Central Coast Wetlands Group

Using New Methodologies to Assess Bar-built Estuaries along California's Coastline

Final Report

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Introduction

Connecting marine, freshwater and terrestrial ecosystems, bar-built estuaries (BBE), often referred to as coastal lagoons, are complex and dynamic systems. BBEs are unique in the world in that they are mostly located along high wave energy coasts, with swell-exposed beaches, and are associated with streams that often have high seasonal discharge. BBEs are only found in the Central West Coast of North America, East and South Coast of Australia, East Coast of South America, South Africa and part of the West Coast of France.

These systems fluctuate between fresh and brackish conditions, providing a wide range of unique ecological services that benefit rare and endangered species. These types of coastal confluences are generally found at the mouths of watersheds in Mediterranean climates with episodic streamflow and seasonal fluctuations in swell dynamics (Haines et al. 2006). The typical BBE formation pattern is 1) high stream flows coupled with strong swells keep the stream mouth open in the winter; 2) low stream flows and a concomitant shift in swells during summers cause a sand bar to form at the mouth restricting or isolating the stream from the ocean, pooling fresh and marine waters within a rising estuary, 3) water elevation rises behind the berm till water overtops or leads to structural failure and draining of the estuary.

This process results in water impounding behind the berm and providing increased open water and inundated marsh plain habitat, during the otherwise dry summer season. Even when closed, waves frequently overtop the sand bar delivering salt water, and nutrients to the impounded lagoon. The flooded and still nature of Bar-built estuary waters provides important nursery habitat for aquatic species from both the freshwater and marine ecosystems including anadromous species such as steelhead that migrate between the two (Beck et al. 2001; Bond et al. 2008; Hayes et al. 2011).

BBE Management

With California's growing human population centered in coastal areas, these habitats experience varying and often extreme levels of alteration (Dahl 1990; Zedler 1996). Land reclamation, flood control practices, increased demands for freshwater, management of barrier beach formation and persistence, and climate and sea level changes all further threaten these habitats and the services they provide (Dahl 2000; Griggs 2005). Some alterations are accepted as unavoidable due to legal water diversions, flood protection for adjacent land uses and protection of coastal infrastructure (Highway 1 road and bridges). However, there are a number of lagoon characteristics that can be improved even in the face of inevitable human impacts on these coastal aquatic systems (i.e. temperature, nitrogen availability, circulation dynamics and food chain dynamics).

State regulatory agencies are routinely tasked with making management decisions through permitting of construction projects and breaching activities without a full understanding of the impact of these projects. Management strategies often focus on the management of specific species, services or environmental objectives (i.e. water quality) sometimes at the detriment of other services and species. This project aimed to improve our regional understanding of the current ecological services these systems provide through the development of the CRAM tool for these wetlands and the compilation of a standardized assessment of condition and an evaluation of habitat impacts of various activities. This project has developed and assembled a suite of assessment techniques that can generate the information necessary for resource managers to devise better strategies to modify and enhance lagoon ecosystems for multiple objectives and species and evaluate the effectiveness of implemented actions. Thus there exists a critical need for a standardized and cost-effective method to assess the extent and condition of bar-built estuaries to aid management of these coastal ecosystems.

Definition

A Bar-built estuary is a creek or river-mouth system with some secondary floodplain wetland resources. The BBE beach mouth formation and marine/freshwater hydrologic interactions are driven by a dynamic set of processes that vary regionally depending on watershed and climatic conditions, the volume of river sediment input, long-shore sediment transport, and wave exposure. Depending on the local geology, these systems can support a vast set of tidally influenced wetland resources or support little more than a channel width lagoon, based on the level of confinement provided by adjacent hills.

