SF Estuary wetlands.**

## Ambient Survey Results

### *Precision and Guidance for Interpreting Scores*

Interpretation of the CRAM probability-based survey results requires an understanding of the statistical uncertainty of the CRAM scores. This uncertainty has two components: the precision of the method (i.e., the rate at which scores for the same condition vary among users) and variability in condition. Inter-team calibration exercises documented an average error rate among users of ±6 points for attribute scores and ±9 points for index scores. The variability in condition as measured by the standard error of the mean for index and attribute scores was generally much less (approximately 3%; Figure 9). Thus, differences in index scores of 10 percentage points or more among regions are meaningful, and differences of 10 points in inter-regional attribute scores are likely to be very significant. Beyond this, interpretation of differences in CRAM scores among regions should consider the natural variability in the attributes of estuarine marshes among regions. These considerations are explored in the Discussion section of this report.

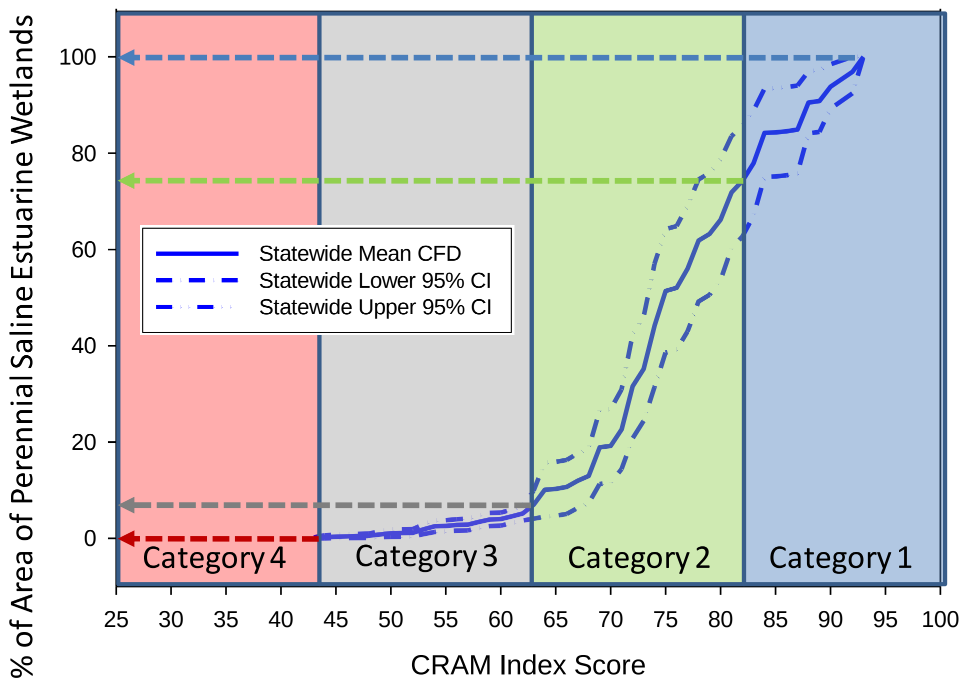


**Figure 9. Cumulative Frequency Distribution (CFD) of CRAM index scores as a function of percent of area of saline perennial estuarine wetlands statewide. The solid curve represents the mean CFD. Dashed curve represents the 95% confidence intervals. Colored categories within each graphic represent the total range in possible index scores (25 - 100), separated into four equal categories. These categories correspond to an internal reference network for CRAM, based upon "best attainable condition." The horizontal lines drawn back to the Y-axis shows how the percent of area within each of these categories (e.g., 100 - 84 = 16% of area found within Category 1) might be calculated.**

The results of the field survey of estuarine wetland ambient condition are presented in two basic ways. First, the average index and attribute scores were computed for each region and statewide. Next, the Cumulative Frequency Distributions (CFDs) were plotted from cumulative distribution functions of CRAM index and attribute scores for each region and statewide. The CFDs are 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 then separated into four equal categories. Scores greater than 82 were assigned to Category 1; scores between 63 and 82 were assigned to Category 2; scores between 44 and 63 were assigned to Category 3; and scores less than 44 were assigned to Category 4. Based on CRAM, higher scores represent better condition and higher potential to provide the functions and services expected for the kind of wetland being assessed. These categories of scores were then overlaid onto the CFDs to estimate the percentage of wetland area in each category of condition for each region and statewide. The mean scores, as well as the percent of area within each of the categories, represent statistical estimates derived from a probability-based selection of sites.

### *Statewide Estimates of Estuarine Wetland Condition*

An estimated 16% of the State's 44,456 acres of saline, perennial estuarine wetlands received CRAM index scores were assigned to Category 1 (Figure 10; Table 2). The majority of acreage (69%) was in Category 2. Less than 1% of the acreage of the state's estuarine marsh was assigned to Category 4.

Among the four CRAM attributes, landscape context was the attribute for which estuarine wetlands had the highest scores statewide. An estimated 64% of the total acreage was assigned to Category 1. Physical structure was the attribute for which the State's wetlands scored the lowest. 62% of the total estuarine acreage statewide had scores within the range of Categories 3 and 4.

For Category 1, the distribution of Hydrology and Biotic Structure scores for statewide acreage of perennially tidal estuarine wetlands (35 and 36%, respectively) were similar to those for estuarine marsh acreage. One-fifth to one-quarter of total acreage statewide was assigned to Categories 3 and 4, respectively, based on these two attributes.

**Table 2. Summary of Statewide CRAM index and attribute scores. The first column presents the mean and standard error (in parentheses) of CRAM index and attribute scores statewide. The last four columns present the estimated percentage of estuarine wetland area to score within each category.**

| Statewide | Mean Score | Percent of Estuarine Wetland Area in Four Score Bins | | | |
|---|---|---|---|---|---|
| | | Category 1<br>>82 | Category 2<br>63 - 82 | Category 3<br>44 - 63 | Category 4<br>< 44 |
| CRAM Index | 76 (1) | 16 | **69** | 14 | 1 |
| Landscape Context | 88 (2) | **64** | 32 | 4 | 0 |
| Hydrology | 80 (2) | 36 | **44** | 18 | 2 |
| Physical Structure | 59 (2) | 10 | 28 | **31** | **31** |
| Biotic Structure | 76 (2) | 35 | **40** | 23 | 2 |

### *Analysis of Common Stressors*

CRAM index scores were significantly correlated with the number of stressors and severe stressors found at each site (non-parametric spearman's rank correlation $r = -0.44$ and $-0.44$, respectively; p-value $<0.0001$). Dike/levees, lack of treatment of invasive plants, bacteria and pathogens impaired, nonpoint source discharges, and heavy metal impaired were among the five most frequently cited severe stressors noted statewide (Table 3). Dikes/levees were the number one stressor on wetlands statewide, affecting 43% of the sites visited. The degree of impoundment due to dikes and levees was judged to be severe at 34% of the sites visited (Table 4). In South Coast, the number of stressors and the number of severe stressors did not significantly differ between large and small estuaries (<500 acres in size).

**Table 3. 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. CC= Central Coast, NC= North Coast, SC= South Coast, SF= SF Estuary.**

| Stressor Name | State (n=150) | NC (n=30) | SF (n=30) | CC (n=30) | SC (n=60) |
|---|---|---|---|---|---|
| Dike/levees | 43 | 30 | 50 | 23 | 70 |
| Non-point Source (Non-PS) discharges | 38 | 47 | 7 | 57 | 43 |
| Lack of treatment of invasives adjacent to AA/ buffer | 34 | 80 | 7 | 17 | 33 |
| Heavy metal impaired | 28 | 7 | 33 | 23 | 48 |
| Bacteria and pathogens impaired | 25 | 13 | 17 | 27 | 43 |
| Pesticides or trace organics impaired | 25 | 17 | 30 | 27 | 28 |
| Nutrient impaired | 20 | 3 | 0 | 30 | 45 |
| Predation & habitat destruction by non-native vertebrates | 20 | 0 | 53 | 3 | 23 |
| Trash or refuse | 18 | 17 | 3 | 30 | 22 |
| Excessive sediment or organic debris from watershed | 20 | 67 | 7 | 3 | 3 |
| Ditches (borrow, agricultural drainage, mosquito control) | 16 | 23 | 33 | 0 | 7 |
| Excessive runoff from watershed | 11 | 7 | 10 | 7 | 20 |
| Grading/ compaction (N/A for restoration areas) | 7 | 7 | 0 | 0 | 22 |
| Flow obstructions (culverts, paved stream crossings) | 8 | 3 | 0 | 13 | 13 |
| Excessive human visitation | 8 | 7 | 3 | 13 | 10 |
| Flow diversions or unnatural inflows | 5 | 0 | 0 | 3 | 18 |
| Pesticide application or vector control | 6 | 0 | 10 | 3 | 12 |
| Mowing, grazing, excessive herbivory (within AA) | 6 | 7 | 3 | 13 | 0 |
| Engineered channel (riprap, armored channel bank, bed) | 3 | 0 | 3 | 3 | 7 |
| Dredged inlet/channel | 3 | 7 | 0 | 0 | 7 |
| Lack of vegetation management to conserve natural resources | 4 | 0 | 0 | 10 | 5 |
| Actively managed hydrology | 3 | 3 | 0 | 7 | 3 |
| Weir/drop structure, tide gates | 3 | 0 | 0 | 10 | 3 |
| Filling or dumping of sediment/soils (N/A - restoration areas) | 2 | 3 | 0 | 0 | 5 |
| Point Source (PS) discharges | 2 | 3 | 0 | 0 | 5 |
| Plowing/Discing (N/A for restoration areas) | 3 | 0 | 10 | 0 | 2 |
| Dams (reservoirs, detention basins, recharge basins) | 3 | 0 | 0 | 10 | 2 |
| Vegetation management | 3 | 0 | 3 | 7 | 0 |
| **Median Number of Stressors per Site** | 10 | 6 | 9 | 9 | 15 |

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

| Stressor Name | State (n=150) | NC (n=30) | SF (n=30) | CC (n=30) | SF (n=30) |
|---|---|---|---|---|---|
| Dike/levees | 34 | 20 | 37 | 17 | 37 |
| Lack of treatment of invasive plants adjacent to AA or buffer | 24 | 70 | 0 | 10 | 0 |
| Bacteria and pathogens impaired (PS or Non-PS pollution) | 15 | 7 | 0 | 17 | 0 |
| Non-point Source (Non-PS) discharges | 16 | 13 | 0 | 23 | 0 |
| Heavy metal impaired | 13 | 0 | 0 | 17 | 0 |
| Nutrient impaired | 13 | 0 | 0 | 20 | 0 |
| Pesticides or trace organics impaired | 12 | 3 | 0 | 23 | 0 |
| Excessive runoff from watershed | 7 | 0 | 3 | 3 | 3 |
| Flow obstructions (culverts, paved stream crossings) | 7 | 3 | 0 | 13 | 0 |
| Trash or refuse | 7 | 0 | 0 | 17 | 0 |
| Flow diversions or unnatural inflows | 5 | 0 | 0 | 3 | 0 |
| Ditches (borrow, ag drainage, mosquito control, etc.) | 7 | 13 | 10 | 0 | 10 |
| Grading/compaction (N/A for restoration areas) | 4 | 0 | 0 | 0 | 0 |
| Excessive sediment or organic debris from watershed | 6 | 20 | 0 | 0 | 0 |
| Excessive human visitation | 3 | 0 | 0 | 7 | 0 |
| Engineered channel (riprap, armored channel bank, bed) | 3 | 0 | 0 | 3 | 0 |
| Predation and habitat destruction by non-native vertebrates | 3 | 0 | 7 | 0 | 7 |
| Weir/drop structure, tide gates | 3 | 0 | 0 | 10 | 0 |
| Mowing, grazing, excessive herbivory (within AA) | 4 | 7 | 0 | 9 | 0 |
| Filling or dumping of sediment/soils (N/A- restoration areas) | 1 | 0 | 0 | 0 | 0 |
| Point Source (PS) discharges | 1 | 0 | 0 | 0 | 0 |
| Dredged inlet/channel | 1 | 0 | 0 | 0 | 0 |
| Actively managed hydrology | 2 | 0 | 0 | 3 | 0 |
| Pesticide application or vector control | 2 | 0 | 0 | 3 | 0 |
| Lack of vegetation management to conserve natural resources | 2 | 0 | 0 | 3 | 0 |
| **Median Number of Severe Stressors per SIte** | 4 | 3 | 9 | 2 | 9 |

Non-parametric ANOVAs were conducted to test differences in CRAM index score with respect to major individual stressor variables. Dikes/levees, excessive sedimentation (from watershed), and flow obstructions, such as culverts, were highly significant statewide (Table 5). Within regions, the significance of individual stressors varied.

**Table 5. Summary of results of non-parametric ANOVAs to examine effect of stressor severity on CRAM index score. Numbers in parentheses are the numbers of sites in which the stressor was absent, present but not severe, and severe, respectively. CC= Central Coast, NC= North Coast, SC= South Coast, SF= SF Estuary.**

| **Stressor Variable** | **Kruskal-Wallis Test (Pr >Chi-Square)** | | | | |
|---|---|---|---|---|---|
| | **Statewide** | **NC** | **SF** | **CC** | **SC** |
| Dikes/Levees | 0.0001 (n=76,14,59) | 0.14 (n=20,3,6) | 0.19 (n=17,4,11) | 0.21 (n=21,3,4) | 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) | -- | 0.11 (n=23,0,5) | 0.0012 (n=52,2,6) |

## *Regional Estimates of Condition and Stress*

A comparison of regional CFDs of CRAM index scores (Table 6; Figure 10) indicates that estuarine wetland condition generally decreases from north to south. North Coast wetlands had the highest mean ambient scores (82 ±1), followed by the San Francisco Bay region, and Central Coast. The mean ambient scores for South Coast was 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 SF Estuary was 5% lower. The attribute scores generally followed the same trends as the index scores.

All regions scored best for landscape context (81 - 90; Category 1). Biotic Structure was the lowest scoring attribute in the North Coast (72 ±2; Category 2); all other attributes for North Coast scored within Category 1. Physical Structure was the lowest scoring attribute among the other regions. Differences among regions were most significant with respect to Physical Structure and Hydrology. The mean score for Physical Structure was 25 - 27 points higher for North Coast than for the other regions. Hydrology scores in were 21 - 28 points lower than the other three regions.

The CFD data can be also be used to describe the statistical distribution of CRAM scores statewide. 25% of the area of estuarine wetland is likely to have an index score greater than 82. 75% of the area is likely to have a score above 71. Only 14% of the North Coast estuarine wetlands area, compared to 68% of the South Coast area, is likely to score in the lower 25% of index scores (Table 7).

**Table 6. Mean and standard error (SE) CRAM index and attribute scores statewide and by region. Numbers represent percent of possible points, with scores ranging from 25 to 100% and standard error given in parenthesis. Differences of ±10 percentage points or more can be considered meaningful between regions. Blue shaded cells represent Category 1; Green cells represent Category 2; and Gray cells represent Category 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) | 67 (1) |
| Landscape Context | 83 (1) | 90 (2) | 81 (2) | 82 (2) |
| Hydrology | 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) | 67 (2) |

**Table 7. Percentage of estuarine marsh area within each region that fell into the top and bottom quartiles (top 25% and bottom 25%) of Statewide CRAM index scores.**

| Region | Estuarine Marsh Area (Acres) | % Estuarine Marsh Area in Top 25% | % Estuarine Marsh Area in Bottom 25% |
|---|---|---|---|
| North Coast | 1,486 | 45% | 14% |
| SF Estuary | 34,328 | 29% | 27% |
| Central Coast | 4,490 | 11% | 48% |
| South Coast | 4,193 | 3% | 63% |

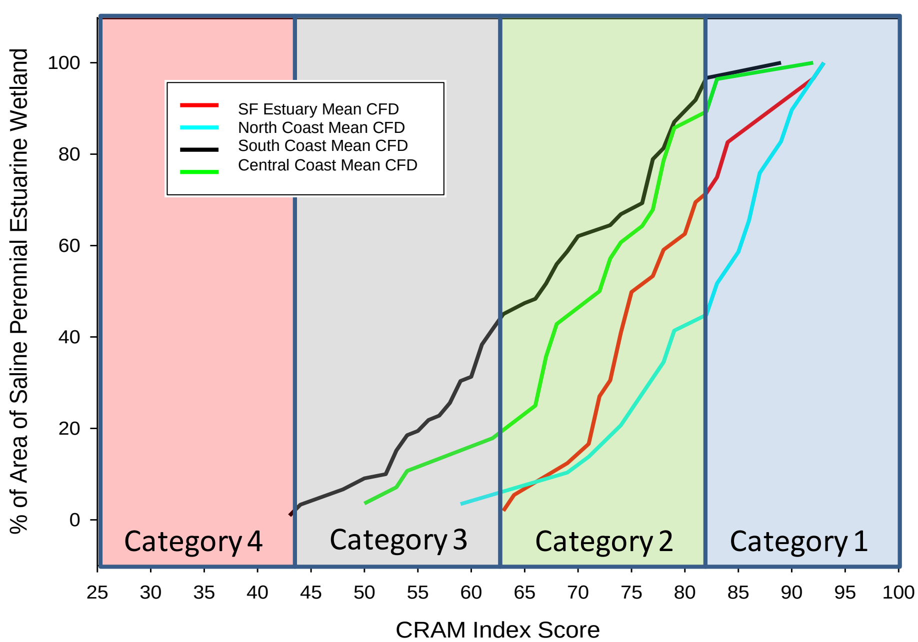


**Figure 10. Cumulative frequency distribution (CFD) of CRAM Index scores as a function of percent of area of perennially tidal estuarine marsh as a function of CRAM Index score by region.**

***North Coast.*** Within North Coast, 55% of the 1485 acres of perennially tidal estuarine marsh received index scores in Category 1 (Table 7; Figure 10) and 45% was in Category 2; a statistically insignificant acreage received scores below the 50$^{th}$ percentile (Categories 3 and 4 combined).

Among the four CRAM attributes, Hydrology was the attribute for which the North Coast estuarine marsh scored the highest; 71% of the total acreage is expected to score in Category 1. North Coast estuarine wetlands also scored well for Landscape Context and Physical Structure; 51% and 45% of the total acreage is expected to score in Category 1 for these two attributes. For both the Landscape and Hydrology attributes, more than 90% of the perennially tidal estuarine wetland area would be expected to score in Categories 1 or 2.

**Table 8. Distribution of North Coast intertidal wetland acreage among categories of condition. The first column present the mean and standard error (in parentheses) of CRAM index and attribute scores statewide. The last four columns present the estimated percentage of estuarine wetland area to score within each category.**

| North Coast | Mean | Percent of Estuarine Wetland Area in Four Score Bins | | | |
|---|---|---|---|---|---|
| | | Category 1 >82 | Category 2 63-82 | Category 3 44-63 | Category 4 <44 |
| CRAM Index | 82 (1) | **55** | 45 | 0 | 0 |
| Landscape Context | 83 (1) | **51** | 46 | 3 | 0 |
| Hydrology | 89 (2) | **71** | 29 | 0 | 0 |
| Physical Structure | 84 (2) | **45** | 38 | 17 | 0 |
| Biotic Structure | 72 (2) | 30 | **56** | 24 | 0 |

The Biotic Structure attribute (composed of metrics measuring of the emergent wetland plant species diversity, dominance by non-native species, and plant vertical structure and horizontal interspersion) was the component for which the North Coast estuarine wetland scored the lowest. About 30% of the North Coast estuarine wetland area is likely to score in Category 1 for this attribute. About 24% of the total estuarine wetland area in North Coast is likely to score in Categories 3 or 4 for this attribute   Analysis of data at the metric level indicates that the majority of the North Coast sites scored relatively low for dominance by non-native species, vertical structure metrics, and horizontal interspersion.

The results regarding the significance of non-native species are corroborated by stressor data. Lack of treatment of invasive plant species was the most frequently occurring stressor at North Coast sites (88% of sites; Table 3) and the most severe stressor (70% of sites; Table 4). North Coast CRAM index scores were significantly lower for sites where this stressor was severe ($p = 0.046$, Table 5). The dominant invasive species was identified as *Spartina densiflora*. Excessive sediment from local watersheds (20% of sites), dikes and levees (20%), NPS pollution (13%), and mosquito ditching (13%) were the top five severe stressors occurring in North Coast.

***San Francisco Estuary.*** Within the SF Estuary, 31% of the more than 34,000 acres of perennially tidal estuarine wetland is likely to scores in Category 1 for overall condition (Table 9; Figure 10). The majority of the acreage (69%) is likely to score in Category 2, with a statistically insignificant percentage of acreage below the 50$^{th}$ percentile (Categories 3 and 4).

Among the four CRAM attributes, Landscape Context was the attribute for which the SF Estuary wetlands scored the highest (mean of 90%). Approximately 71% of the total acreage is likely to score in Category 1 for this attribute. SF estuarine wetlands also scored well for Hydrology; 43% of the total acreage within this region is expected to score within Category 1 for the Hydrology attribute. For Landscape Context, Hydrology, and Biotic Structure, more than 83% of the wetland area of the SF Estuary is likely to score in Categories 1 or 2. Physical Structure is the attribute for which the SF estuarine wetlands scored the lowest (mean of 59; Table 9). Analysis of metric level data showed that wetlands in this region has many sites in Category 3 (42%) for the number of physical patch types (pannes, pools, channels, etc.) and Category 2 (52%) for topographic complexity (52%).