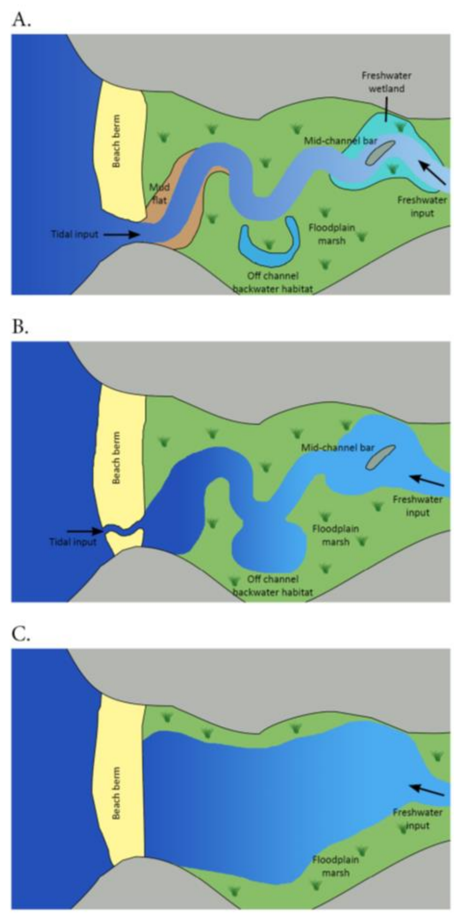


Figure 1.1: The three primary phases of a BBE. A) Fully open to tidal input B) Partially open to tidal input C) Closed to tidal input.

Bar-built estuaries are the reaches of coastal rivers and streams that are ecologically influenced by seasonal closures of their tidal inlets through the formation of a sand bar or small barrier beaches with three primary phases (Figure 1.1). The frequency and duration of inlet closure can be natural or managed. Many of these systems frequently exhibit prolonged non-tidal phases, seepage tides, or significant tidal choking, resulting in the tidal regime being muted in comparison to the adjacent marine system when the tidal inlet is open. The salinity regime of a bar-built estuary can be highly variable, ranging from fresh throughout very wet years to hypersaline during extended droughts. This salinity regime trends toward freshwater in more northern systems where rainfall averages are greater.

Conceptual Model

This BBE conceptual model aims to define the population for which this method can be used and to guide the Technical Guidance Team's efforts to synthesize the assumptions and concepts for which the CRAM module will assess condition (Figure 1.2).