**Table 9. Distribution of SF Estuary intertidal wetland acreage among categories of condition. The first column presents the mean and standard error (in parentheses) of CRAM index and attribute scores statewide. The last four columns present the estimated percentage of estuarine wetland area to score within each category.**

| SF Estuary | Mean | Percent of Estuarine Wetland Area in Four Score Bins | | | |
|---|---|---|---|---|---|
| | | Category 1 >82 | Category 2 63-82 | Category 3 44-63 | Category 4 <44 |
| CRAM Index | 78 (1) | **31** | 69 | 0 | 0 |
| Landscape Context | 90 (2) | **71** | 26 | 3 | 0 |
| Hydrology | 82 (2) | **43** | **43** | 14 | 0 |
| Physical Structure | 59 (3) | 5 | 31 | **33** | 31 |
| Biotic Structure | 78 (2) | 41 | **49** | 10 | 0 |

Dikes and levees were among the most frequently occurring stressors (50% of sites; Table 3) and the most severe stressor for the SF Estuary wetlands (37% of sites; Table 4). Sites with levees present had a mean CRAM index score seven points lower than sites lacking this stressor, though this difference was not significant (Table 5). Mosquito ditching (10% of sites) and predation by non-native vertebrates (7% of sites) were among the most severe stressors, while heavy metal and pesticide/organic contamination were among the most frequently occurring stressors.

***Central Coast.*** Within the Central Coast region, 11% of the 4,500 acres of perennially tidal estuarine marsh is expected to score in Category 1 for overall condition (Table 10; Figure 10). The majority of the acreage (17%) would probably score in Category 2, with 17% of the wetlands area below the 50$^{th}$ percentile.

Among the four CRAM attributes, Hydrology was the attribute for which Central Coast perennially tidal estuarine marsh scored the highest. Approximately 53% of the total acreage is expected score in Category 1 for the Hydrology attribute. Central Coast estuarine wetlands also scored well for Landscape Context; 36% of the total acreage within this region would probably score in Category 1 for Landscape Context. For Landscape Context and Hydrology, more than 81% of the acreage of perennially tidal estuarine marsh in Central Coast is likely to score in Categories 1 or 2.

Physical structure was the attribute for which the Central Coast estuarine wetland scored the lowest. Only 5% of estuarine wetland in this region scored is likely to score in Category 1. Approximately 64% of the total estuarine wetland acreage in Central Coast would have scores below the 50$^{th}$ percentile for the whole state, with 31% likely to score in Category 4. Analysis of metric level data indicated that 50% of the acreage of Central Coast estuarine wetlands would tend to score in Categories 3 or 4 for both structural patch richness and topographic complexity.

The Central Coast estuarine wetlands also scored somewhat low for Biotic Structure. Only 11% of the wetland acreage in this region would tend to score in Category 1. A total of 57% of the Central Coast wetland acreage would probably score below the 50$^{th}$ percentile for the state as a whole, with 12% in Category 4. Analysis of metric level data indicates that the majority of Central Coast sites scored lowest in horizontal interspersion (75% of acreage in Category 4) and highest in percent invasion (93% of acreage in Category 1).

**Table 10. Distribution of Central Coast intertidal wetland acreage among categories of condition. The first column presents the mean and standard error (in parentheses) of CRAM index and attribute scores statewide. The last four columns present the estimated percentage of estuarine wetland area to score within each category.**

| Central Coast | Mean | Percent of Estuarine Wetland Area in Four Score Bins | | | |
|---|---|---|---|---|---|
| | | Category 1 >82 | Category 2 63-82 | Category 3 44-63 | Category 4 <44 |
| CRAM Index | 71 (2) | 11 | **72** | 17 | 0 |
| Landscape Context | 81 (2) | 36 | **59** | 5 | 0 |
| Hydrology | 82 (2) | **53** | 28 | 15 | 4 |
| Physical Structure | 57 (3) | 5 | 31 | **33** | 31 |
| Biotic Structure | 63 (2) | 11 | 32 | **45** | 12 |

Nonpoint Source (NPS) pollution was identified as the most frequently occurring stressor in Central Coast (56% of sites; Table 3) and the most severe stressor (23% of sites; Table 4). Dike/levees (17% of sites), nutrient, pesticide, bacteria and heavy metal impairment and trash (17 - 20% of sites) were the most prevalent stressors. Dikes/levees (17% of sites) and trash (13% of sites) were among the most severe stressors in estuarine marshes of this region. Sites with levees present had a mean CRAM index score 10 points lower than that of other sites, though this difference was not significant in a non-parametric ANOVA (Table 5)

***South Coast.*** Within the South Coast, 13% of the almost 4,000 acres of perennially tidal estuarine wetland is likely to have CRAM index score in Category 1 (Table 11; Figure 10). The majority of the acreage would probably score in Categories 2 or 3 (55 % and 39% respectively), with just 3% scoring in Category 4.

Among the four CRAM attributes, Landscape Context was the attribute for which South Coast perennially tidal estuarine wetland scored the highest. Approximately 51% of the total acreage scored in Category 1 for overall condition, and approximately 38% scored in Category 2. South Coast estuarine wetlands also scored moderately well for Biotic Structure; approximately 76% of the total estuarine wetland acreage within this region would probably score in either Category 1 or 2.

**Table 11. Distribution of South Coast intertidal wetland acreage among categories of condition. The first column presents the mean and standard error (in parentheses) of CRAM index and attribute scores statewide. The last four columns present the estimated percentage of estuarine wetland area to score within each category.**

| **South Coast** | **Mean** | **Percent of Estuarine Wetland Area in Four Score Bins** | | | |
|---|---|---|---|---|---|
| | | Category 1 >82 | Category 2 62-82 | Category 3 44-62 | Category 4 <44 |
| CRAM Index | 67 (1) | 3 | **55** | 39 | 3 |
| Landscape Context | 82 (2) | **51** | 38 | 11 | 0 |
| Hydrology | 61 (1) | 5 | 28 | **49** | 0 |
| Physical Structure | 59 (3) | 14 | 15 | **46** | 25 |
| Biotic Structure | 67 (2) | 30 | **46** | 24 | 0 |

Physical structure was the attribute for which the South Coast estuarine marsh scored the lowest. About 71% of the total estuarine acreage within the region had scores below the 50$^{th}$ percentile of possible points for the state as a whole (Categories 3 and 4 combined), with 25% scoring in (Category 4). Results of metric level scores illustrate that the majority of acreage of South Coast estuarine wetland had Category 3 scores for both topographic complexity and structural patch richness.

The South Coast estuarine wetlands also scored somewhat low for Hydrology with only 5% of the acreage likely to score in Category 1 for this attribute. The majority of the acreage (approximately 49%) is likely to score below the 50$^{th}$ percentile based on the statewide data. Estuarine wetland marsh in this highly urbanized region scored lowest for water source (87% of sites in Category 3) and hydrologic connectivity (55% of sites in Categories 3 and 4 combined).

Approximately 75% of the South Coast estuarine wetland (3070 acres) is located in large estuaries, defined for this study as having a total acreage of subtidal and intertidal habitats combined that exceeds 500 acres. Wetlands in large estuaries had significantly higher CRAM index scores, primarily due to higher Hydrology and Biotic Structure attribute scores, than small estuaries (p-value >0.05; Figure 11). This difference was greatest for Biotic Structure, which was 13 % higher.

Dikes and levees were the most frequent stressor (70% of sites; Table 3) and the most prevalent severe stressor for South Coast sites (63% of sites; Table 4)). Contaminant pollution (heavy metals, nutrients, bacteria, pesticides/organic compounds), lack of treatment of invasive plants in the buffer, culverts and other flow obstructions, and grading or compaction were also among the most cited severe stressors in this region. Sites where dikes/levees or lack of treatment of invasive plants was identified as a severe stressor had on average a 10 point lower CRAM index score than other sites (p <0.02; Table 5). Sites with culverts or other flow obstructions had average CRAM index scores that were 15 points lower than other sites where this stressor was absent (p = 0.001; Table 5). Non-parametric ANOVA tests showed that the number of stressors and number of severe stressors did not significantly differ between large and small estuaries p-value = 0.98 and 0.78, respectively.

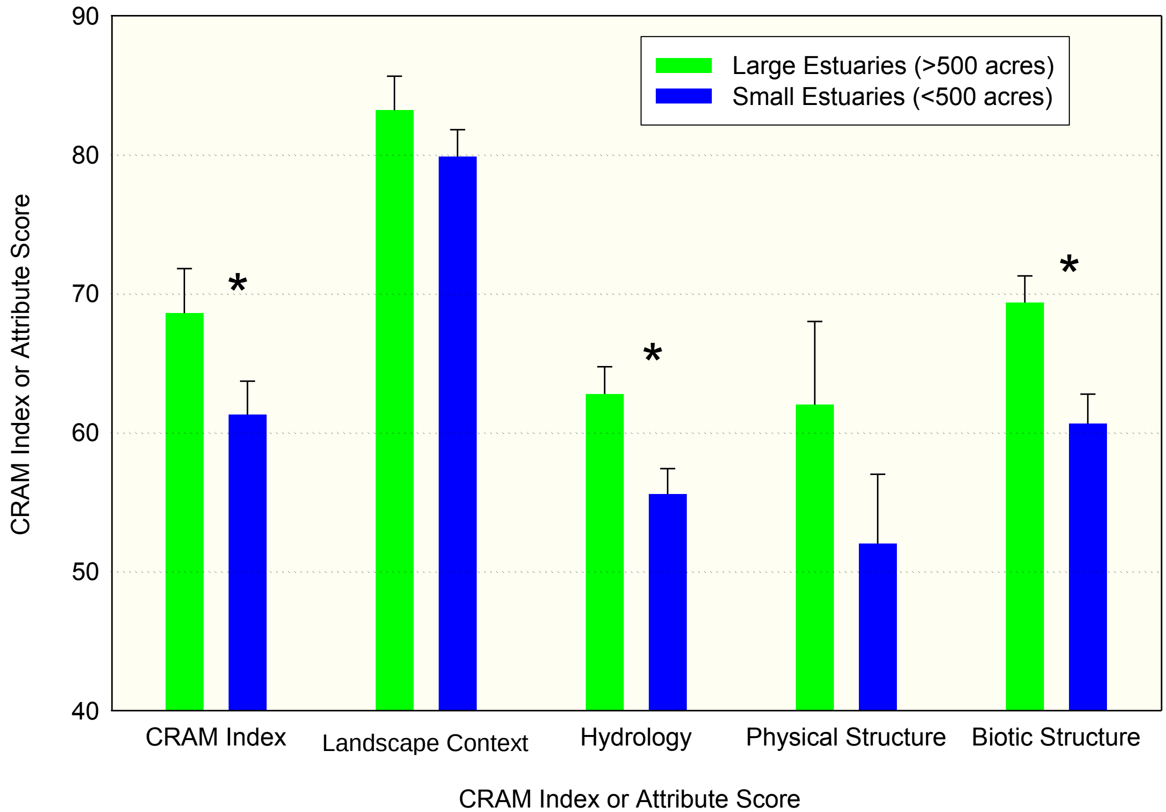


**Figure 11. Plots of mean and upper 95% confidence interval for CRAM index and attribute scores for large and small estuaries in South Coast. Size threshold of 500 acres includes both subtidal and intertidal acreage. An asterick (*) indicates significant difference between large and small estuaries (p-value < 0.05).**

## Assessment of Projects

Table 12 summarizes the CRAM assessments of completed restoration projects. Notably, the projects assessed (n = 30, 120 acres) represent less than 1% of the total ambient acreage of the state. The CDFs of CRAM index scores from projects assessed in all regions relative to that of statewide ambient conditions show that projects had on average 10% lower scores (Figure 12). The upper range of Landscape Context and Hydrology attribute scores for projects were 15 - 18% lower than the statewide ambient scores for these attributes (Table 13). Project related sites had higher scores than ambient sites for Physical Structure in the SF 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.