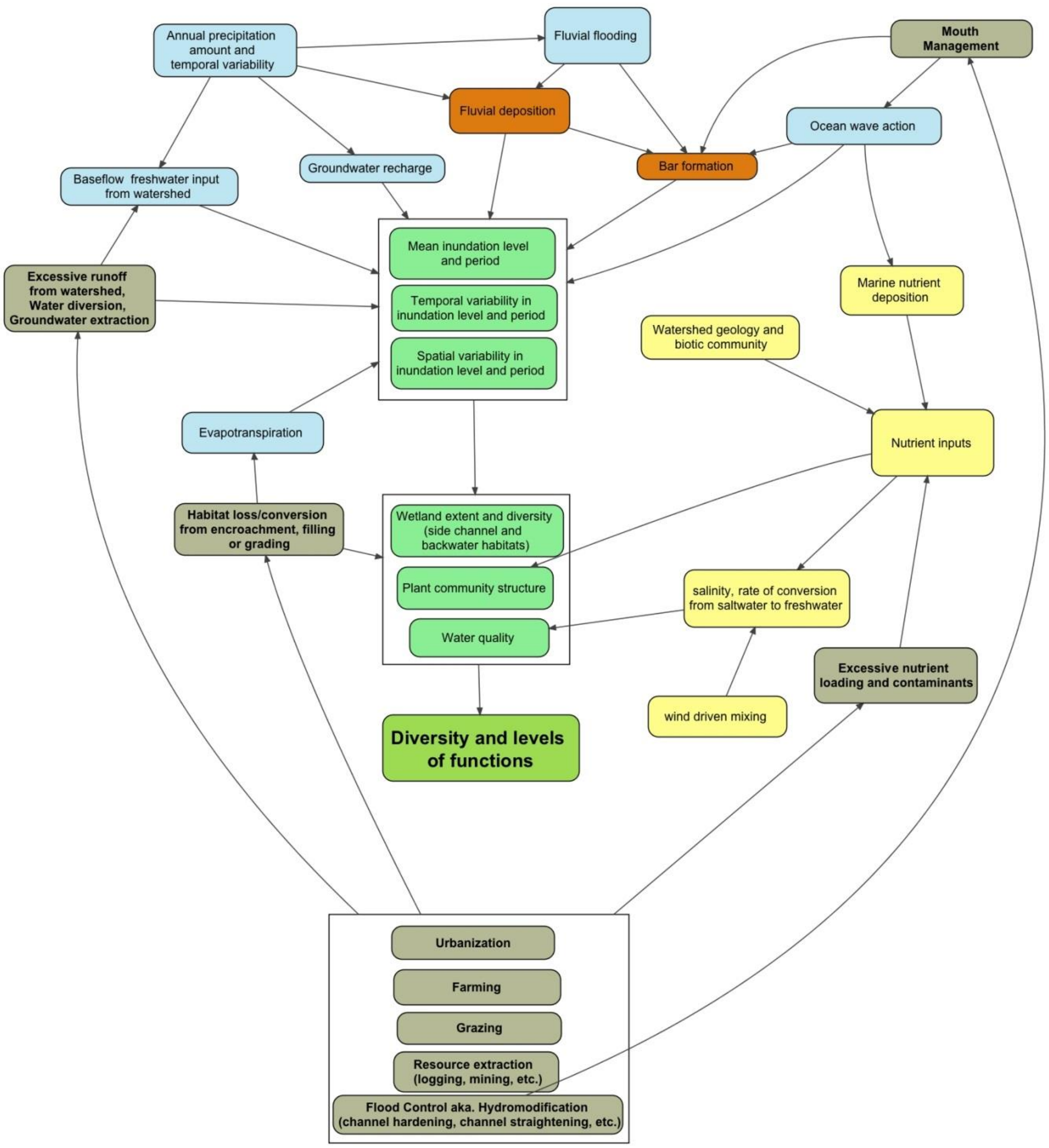


Figure 1.2: Diagram outlining conceptual model of natural inputs and outputs of water (blue boxes) and sediment (brown boxes), stressors and their effective processes (gray boxes), nutrients (yellow boxes), and BBE responses (green boxes).

Characteristic Hydrologic Processes:

(adapted from Australian Online Coastal Information- www.ozcoasts.org.au, see Figure 1.3)

Freshwater input: Freshwater enters from the watershed. Although the volume of freshwater input varies regionally and seasonally (depending on local watershed and climatic conditions), it is typically relatively high in most riverine BBEs.

Fresh water inundation of low-lying areas: Floods, or high runoff events, driven by climatic and watershed processes, can result in the inundation of low-lying marsh areas adjacent to the main channel by fresh water. This water often supports freshwater wetland ecosystems (side channel and backwater habitats), and typically is either taken up by vegetation, or evaporates. In some cases there is a direct hydrologic link to the main channel allowing the water to drain back out. Inundation of these marsh areas can also occur when the mouth of the system closes. The natural formation or expansion of backwater habitats is possible under some infrequent extreme fluvial flood events that cause erosion of meander scars or secondary channels, followed by abandonment of channels (WWR 2010).

Freshwater flow: When the mouth is open, current flow in channels is strong, due to their small relative volume, and the consequent short residence time of water (the time taken for water to travel through the BBE). Floods may completely force marine water out of the BBE. When the mouth is closed, water circulation in BBE systems generally ranges from well mixed to salinity-stratified, depending on the degree of wave over-wash from the marine environment, volume of freshwater input, and climate (Nichols et al. 1985). In most cases, BBEs have lower salinity water towards their head, with the salinity of the water in the central basin and next to the inlet increasing. The volume of freshwater causes stratification (or layering) in the water column, which varies with seasonal flow. Buoyant low-salinity fresh water floats above the denser, high-salinity ocean water.

Salt wedge inflow of more dense seawater: After bar formation, high tides often continue to wash over the bar for several weeks and can continue for the remainder of the summer during extreme high tide events. The volume of this addition is usually relatively insignificant compared to the freshwater flow; however, this depends on the size of the BBE (Smith 1990). A 'salt-wedge', or intrusion of denser saline marine water can penetrate the BBE through the entrance when the mouth is open. Riverine BBEs are generally characterized by limited tidal intrusion because of friction effects and the relatively strong river flow. Some mixing occurs at the interface between the less-dense freshwater, and higher-density marine water. The distance that the salt-wedge penetrates is dependent on tidal range and the amount of fluvial flow received by the system (Kurup et al. 1998; WWR 2008). During high fluvial flow events (which may be seasonal), fresh floodwater rapidly pushes the salt water intrusion seaward (beyond the mouth), completely removing stratification from the delta (Hossain et al. 2001; Eyre 1998).