**Table 12. Summary of project assessment data. All projects assessed were completed as "as-built" restoration projects.**

| Region | Number of Projects | Number of Assessment Areas | Total Area Assessed (Acres) |
|---|---|---|---|
| SF Estuary | 10 | 22 | 41 |
| Central Coast | 10 | 13 | 31 |
| South Coast | 10 | 20 | 48 |
| Total | 30 | 54 | 120 |

**Table 13. Comparison of statewide (Ambient) and project related (Project) mean CRAM index and attribute scores for SF Estuary, Central Coast, and South Coast.**

| Mean 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 |
| Hydrology | 82 | 65 | 82 | 67 | 61 | 55 |
| Physical Structure | 59 | 68 | 57 | 66 | 59 | 56 |
| Biotic Structure | 78 | 65 | 63 | 57 | 67 | 59 |

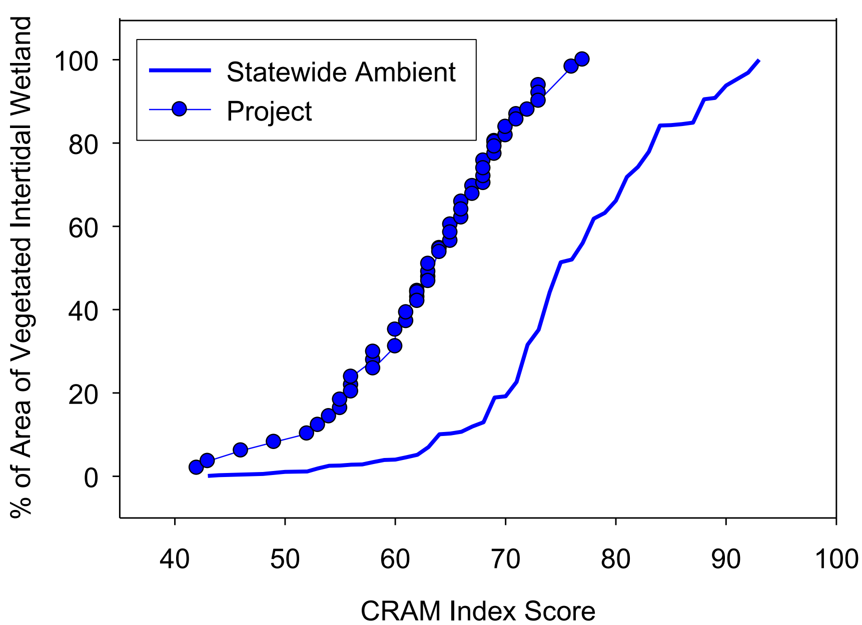


**Figure 12. CDFs of 30 projects in the SF Estuary, Central Coast, and South Coast relative to statewide CDF of CRAM index scores. Note that the total area of projects assessed is 120 acres, relative to the statewide ambient total of almost 44,500 acres.**

# DISCUSSION

## Why the Distributions, Amounts, and Shapes of Estuarine Wetlands are Important

The ecological and social values or services of estuarine wetlands are well celebrated (Day *et al*. 1989). Flood control, pollution filtration, carbon entrapment, and hunting and fishing are some of the local services that are common to many estuaries. Many species of migratory birds and fish depend on estuarine wetlands along their migratory pathways. These kinds of services link one location or region to another all along the California coast. The locations of wetlands, their sizes, and their shapes strongly influence all of their services. In general, as the size of an estuarine wetland increases, the amounts and kinds of services it can provide also increase. As wetlands become more abundant, their collective service capacity tends to increase, and the overall risk that their services will decline tends to decrease. This is because the negative effects of declining services in one wetland can be offset by other wetlands that provide the same services.

The shapes of wetlands affect their services in a variety of ways. In essence, the more edge a wetland has relative to its aerial extent, the more it tends to interact with adjoining environments. Increasing the amount of edge of an estuarine wetland tends to increase its chances to filter sediment and pollutants from incoming tides, to supply nutrients to outgoing tides, and to be colonized by species of intertidal plants and animals. Some species prefer to inhabit wetland edges, while others prefer interior areas of wetlands away from edges. Some of these species will not inhabit wetlands that have more edge than interior areas.

In practical terms, any wetland is large enough and has the right shape if it tends to sustain the services expected of it despite the usual natural and unnatural threats. Wetlands are abundant when the threats against their services are more than offset by the amount of those services that they can collectively provide. There are many factors that control the particular kinds and levels of services provided by estuarine wetlands. However, to provide all the services that are appropriate and needed, the ideal estuarine landscape is likely to have abundant, large, round, wetlands.

## Effect of Land Use Changes on the Landscape Profile of Estuarine Wetlands

State-wide, California has lost approximately 91% of its wetlands, reducing the total surface area occupied by wetlands from 5% of the land to less than one-half of one percent (Dahl 1990). Utilizing existing maps with base imagery dating from 1980 to 2002, with local updates by regional teams of wetland experts, this survey estimates that California has 44,456 acres of perennial estuarine wetland remaining statewide. 77% of this acreage is in the SF Estuary. Accurate estimates of estuarine wetlands loss are not available for California (California Coastal Commission 1989). However, the historical change in the distribution and abundance of estuarine wetlands and other habitats is better documented for the SF Estuary than for any other region in California.

Since European contact, the amount of wetlands in the SF Estuary has decreased by nearly 99%. Most of its historical wetland was non-saline, and less than 1% of that remains. Only about 15% of its historical saline wetland remains (Goals Project 1999). The rest of the existing area of estuarine wetland in the SF Estuary has evolved since the advent of European land use in the region due land use that has increased sediment supplies and changed the locations where sediment accumulates along the estuary shoreline. The work accomplished to date has documented not only the magnitude of the loss, but also how the changes in spatial distribution, shape, and size of estuarine wetlands have affected the distribution of wildlife and created opportunities for estuarine wetland restoration.

Connectivity refers to the connection between habitat patches that permit the dispersal of plants and movements of wildlife essential to their survival. Habitat patches and their connections vary among species depending on their life histories (Wiens 1976). Anthropogenic activities such as diking, filling and altering the hydrology of wetlands tend to disrupt connectivity (Fell *et al*. 1991, Ferren 1989, Grossinger 2001). Historic maps of SF Estuary show that alterations in land use have decreased patch size as well as severely altering the shapes. Historic trend analysis of estuarine wetlands from SF Estuary shows that the fewer large patches now exist, while the number of small wetland patches has increased. The historical changes in the size-frequency distribution of estuarine wetlands in SF Estuary undoubtedly represent a decrease in connectivity for some of species, especially species with small home ranges restricted to estuarine wetlands.

Urbanization of estuarine wetlands has also increased their perimeter length relative to their aerial extent, which increases the exposure of even large wetland patches to disturbance factors. In the more urbanized estuaries of the South Coast and the SF Estuary, many wetlands are embedded in intensive land uses and bounded by levees. These conditions diminish the hydrological and ecological connectivity among wetlands and increase their susceptibility to adverse changes in wetland function because of stressors (Grossinger 2001).

Use of the current landscape profile of the State and the historical landscape profile of the SF Estuary provides evidence that estuarine wetlands are tightly linked to their immediate watersheds, and that this linkage can be weakened by land use. The strength of relationship between watershed area and wetland area likely reflects the truism that larger watersheds tend to have larger valleys, which accommodates ongoing estuarine transgression and wetland development, and that larger watersheds tend to have larger sediment supplies that can sustain larger areas of wetlands after they have evolved. A stronger correlation between watershed size and wetland area was found for the historical landscape than for the modern, more urbanized landscape. Among regions, this correlation was weakest for the South Coast, where remaining wetlands have been severely reduced in size by land use. For Central Coast and SF Estuary, the residual errors of the correlations were primarily due to urbanized estuaries. These correlations are stronger when restricted to undeveloped and largely agricultural estuaries because of historical reclamation of estuarine wetlands for agriculture seldom involved all wetland areas and reclamation that was delimited by large tidal channels. The reductions in tidal prism caused by reclamation caused many of these channels to “downsize” as they became places where sediment accumulated and wetlands evolved. A strong correlation exists for the North Coast, which has the largest proportion of estuaries dominated by agriculture. These results support the hypothesis that the inter-regional variability in the correlation between watershed size and wetland area is partially related to regional differences in the amount of urbanization.

Although land use varies in kind and intensity among the estuaries of California, it has affected the distribution, abundance, size, and shape of estuarine wetlands in consistently deleterious ways. It has decreased the amount of estuarine wetland, increased the number of wetlands, decreased their size, and therefore increased the distance between wetlands. It has also increased their perimeter length relative to their aerial extent. In the more urbanized estuaries of the South Coast and the SF Estuary, many wetlands are embedded in intensive land uses and bounded by levees. These conditions diminish the hydrological and ecological connectivity among the wetlands, increase their susceptibility to invasion and local catastrophic events, and reduce their overall capacity to serve society.

The profile of ecological change can help to create a common vision for ecosystem restoration, and inform regional efforts to set quantitative acreage targets (Gwin *et al*. 1999). Data of this kind were essential to a multi-agency process adopted to establish targets for future restoration of SF Estuary wetlands that successfully demonstrated how science-based assessments can guide planning and management actions (Goals Project 1999). Studies of historical landscapes can reveal a broader palette of restoration choices than otherwise recognized by recovering lost knowledge about the full range of habitat types and conditions that naturally characterized a region before it was transformed by modern land use. This has practical value in many ways. For example, the careful analysis of historical conditions can reveal no-longer-visible variations in habitat along large-scale gradients of environmental moisture and temperature that serve as models for predicting the effects of climate change and assessing how it can be exploited to restore ecological services in the future. Studies similar to those conducted in the SF Estuary are needed elsewhere. Comparable studies have been initiated in South Coast (Stein *et al*. 2007), Elkhorn Slough (Van Dyke and Wasson 2005), and within a diverse selection of watersheds draining to the SF Estuary (Robin Grossinger - SFEI, personal communication).

### *Accuracy of the Inventory of Estuarine Habitats*

One of the objectives of this assessment was to establish a baseline against which future assessments can be compared. The landscape profile of perennial estuarine wetland habitat maps generated for this study should be used with caution for this purpose. There are two reasons for this: 1) accuracy of mapping at the scale typically conducted and 2) the cost of comprehensively mapping a region or state with sufficient frequency to provide an up-to-date analysis of trends (e.g., on the order of every 5 to 10 years). This assessment was based on existing maps of estuarine wetlands included in the National Wetland Inventory, and these data are known to have both of the above constraints.

Acknowledging these difficulties, the USFWS NWI has gone to a probability-based survey approach to assess trends in wetland acreage on a national level (Dahl 2005). The approach involves random selection of 4,682 randomly selected sample plots; each plot is four square miles (2,560 acres) in area. Wetlands within these plots are mapped with remote sensing data in combination with a greater degree of ground-truthing to determine wetland change (a.k.a. “status and trends plots”). Because of the lower error rate in mapping with this approach, trends in wetland change can be detected earlier than with conventional NWI mapping methods (Dahl 2005).

California faces similar problems with respect to the costs of comprehensive mapping and the accuracy of existing maps of estuarine habitat. For this reason, a statistical approach is recommended to improve the tracking of trends in habitat acreage. These data would also assist in tracking the impacts of climate change on estuarine wetlands. Notably, California wetlands have been under-represented in the NWI National Status and Trends assessments (T. Dahl, pers. Comm.). With the National Wetland Assessment that will be conducted, additional plots will be added to the State, with approximately 40 to 60 plots in estuarine habitat and roughly 277 statewide. The State of California should consider intensifying this status and trends assessment and assuring that the data acquired are classified in a manner consistent with emerging hydrogeomorphic typologies for CRAM and project tracking (see detailed recommendation in Sutula *et al*. (2008).

## Statewide and Regional Patterns in Estuarine Wetland Condition and Common Stressors

An estimated 85% of the State's nearly 44,500 acres of saline estuarine wetland scored within the top 50% of possible CRAM index scores. The statewide results were strongly influenced by the SF Estuary, because it has the most saline estuarine wetland. The statewide results must always be interpreted with this influence in mind. Perhaps the most useful aspect of the probabilistic survey design using CRAM is that it provides a basis for calculating the proportions of the total area of saline estuarine wetlands within a region or statewide that are estimated to score within any given category of condition, relative to the best attainable condition. When this is combined with the Landscape Profile and Stressor Checklist, then the likely distribution of condition can be assessed relative to location, based on where the various stressors and other environmental factors are operating.

Landscape Context was the attribute for which the State's estuarine wetlands scored the highest. Approximately 64% of the total acreage of estuarine wetland would tend to have Landscape Context scores within the top category of possible scores. Two factors drive this result. First, Landscape Context scores tend to increase with wetland size and decrease with percent developed lands adjacent to wetlands. Because SF Estuary has the largest remaining estuarine wetlands and most of the wetland acreage, the statewide Landscape Context score reflects conditions in the SF Estuary. 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). This phenomenon is expected to have occurred not only for the SF Estuary, but also in the other regions, including southern California – a region known for fragmentation of its estuarine wetland and highly developed surroundings.

Hydrology is the critical factor affecting the physical structure and vegetation in all wetlands (Mitsch and Gosselink 2000). The CRAM Hydrology attribute is composed of measures relating to freshwater water source, hydrologic connectivity and hydroperiod. The CRAM Biotic Structure attribute is composed of measures of plant community composition, vertical structure and horizontal zonation and interspersion. Statewide, 35 to 36% of estuarine marsh acreage had scores for Hydrology and Biological Structure within the top category of possible CRAM scores, another a reflection of conditions in the SF Estuary. A positive correlation is evident between Biotic Structure scores and estuarine wetland size. This reflects the well-established relationship between habitat area and species richness (Rosenzweig 1995). The SF Estuary, which has the largest estuarine wetlands, also had the highest Biotic Structure scores. Regions that are more fragmented (by roads, railroads, levees, and developed areas) and muted from the tides typically have lower species richness (Noss and Csuti 1994). This helps to explain the lower Biotic Structure scores for Central Coast and South Coast.

Physical Structure was the attribute for which the State's estuarine marshes scored the lowest. About 62% of the acreage tends to be in the bottom 50% of possible scores for this attribute. The Physical Structure attribute is composed of measures of topographic complexity and the number of physical patch types (e.g., pannes, pools, channels etc.). The richness of physical, structural surfaces and features in a wetland reflects the diversity of physical processes, such as energy dissipation, water storage, and sediment transport, which strongly affect the potential ecological complexity of the wetland (Maddock 1999). The expectation is that immature and invaded wetlands tend to have low scores for Physical Structure because they are not fully developed or the invasions are homogenizing conditions by creating more uniform rates of sedimentation. Anthropogenic modifications to the tidal and freshwater hydrology, sediment transport, and geomorphology of the marsh through watershed urbanization, dredging, dikes and levees, mosquito ditching, tide gates, etc., result in reduced integrity of marsh physical structure (Day *et al*. 1989). These reasons help explain the low scores for Physical Structure for all region except North Coast, where the scores were high.

North Coast estuarine wetlands are subject to high levels of sedimentation because of an extensive history of logging and grazing in their watersheds; given the presence of these stressors, the high scores for Physical Structure appear to be somewhat anomalous. Many North Coast estuarine wetlands are subject to extensive riverine flooding and wind-driven waves that deposit sediment extensively in channels as well as in the fringing marshes themselves. However, the tidal range in North Coast estuaries is relatively large, which can be associated with bank slumps and other sources of physical structure in tidal creeks. The effects of the invasion of these wetlands by *Spartina densiflora* on sediment dynamics are unclear, because *S. densiflora* changes the Biotic Structure attribute of the marshes as it increases in abundance. At low to moderate densities *S. densiflora* clumps appear to result in hummocks that increase the Physical Structure attribute. At high density, it appears that *S. densiflora* helps to stabilize sediment deposited in these estuarine wetlands in recent decades, resulting in less structural complexity in the marsh substrate. The interaction of increased sedimentation and the increasing abundance of this invasive species apparently affect both the Physical Structure and Biotic Structure attributes in North Coast estuarine marshes, one reason why *S. densiflora* management is a high priority for this region. A further factor in creating high values of the Physical Structure attribute undoubtedly is the abundance of large pieces of woody debris (logs, stumps, etc.) in aquatic ecosystems in the North Coast (and in other forested regions).

Not surprisingly, dikes/levees was 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, etc (Zedler and Callaway 2000, Fell *et al*. 1991, E. Fetscher, unpublished data). Presence of culverts and other flow obstructions compound the negative effect of levees; South Coast sites with this stressor had on average 15-point lower CRAM scores than sites where this stressor was absent. Sites bounded by levees or other water control structures that reduce the wetland tidal action can be expected to have lower scores for almost all metrics relative to other sites. In this case, the results are not area-weighted and thus are not skewed by conditions in the SF Estuary.

CRAM index and attribute scores showed a general decrease from north to south. This difference was most pronounced for Hydrology and Physical Structure attributes (25- to 30-point difference between North and South Coast) and least different for the Landscape Context attribute (less than a 10 point difference). These patterns are suggestive of an overall north-south gradient in condition relating to urbanization along the coastline. Previous studies have found negative correlations between coastal urbanization and various ecological parameters (Brown and Vivas 2005, Mack 2006, Sutula *et al*. 2008). For estuarine wetlands, urbanization is a complex mix of factors and processes that affect wetland shape, size, abundance, and structure. It usually represents the latest and most intensive phase in a complex history of land use development, which typically begins with relatively low intensity indigenous management, transitions through a series of increasingly intensive agricultural uses to suburban development, and culminates in industrial and/or dense residential development, perhaps with the addition of wetland restoration projects. Each phase tends to leave a mark on the estuarine landscape, and most of these marks are levees, dikes and drainage ditches that carve the landscape into remnant patches of historical estuarine habitats. At the same time, natural sedimentary processes develop new intertidal flats and wetlands, usually along the margins of altered or artificial shorelines. While the general negative correlation between estuarine wetland condition and intensity of adjacent land use is clear, the corrective measures will vary with the particulars of local land use history and practice.

### Natural Variability and the Need for Regional Reference Networks

The four categories of CRAM scores developed for this survey 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 (Collins *et al*. 2007, Sutula *et al*. 2006). The data obtained in the field studies indicate that CRAM captured a variety of important regional differences among perennial saline estuarine wetlands in California.

These differences must be interpreted carefully however, as gradients in geomorphology, hydrology, and ecology among estuarine embayments, river mouths, and coastal lagoons will control to some extent the "best attainable" condition. Several examples exist that are relevant for the interpretation of CRAM. First, Physical Structure scores could be expected to be somewhat lower in coastal lagoons with restricted tidal inlets relative to SF Estuary, an embayment with a large tidal prism. Second, North Coast estuarine wetlands apparently tend to have fewer co-dominant plant species than estuarine wetlands of other regions (Grewell *et al*. 2008). Because CRAM assumes that greater diversity of co-dominant plants represents greater potential to provide more services or higher levels of service, the less diverse wetlands of North Coast tend to result in lower scores for Biotic Structure (the attribute scores for North Coast wetlands are also reduced by the lower architectural complexity of the native vegetation and the dominance in many locations by an invasive species). This result is an indication that North Coast wetlands achieve lower scores than estuarine wetlands that have higher intrinsic species richness. This is a measured result that demonstrates a regional difference, and it indicates that North Coast estuarine wetlands should be compared with estuarine wetlands in other regions with this difference clearly understood. Similar considerations are relevant for other inter-regional comparisons.

In order to address these 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 Rheinhart 1996). This regional survey provides important opportunities for selecting sites to comprise the reference networks. The CRAM methodology provides a single internal statewide standard with which to assess all sites, but differences between regions must be interpreted with an awareness of the existing natural variability among regions. The internal CRAM standard should continue to be evaluated in the light of this first-time statewide ambient survey in order to 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.

### Comparison of Projects versus Ambient Condition

Project assessment results reported in this survey are intended to demonstrate how the condition of estuarine wetland "projects" can be assessed within the context of regional or statewide ambient survey of wetland condition. For this survey, a project is defined as "any activity that can result a change in the extent or condition of a wetland." Thus a project will include impact sites from development activities, mitigation sites resulting from compensatory mitigation or non-regulatory wetland creation, restoration or enhancement.

As envisioned, project assessment would occur prior to impact or restoration, then repeated as the project matures and wetlands evolve. This would allow documentation of the net change in acreage and condition of the wetland due to construction activities and subsequent geomorphic and ecological succession. As no pre-project CRAM assessment were available for this study, only completed projects were assessed. For the purpose of this study, a project is completed when all construction plans and designs have been implemented. Projects were not selected based on their size or age. This means that projects varied in size and some were older and more ecologically mature than others. Additional analyses involving careful control on project age, landscape position, and pre- and post-construction condition are required to better assess the differences between projects and ambient sites (Kentula 199). As explained in the methods section, the projects were not selected probabilistically and thus are not statistically representative of the population of estuarine wetland projects in any region or statewide.