Seepage through the bar: Seepage through the bar is potentially sufficient to stabilize BBE water levels at low freshwater inflows, preventing a bar breach from occurring. However, the rate of seepage depends on the water depth and hydraulic pressure that it provides, which can result in deep impoundments. Alternatively, at extremely low inflows, seepage can result in very low depths behind the berm. When this occurs, seepage from the ocean can occur at high tides, which can increase salinity stratification and mean salinity in the BBE (Smith 1990).

Outflow of brackish water: Exchange of ocean water and estuarine water occurs through the entrance of the estuary, although the amount of exchange depends on the size and length of the entrance channel. Often the outflow of freshwater exceeds the inflow of marine water.

Internal currents: Wind-induced currents can drive the internal circulation of larger lagoon systems. Secondary circulations can be generated by tides. Tidal ranges are often small (~0.1 m) compared to tidal ranges in the ocean, and internal circulation patterns are disrupted during extreme high-flow events.

Evaporation: In general, due to the relatively low surface area of most BBEs, evaporation is a minor component (depending on climatic conditions) and does not exceed river input. While significant evaporation can occur in larger lagoon systems, it does not exceed the amount of freshwater input (Heggie et al. 1999).

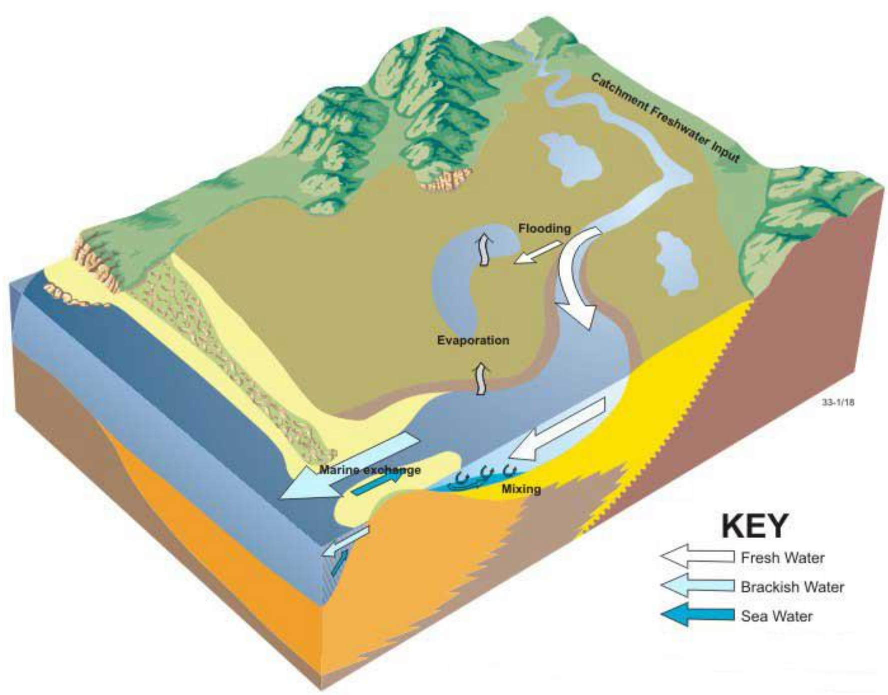


Figure 1.3: Conceptual figure of characteristic hydrologic processes for a bar-built estuary

Characteristic Sediment Processes:

(adapted from Australian Online Coastal Information- www.ozcoasts.org.au, see Figure 1.4)

Fine and coarse sediment input from the watershed: Fine and coarse sediment enters the estuary from the watershed. The amount of sediment input varies regionally depending on watershed and climatic conditions, and the volume of river input. However, the amount of terrigenous sediment delivered to these systems is usually relatively large. Seasonal and climate factors dominate the function of BBEs, with episodic high-flow events causing intense flushing, sedimentation, and erosion in the main channels and floodplain (Eyre et al. 1999).