The CRAM Index and Attribute scores of restoration projects tended to be 5 - 20% lower than ambient scores for their region, with the gap most pronounced for South Coast. Landscape Context scores and hydrology scores in projects were 15 - 18% lower than ambient scores in all regions. Projects tended to be smaller and more completely embedded in urbanized landscapes than ambient sites, and thus could be expected to have lower Buffer and Landscape Context scores. The project sites also had more urbanized water sources resulting in most sites scoring in Category 3 for water source, where most ambient sites scored in Category 2 for this metric. Because of the probability-based ambient survey design, ambient sites tended to be in larger wetland patches, and this would also tend to elevate their Landscape Context scores relative to projects.

Biotic Structure scores were 6 - 13% higher for ambient sites than project sites in all regions. These differences probably relate to differences in age; most ambient sites are probably older with more developed plant communities. Projects in SF Estuary and Central Coast had higher Physical Structure scores than ambient sites. In the more completely urbanized South Coast, Physical Structure scores did not differ between projects and ambient sites. Differences can be attributed to a number of factors: size of project versus ambient wetland patches, landscape context, project age and maturation. True differences are difficult to tease out without control on these confounding factors.

Figure 13 illustrates how CRAM could be used to document the improvement in acreage and condition that a restoration project provides. Talbert Marsh, formerly a remnant estuarine wetland, was restored to full tidal action in 1989, providing 27 acres of estuarine habitat, including 15 acres of estuarine wetland. The CRAM assessment of this project provided an average index score of 56. Since a pre-restoration CRAM baseline was not available for this project, an adjoining piece of remnant wetland comparable to the pre-project conditions of the project site was conducted. Assuming that the Talbert pre-restoration baseline was equivalent to that of the adjacent remnant wetland, Talbert Marsh has likely experienced a 31 percentage point increase in condition due to the restoration of full tidal action.

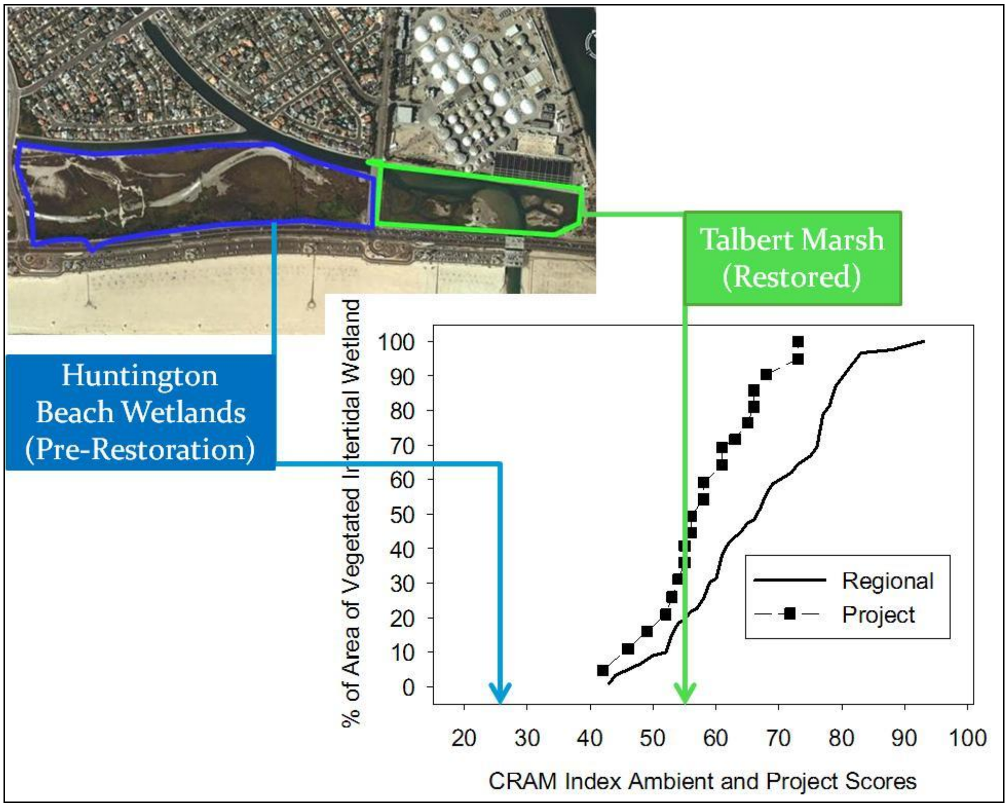


**Figure 13. Improved condition of an estuarine wetland due to restoration of full tidal action. The pre-project CRAM index score for Talbert Marsh Restoration Project is presented by the score for the Huntington Beach Wetlands because both sites were historically part of the same larger estuarine wetland.**

One important purpose of wetland monitoring and assessment is to evaluate the effects of wetland policies, programs, and projects on the ambient condition of wetlands (NAS 2001). Data of this kind are critical to enable state and regional wetland managers to track the effects of policies and programs, assess net wetland change in acreage and condition and report on the effectiveness of public investment in restoration. In addition, these data would lend themselves to the development of performance curves for restoration sites that would help to scale expectations for restoration or mitigation efforts. The expectations could be calibrated for wetland size and shape, landscape position, surrounding land uses, hydrology, and the age of the project.

## Suggested Management Actions

Within each region, CRAM scores and the stressor checklist suggest possible management actions to increase the overall condition of some wetlands. Table 14 summarizes the percentage of estuarine wetland acreage within each region that tends to score within the two lowest categories of condition, the severe stressors associated with these areas, and possible management actions to reduce or ameliorate these stressors. The assumption is that the observed stressors cause the observed conditions. Before any management actions are taken, the effects of the possible causes should be more thoroughly investigated. It is important to note that relatively high average scores for a region do not signify that the management issues of its estuarine wetlands do not warrant attention.

Conditions in North Coast estuarine wetlands will be improved by controlling sediment and removing limitations on hydrology, as described below. Improving biotic conditions in the North Coast region requires a specific focus on controlling the invasive cordgrass *Spartina densiflora*. This species was introduced regionally through shipping operations approximately 150 years ago. Its current dominance clearly indicates that North Coast wetlands are unlikely to attain higher conditions of species richness or biological structure unless the dominance by this exotic species is addressed. This is particularly important in the North Coast owing to a strong regional interest in restoring or enhancing estuarine wetlands for fishery habitat purposes.

While numerous historic and current land use impacts have led to reduced condition of Central and South Coast wetlands, three main management actions have been identified to enhance region-wide estuarine condition. As indicated earlier, historical levees and dikes that have modified tidal circulation have caused a general decline in estuarine wetland condition. They are the one overriding cause of declining condition that is common to all regions. Unfortunately, they are among the most common features in the modern estuarine landscape. They began to appear with the earliest stages of agricultural development following European contact, and have tended to get larger, more numerous, and more intrusive as development has advanced. In many cases, after new intertidal areas have developed outboard of one set of levees, new levees have been built to capture the newly formed areas. Much of the infrastructure that adjoins estuaries, including operational and abandoned railroads and highways, occupies levees or other engineered fills that cross intertidal areas. Careful removal, realignment, or re-engineering of these crossings so they no longer impede tidal circulation is required. Many of these crossings will need to be modified to accommodate rising sea levels and increased wave run-up; improved tidal exchange between estuarine wetlands and their estuaries should be a design criterion, balanced with the cost of infrastructure improvements required for such projects.

Numerous stressors affecting the condition of saline estuarine wetlands originate in their watersheds or adjoining uplands. These include excessive sediment supplies; excessive nutrients, pesticides and other chemical pollutants; and excessive predation. Decreases in water supplies due to upstream withdrawals and diversion or increases due to urban and agricultural runoff have altered the salinity regimes of many estuarine wetlands. In some estuaries, erosion control or impoundment of sediment behind dams has significantly reduced the supplies needed to sustain estuarine wetlands. Conversion of floodplains to agriculture and other development has reduced their abilities to filter runoff and buffer estuaries from upstream contaminants. Better management of urban and agriculture runoff through integration of Best Management Practices within and downstream of these land uses is necessary and has been documented to reduce contaminant inputs to these systems, reduce toxicity of water and sediments and to improve flood control. Expansion of restoration efforts within the upstream reaches of estuaries will greatly reduce the stresses on downstream reaches. At the landscape scale, estuaries should be regarded as downstream extension of their watersheds. Improving the overall condition of estuaries and their wetlands will ultimately require changes in watershed management to assure adequate supplies of clean water and sediment, improved tidal circulation between the wetlands and their estuaries, and adequate lands to accommodate estuarine transgression due to sea level.

**Table 14. Summary of CRAM attribute results, severe stressors identified, and recommended management action.**

| Region | % marsh area with CRAM Index or attribute scores within the lower two categories of CRAM scores | | | | | Major Stressors Identified | Recommended Management Actions |
|---|---|---|---|---|---|---|---|
| | Index | LC | Hydro | PS | BS | | |
| North Coast | 0 | 3 | 0 | 17 | 24 | Invasive plants, dikes and levees, excessive sedimentation, ditching | 1. Remove invasive plant species from estuarine wetlands regionally, and include measures to control re-invasion in restoration and enhancement projects. Reestablish or reintroduce native species.<br>2. Use BMPs, where feasible, to reduce sedimentation from upland land uses in wetland watersheds.<br>3. Assure adequate tidal circulation in estuarine restoration or enhancement projects through levee removal or setback, tidegate removal, and tidal circulation improvement.<br>4. Develop mosquito management approaches that are consistent with reduced hydrological impacts to wetlands. |
| SF Estuary | 0 | 3 | 14 | 64 | 10 | Levees, predators, ditching heavy metal and organic contaminants | 1. Remove invasive plant species from estuarine wetlands regionally, and include measures to control re-invasion in restoration and enhancement projects. Re-establish or reintroduce native species.<br>2. Increase the size of estuarine wetlands to reduce the effects of terrestrial predators and other stressors.<br>3. Improve tidal circulation to minimize the need for ditching.<br>4. Assess the opportunity to integrate estuarine wetland restoration and enhancement to infrastructure repair and replacement<br>5. Link estuarine wetland restoration to upstream management of sediment and water quality by integrating estuarine wetland management to watershed management |
| Central Coast | 17 | 5 | 20 | 64 | 57 | NPS runoff, contaminants, dikes/levees and trash | 1. Restore aquatic transitions (creeks, drainage swales and brackish systems) to increase filtration of water prior to discharge into estuaries.<br>2. Expand use of agriculture and urban BMPs within watersheds.<br>3. Remove or redesign flow restrictions to establish more stable marsh plain and/or replicate historic estuarine tidal exchange.<br>4. Implement enhancement projects through levee removal, setback, tidegate removal/redesign, and tidal circulation management to allow for expansion of marsh plain. |
| South Coast | 42 | 11 | 49 | 71 | 25 | Dikes/levees, NPS runoff, contaminants, trash, excessive sediment | 1. Assure adequate tidal circulation in estuarine restoration or enhancement projects through levee removal or setback, tidegate removal, and tidal circulation improvement.<br>2. Expand use of agriculture and urban BMPs within watersheds<br>3. Restore aquatic transitions (creeks, drainage swales and brackish systems) to increase filtration of water prior to discharge into estuaries.<br>4. Remove invasive plants from upland transitions zones and buffer.<br>5. Incorporate historical ecology to guide restoration planning, particularly with respect to the distribution of subhabitat types. |