Deposition of fines in freshwater wetlands: Limited deposition of fine sediment (including clays, muds and organic material) occurs upon the floodplain during high flow events (Jones et al. 1993). This is enhanced by the baffling effects of floodplain vegetation associated with marsh areas, and leads to slow vertical accretion of the floodplain. Some lateral deposition of sediment can occur, including the development of coarse sediment point-bar deposits.

Fine sediment accumulation: Fine sediment (i.e., muds, clays, and organic material) is deposited on the fringes of the central basin by river processes, and tides. Deposition in these environments is aided by the baffling effects of vegetation such as saltmarshes (Boorman et al. 1998; Brown 1998; Temmerman et al. 2003). Coarse sediment (i.e., sands and gravels) may also accumulate in the fringing environments during floods. Biological activity and waves cause significant reworking of fine sediment on un-vegetated intertidal flats.

Downstream transport of fines: BBEs are characterized by net seaward-directed sediment transport, associated with the relatively high river discharge and relative absence of available accommodation space for sediment deposition (Bhattacharya et al. 1992). Consequently, fine suspended sediment, and coarse sediment (as bedload) is moved downstream along the bottom of the channels, due to unimpeded river flow. Some lateral deposition of both types of sediment can occur, including the development of coarse sediment point-bar deposits.

Transport of fine material into the central basin: Suspended sediment is transported into the central basin, where it is deposited in a low-energy environment. Benthic micro-algae (BMA) assist in the stabilization of fine sediment (Wulff et al. 1997; Cahoon et al. 1999; Murray et al. 2002). Seagrasses, where present, also promote sedimentation and stabilize the substrate (Moriarty et al. 1985). The low-energy condition and large relative size of the central basin means that this region is the primary repository for fine material and particle-associated contaminants (Hodgkin et al. 1998; Heggie et al. 1999; Heap et al. 2001; Harris et al. 2002). Resuspension of the fine sediment can occur in BBEs with either very shallow central basins or a lack of stabilizing vegetation, causing significant turbidity.

Export of sediment: The majority of deposition occurs seaward of the mouth, and results in the net export of sediment into the marine environment (Jones et al. 1993; Hume et al. 1993). Fine suspended sediment is generally transported offshore; coarser sediment tends to accumulate close to the entrance, although this material is generally redistributed by wave action (Melville 1984; Cooper 1993).

Tidal infilling by coarse marine sediments: At the entrance, tidal currents are locally accelerated in the constricted entrance, and form flood and ebb tidal deltas (Roy 1984). Sedimentary processes are dominated by the landward transport of coarse sediment derived from the marine environment (Green et al. 2001). Sediment can be exported to the ocean through the inlet, particularly during spring tides and flood events (Harvey 1996). After bar formation, high tides often continue to wash over the bar for several weeks and can continue for the remainder of the summer during extreme high tide events (Smith 1990).