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# APPENDICES

## Appendix 1: List of Ambient Survey Sites

**List of Ambient Survey Sites**

| Region Code | StationID | StationName | AA Latitude | AA Longitude | Stratum |
|---|---|---|---|---|---|
| SC | CASouth-017 | Tijuana River estuary | 32.5482 | -117.1245 | Large |
| SC | CASouth-021 | Tijuana River estuary | 32.5568 | -117.124 | Large |
| SC | CASouth-049 | Tijuana River estuary | 32.5649 | -117.1317 | Large |
| SC | CASouth-069 | San Diego Bay | 32.5903 | -117.114 | Large |
| SC | CASouth-001 | San Diego Bay | 32.6065 | -117.1283 | Large |
| SC | CASouth-037 | San Diego Bay | 32.6135 | -117.1061 | Large |
| SC | CASouth-009 | Sweetwater Marsh | 32.6433 | -117.1101 | Large |
| SC | CASouth-053 | Sweetwater Marsh | 32.6482 | -117.1077 | Large |
| SC | CASouth-050 | San Diego River | 32.759 | -117.2174 | Small |
| SC | CASouth-034 | San Diego River | 32.7598 | -117.2226 | Small |
| SC | CASouth-002 | San Diego River | 32.7612 | -117.2057 | Small |
| SC | CASouth-018 | Mission Bay | 32.7919 | -117.2309 | Large |
| SC | CASouth-038 | Los Penasquitos Lagoon | 32.9272 | -117.2495 | Small |
| SC | CASouth-022 | Los Penasquitos Lagoon | 32.9276 | -117.2514 | Small |
| SC | CASouth-066 | Los Penasquitos Lagoon | 32.9286 | -117.2551 | Small |
| SC | CASouth-006 | Los Penasquitos Lagoon | 32.9329 | -117.2555 | Small |
| SC | CASouth-054 | Los Penasquitos Lagoon | 32.9345 | -117.2582 | Small |
| SC | CASouth-070 | San Dieguito Lagoon | 32.9654 | -117.2504 | Small |
| SC | CASouth-010 | San Dieguito Lagoon | 32.9658 | -117.2546 | Small |
| SC | CASouth-026 | San Dieguito Lagoon | 32.9703 | -117.2606 | Small |
| SC | CASouth-073 | San Dieguito Lagoon | 32.9776 | -117.2683 | Small |
| SC | CASouth-045 | San Elijo Lagoon | 33.005 | -117.2753 | Small |
| SC | CASouth-013 | San Elijo Lagoon | 33.0069 | -117.2774 | Small |
| SC | CASouth-029 | San Elijo Lagoon | 33.0082 | -117.268 | Small |
| SC | CASouth-057 | Batiquitos Lagoon | 33.0868 | -117.2987 | Small |
| SC | CASouth-025 | Batiquitos Lagoon | 33.0878 | -117.2995 | Small |
| SC | CASouth-061 | Agua Hedionda | 33.1397 | -117.3112 | Small |
| SC | CASouth-014 | Newport Bay | 33.63 | -117.8892 | Large |
| SC | CASouth-027 | Santa Ana River-all | 33.6346 | -117.9538 | Small |
| SC | CASouth-043 | Talbert | 33.639 | -117.9696 | Small |
| SC | CASouth-058 | Newport Bay | 33.6437 | -117.8841 | Large |
| SC | CASouth-042 | Newport Bay | 33.6491 | -117.8871 | Large |
| SC | CASouth-023 | Bolsa Chica | 33.703 | -118.0471 | Small |
| SC | CASouth-055 | Bolsa Chica | 33.7041 | -118.0489 | Small |
| SC | CASouth-003 | Seal Beach | 33.7312 | -118.0689 | Large |
| SC | CASouth-062 | Seal Beach | 33.7345 | -118.0716 | Large |
| SC | CASouth-035 | Seal Beach | 33.736 | -118.0793 | Large |
| SC | CASouth-051 | Seal Beach | 33.743 | -118.0861 | Large |
| SC | CASouth-030 | Seal Beach | 33.7444 | -118.0761 | Large |
| SC | CASouth-063 | Ballona wetlands | 33.9639 | -118.4484 | Small |
| SC | CASouth-016 | Mugu Lagoon-south | 34.0948 | -119.0726 | Large |
| SC | CASouth-052 | Mugu Lagoon-south | 34.1014 | -119.112 | Large |
| SC | CASouth-004 | Mugu Lagoon-south | 34.1021 | -119.0844 | Large |
| SC | CASouth-024 | Mugu Lagoon-south | 34.1021 | -119.1267 | Large |
| SC | CASouth-056 | Mugu Lagoon-south | 34.106 | -119.0878 | Large |
| SC | CASouth-040 | Mugu Lagoon-south | 34.1073 | -119.1274 | Large |
| SC | CASouth-012 | Mugu Lagoon-south | 34.109 | -119.1105 | Large |
| SC | CASouth-008 | Mugu Lagoon-south | 34.1099 | -119.1159 | Large |

| Region Code | StationID | StationName | AA Latitude | AA Longitude | Stratum |
|---|---|---|---|---|---|
| SC | CASouth-060 | Mugu Lagoon-north | 34.1102 | -119.1422 | Large |
| SC | CASouth-068 | Mugu Lagoon-south | 34.1106 | -119.1138 | Large |
| SC | CASouth-072 | Mugu Lagoon-south | 34.1117 | -119.0932 | Large |
| SC | CASouth-044 | Mugu Lagoon-north | 34.1121 | -119.1424 | Large |
| SC | CASouth-028 | Mugu Lagoon-south | 34.1126 | -119.0993 | Large |
| SC | CASouth-032 | Carpinteria Marsh | 34.4006 | -119.5378 | Small |
| SC | CASouth-064 | Carpinteria Marsh | 34.403 | -119.5369 | Small |
| SC | CASouth-048 | Carpinteria Marsh | 34.4043 | -119.5388 | Small |
| SC | CASouth-047 | Goleta Slough | 34.4172 | -119.8366 | Small |
| SC | CASouth-031 | Goleta Slough | 34.4187 | -119.8399 | Small |
| SC | CASouth-015 | Goleta Slough | 34.4239 | -119.8468 | Small |
| SC | CASouth-059 | Goleta Slough | 34.4238 | -119.851 | Small |
| CC | CACRAMCentral-028 | Morro Bay | 35.3222 | -120.8429 | None |
| CC | CACRAMCentral-024 | Morro Bay | 35.3346 | -120.82 | None |
| CC | CACRAMCentral-056 | Morro Bay | 35.3354 | -120.8219 | None |
| CC | CACRAMCentral-116 | Morro Bay | 35.3421 | -120.8265 | None |
| CC | CACRAMCentral-012 | Morro Bay | 35.3504 | -120.8309 | None |
| CC | CACRAMCentral-001 | Elkhorn Slough | 36.7902 | -121.7917 | None |
| CC | CACRAMCentral-017 | Moro Cojo Slough | 36.7932 | -121.7573 | None |
| CC | CACRAMCentral-020 | Elkhorn Slough | 36.81 | -121.7366 | None |
| CC | CACRAMCentral-053 | Elkhorn Slough | 36.815 | -121.7597 | None |
| CC | CACRAMCentral-021 | Elkhorn Slough | 36.8159 | -121.7592 | None |
| CC | CACRAMCentral-033 | Elkhorn Slough | 36.8169 | -121.7855 | None |
| CC | CACRAMCentral-004 | Elkhorn Slough | 36.8186 | -121.7485 | None |
| CC | CACRAMCentral-005 | Elkhorn Slough | 35.3454 | -120.8382 | None |
| CC | CACRAMCentral-009 | Elkhorn Slough | 36.8392 | -121.7356 | None |
| CC | CACRAMCentral-013 | Elkhorn Slough | 36.8578 | -121.7463 | None |
| SFB | CAB07665-077 | Guadalupe Slough | 37.4413 | -122.034 | None |
| SFB | CAB07665-188 | Coyote Creek | 37.4637 | -122.0058 | None |
| SFB | CAB07665-095 | Coyote Creek Lagoon | 37.4669 | -121.9506 | None |
| SFB | CAB07665-071 | Dumbarton Marsh | 37.4997 | -122.1005 | None |
| SFB | CAB07665-103 | Mowry North | 37.5045 | -122.1355 | None |
| SFB | CAB07665-091 | Inner Bair Island | 37.5086 | -122.2221 | None |
| SFB | CAB07665-081 | Ideal Marsh | 37.5331 | -122.111 | None |
| SFB | CAB07665-070 | Outer Bair Island | 37.5386 | -122.2084 | None |
| SFB | CAB07665-131 | Tiburon | 37.8906 | -122.5019 | None |
| CC | CACRAMCentral-090 | Bolinas Lagoon | 37.9148 | -122.687 | None |
| CC | CACRAMCentral-061 | Bolinas Lagoon | 37.9275 | -122.6952 | None |
| CC | CACRAMCentral-045 | Bolinas Lagoon | 37.9333 | -122.6969 | None |
| SFB | CAB07665-067 | Corde Madera | 37.9378 | -122.5087 | None |
| SFB | CAB07665-090 | Pt Pinole | 37.9897 | -122.3593 | None |
| SFB | CAB07665-098 | China Camp | 38.0088 | -122.4835 | None |
| CC | CACRAMCentral-027 | Drakes Estero | 38.0307 | -122.885 | None |
| SFB | CAB07665-094 | Browns Island | 38.0361 | -121.8694 | None |
| SFB | CAB07665-110 | Pacific Atlantic Terminal | 38.0365 | -122.0986 | None |
| SFB | CAB07665-222 | Browns Island Oversample | 38.042 | -121.8609 | None |
| SFB | CAB07665-218 | Mackavoy Marsh | 38.0456 | -121.9558 | None |
| CC | CACRAMCentral-023 | Drakes Estero | 38.0503 | -122.9083 | None |
| SFB | CAB07665-154 | Point Chicago General Chemical | 38.0515 | -121.9939 | None |
| SFB | CAB07665-162 | Hamilton | 38.0532 | -122.4929 | None |
| CC | CACRAMCentral-058 | Drakes Estero | 38.0555 | -122.9628 | None |

| Region Code | StationID | StationName | AA Latitude | AA Longitude | Stratum |
|---|---|---|---|---|---|
| SFB | CAB07665-170 | Port Chicago Pier 2 | 38.0576 | -122.0282 | None |
| CC | CACRAMCentral-067 | Tomales Bay | 38.0795 | -122.8238 | None |
| CC | CACRAMCentral-014 | Drakes Estero | 38.0813 | -122.935 | None |
| CC | CACRAMCentral-075 | Tomales Bay | 38.0851 | -122.8316 | None |
| CC | CACRAMCentral-051 | Tomales Bay | 38.0858 | -122.8217 | None |
| CC | CACRAMCentral-091 | Tomales Bay | 38.0908 | -122.8268 | None |
| SFB | CAB07665-190 | Hwy 37 east | 38.124 | -122.3351 | None |
| SFB | CAB07665-126 | Napa Bridge | 38.1338 | -122.2706 | None |
| SFB | CAB07665-178 | Hwy 37 west | 38.1437 | -122.4046 | None |
| SFB | CAB07665-082 | Pond 2A | 38.1493 | -122.3202 | None |
| SFB | CAB07665-194 | Shultz Slough | 38.1656 | -122.5502 | None |
| SFB | CAB07665-114 | Tolay East Branch | 38.1713 | -122.4314 | None |
| SFB | CAB07665-146 | Coon Island | 38.1904 | -122.3173 | None |
| SFB | CAB07665-206 | Rush Ranch | 38.1909 | -122.013 | None |
| CC | CACRAMCentral-010 | Tomales Bay | 38.1956 | -122.9507 | None |
| SFB | CAB07665-130 | Petaluma North | 38.1972 | -122.5694 | None |
| SFB | CAB07665-142 | Grey Goose | 38.2048 | -122.069 | None |
| SFB | CAB07665-210 | Skaggs Island | 38.2055 | -122.3759 | None |
| SFB | CAB07665-174 | Fagan Marsh | 38.2197 | -122.2962 | None |
| SFB | CAB07665-078 | Suisun City | 38.2297 | -122.0395 | None |
| CC | CACRAMCentral-095 | Bodega Bay Estuary | 38.3137 | -123.0323 | None |
| NC | CAB07665-025 | Big River Upstream | 39.3027 | -123.7765 | None |
| NC | CAB07665-009 | Big River Downstream | 39.3034 | -123.7806 | None |
| NC | CAB07665-037 | Ten Mile River | 39.5455 | -123.7572 | None |
| NC | CAB07665-013 | Moseley Siough | 40.6445 | -124.2969 | None |
| NC | CAB07665-002 | Mosely Slough Mouth | 40.6531 | -124.3015 | None |
| NC | CAB07665-029 | Eel River Delta - North Bay | 40.6542 | -124.2963 | None |
| NC | CAB07665-006 | McNulty Slough North | 40.6624 | -124.2919 | None |
| NC | CAB07665-034 | Eel River Wildlife Area | 40.6665 | -124.2918 | None |
| NC | CAB07665-018 | White Slough Marsh - HBNWR | 40.7046 | -124.2144 | None |
| NC | CAB07665-038 | South Bay - Fields Landing | 40.7204 | -124.2177 | None |
| NC | CAB07665-026 | Elk River Spit | 40.767 | -124.2002 | None |
| NC | CAB07665-003 | Third Slough | 40.8021 | -124.1378 | None |
| NC | CAB07665-019 | Second Slough | 40.8043 | -124.1413 | None |
| NC | CAB07665-030 | Eureka Slough Mouth | 40.8099 | -124.1431 | None |
| NC | CAB07665-027 | Woodley Island | 40.8114 | -124.156 | None |
| NC | CAB07665-023 | Indian Island South | 40.8119 | -124.172 | None |
| NC | CAB07665-039 | Indian Island Central | 40.8146 | -124.1695 | None |
| NC | CAB07665-007 | Indian Island Cypress Grove | 40.8158 | -124.164 | None |
| NC | CAB07665-035 | Indian Island West | 40.8171 | -124.1708 | None |
| NC | CAB07665-011 | Indian Island North | 40.818 | -124.1632 | None |
| NC | CAB07665-014 | Vance Avenue | 40.8287 | -124.1718 | None |
| NC | CAB07665-015 | Bracut | 40.8307 | -124.0848 | None |
| NC | CAB07665-031 | Jacoby Creek South | 40.8427 | -124.083 | None |
| NC | CAB07665-004 | Jacoby Creek North | 40.8443 | -124.083 | None |
| NC | CAB07665-020 | Arcata Bay Northeast | 40.848 | -124.0841 | None |
| NC | CAB07665-040 | Mad River Slough Mouth Marsh - West | 40.8636 | -124.1519 | None |
| NC | CAB07665-024 | Mad River Slough Bridge | 40.8643 | -124.1505 | None |
| NC | CAB07665-008 | Mad River Slough Pipeline Saltmarsh | 40.8714 | -124.1497 | None |
| NC | CAB07665-036 | Mad River Slough - Central Island | 40.8795 | -124.1407 | None |

## Appendix 2: List of Project Sites

### List of Estuarine Projects Assessed with CRAM

| Region Code | Site Name | Project ID | Project Status | AA Latitude | AA Longitude |
|---|---|---|---|---|---|
| SC | Model Marsh | SC-05 | Completed | 32.5461 | -117.1218 |
| SC | Model Marsh | SC-05 | Completed | 32.5461 | -117.119 |
| SC | Model Marsh | SC-05 | Completed | 32.547 | -117.1229 |
| SC | Oneonta Slough | SC-07 | Completed | 32.5738 | -117.1262 |
| SC | Marissma de Nacion | SC-04 | Completed | 32.6463 | -117.107 |
| SC | Connector Marsh South | SC-03 | Completed | 32.6474 | -117.1041 |
| SC | Marissma de Nacion | SC-04 | Completed | 32.6474 | -117.1072 |
| SC | Connector Marsh South | SC-03 | Completed | 32.6496 | -117.1049 |
| SC | Connector Marsh North | SC-03 | Completed | 32.6514 | -117.1057 |
| SC | Connector Marsh North | SC-03 | Completed | 32.6524 | -117.1061 |
| SC | West Point Loma Marsh | SC-10 | Completed | 32.7523 | -117.2279 |
| SC | Santa Ana River | SC-08 | Completed | 33.6321 | -117.9514 |
| SC | Talbert | SC-09 | Completed | 33.6345 | -117.962 |
| SC | Talbert | SC-09 | Completed | 33.6355 | -117.963 |
| SC | Santa Ana River | SC-08 | Completed | 33.6358 | -117.9536 |
| SC | Santa Ana River | SC-08 | Completed | 33.6408 | -117.9529 |
| SC | Ballona | SC-01 | Planned | 33.9635 | -118.4487 |
| SC | Mugu Sewage Pond | SC-06 | Completed | 34.1097 | -119.0903 |
| SC | Mugu Sewage Pond | SC-06 | Completed | 34.1107 | -119.0908 |
| SC | Carpinteria Marsh | SC-02 | Completed | 34.3975 | -119.5299 |
| SC | Carpinteria Marsh | SC-02 | Completed | 34.3986 | -119.5291 |
| CC | Arroyo Burro Estuary | CC-01 | Completed | 34.4045 | -119.7402 |
| CC | Hunter's lot | CC-07 | Completed | 35.3454 | -120.8382 |
| CC | Carmel River Lagoon B | CC-04 | Completed | 36.5334 | -121.9196 |
| CC | Carmel Lagoon A | CC-03 | Completed | 36.5337 | -121.9186 |
| CC | Calcagnos 1 | CC-02 | Completed | 36.7978 | -121.7697 |
| CC | Elkhorn slough | CC-06 | Completed | 36.81 | -121.7366 |
| CC | Elkhorn Slough | CC-06 | Completed | 36.821 | -121.7778 |
| CC | North Marsh at Compana | CC-08 | Completed | 36.8364 | -121.7328 |
| CC | Watsonville Slough site 1 | CC-10 | Completed | 36.8551 | -121.8106 |
| CC | Watsonville Slough | CC-10 | Completed | 36.8592 | -121.8121 |
| CC | Watsonville Slough site 2 | CC-10 | Completed | 36.8669 | -121.8172 |
| SFB | Mt View #3 | SFB-06 | Completed | 37.434 | -122.0839 |
| SFB | Mt View #1 | SFB-06 | Completed | 37.4348 | -122.0849 |
| SFB | Whale's Tail # 25 | SFB-10 | Completed | 37.5891 | -122.1446 |
| SFB | Whale's Tail #19 | SFB-10 | Completed | 37.59 | -122.1447 |
| SFB | Cogswell #1 | SFB-01 | Completed | 37.6317 | -122.1443 |
| SFB | Cogswell #2 | SFB-01 | Completed | 37.6327 | -122.1443 |
| SFB | Cogswell #3 | SFB-01 | Completed | 37.6357 | -122.1455 |
| SFB | Triangle #1 | SFB-09 | Completed | 37.6447 | -122.153 |
| SFB | Triangle #2 | SFB-09 | Completed | 37.6447 | -122.1538 |
| SFB | MLK New Marsh #1 | SFB-05 | Completed | 37.738 | -122.2064 |
| SFB | MLK new marsh #2 | SFB-05 | Completed | 37.7393 | -122.2092 |

| Region Code | Site Name | Project ID | Project Status | AA Latitude | AA Longitude |
|---|---|---|---|---|---|
| SFB | MLK new marsh #3 | SFB-05 | Completed | 37.7402 | -122.2067 |
| CC | Crissy Field | CC-05 | Completed | 37.8046 | -122.4546 |
| SFB | Richardson Bay Bridge Marsh #1 | SFB-07 | Completed | 37.8806 | -122.5141 |
| SFB | Richardson Bay Bridge Marsh #2 | SFB-07 | Completed | 37.8823 | -122.5177 |
| SFB | Mill Valley #2 | SFB-04 | Completed | 37.8933 | -122.5262 |
| SFB | Mill Valley #1 | SFB-04 | Completed | 37.8943 | -122.5263 |
| SFB | Hoffman #3 | SFB-03 | Completed | 37.9007 | -122.3161 |
| SFB | Hoffman #2 | SFB-03 | Completed | 37.9008 | -122.3153 |
| SFB | Hoffman #1 | SFB-03 | Completed | 37.9015 | -122.3163 |
| CC | Stinson Dump/Causway | CC-09 | Completed | 37.9051 | -122.6506 |
| SFB | Color Spot | SFB-02 | Completed | 37.9711 | -122.3732 |
| SFB | Richmond Parkway #1 | SFB-08 | Completed | 37.973 | -122.371 |
| SFB | Richmond Parkway #2 | SFB-08 | Completed | 37.9739 | -122.3712 |