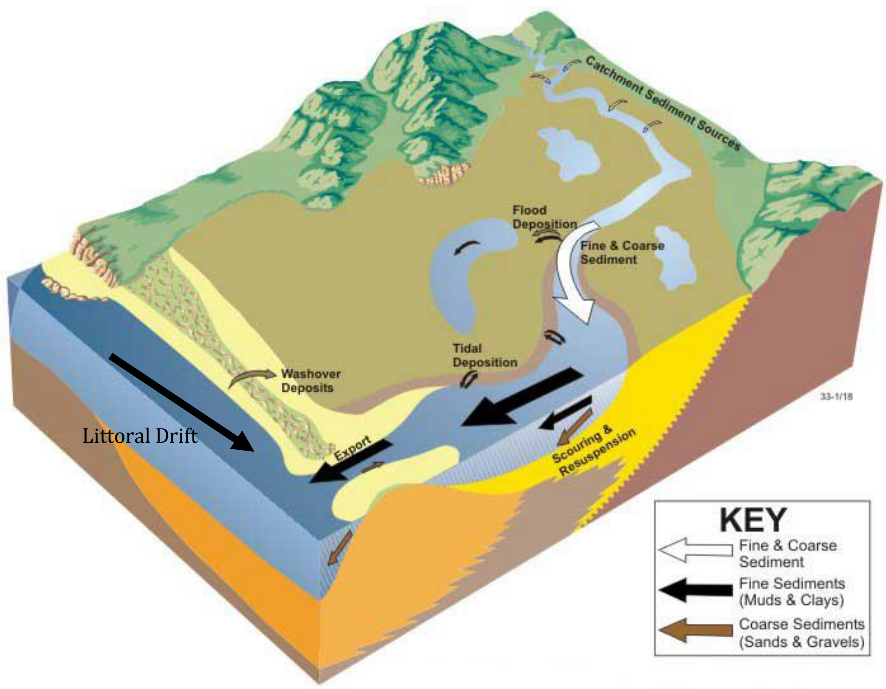


Figure 1.4: Conceptual figure of characteristic sediment processes for a bar-built estuary

Bar Formation:

Bar formation, and thus estuary closer, is dependent on a number of variables including: wave dynamics, sand abundance and distribution, coastline shape, streamflow, and channel width and volume. When seasonal stream discharge recedes to late spring conditions, the timing of seasonal sandbar closure is driven by coastal dynamics such as spring tidal conditions and south swell events. The coastal swell must deliver enough sediment to the beach berm to exceed the elevation of the lagoon water surface.

Cross-sectional constrictions of lagoon width near the mouth, such as bridge structures, likely delay the formation of a sustained sandbar barrier, and can impair ability of the sandbar to remain intact. Heavily flood-controlled lagoons must accommodate lagoon water storage along the beach environment due to the significant reduction in the surface area of the lagoon and the associated lack of horizontal water spreading capacity within the leveed channel (Beck et al. 2006).

In many cases, coastal lagoons transition from a deltaic river-dominated system in the winter and spring, to a backwater fresh/brackish environment in the summer and fall. These changes in circulation and climate result in a relative increase in primary production rates and organic matter accumulation in lagoons from winter to summer.

Emergent Marsh Community:

Natural sources of water other than input from the watershed that can influence BBEs include groundwater, surface runoff from adjacent uplands, and direct precipitation. The plant community of BBEs is highly correlated to spatial and temporal variability in water height as well as average seasonal groundwater heights.

Marsh habitat development on active floodplains is mainly controlled by the magnitude and frequency of flooding caused by watershed runoff and mouth closure. Floods cause complex patterns in topography and sediment texture that strongly influence the duration of inundation and permeability of floodplains. In addition to vertical recharge during overbank flooding, horizontal recharge through channel banks during high flows that do not exceed channel banks, and high base flows in fluvial channels can contribute to high water tables for adjacent floodplains.

System Functions:

Bar-built Estuaries positively influence a variety of highly valued hydrological and ecological processes. These positive influences are termed functions. The most common functions of Bar-built Estuaries are briefly described below:

Fish and Wildlife Support: Bar-built Estuaries provide water, food, and refuge for many native species of residential and migratory wildlife, including numerous endangered or threatened plants and animals. They provide vital resting, breeding and feeding areas for migrating waterfowl. Additionally they serve as nursery habitat, and drought refuge for anadromous fishes, turtles and frogs. Unique services include;

- winter/spring anadromous passage,
- summer rearing,
- winter refuge,
- spring feeding/ growth
- suitable conditions within the estuary complex all year
- escape cover from predators

- spring brackish transition/ feeding habitat
- configuration and size/depth can affect summer rearing
- refuges against droughts and floods
- abundant invertebrate food from marsh and marine detritus

Climate Change Mitigation: BBEs, through accumulation of plant matter, function as carbon sinks.

Water Quality Control: Chemicals and nutrients can enter a wetland through surface water and sediment, or through ground water. The major inorganic nutrients entering wetlands are nitrogen and phosphorus. In the wetland, nitrogen and phosphorus are removed from the surface water and transferred to the sediment, wetland plants or atmosphere.

Groundwater Recharge: BBEs impound freshwater from riverine sources, preventing its escape to the ocean. This allows the water time to percolate into the aquifer, recharging groundwater.

Recreation: Bar-built Estuaries provide a variety of recreational uses including bird-watching, hiking, camping, and hunting. They are often the subject visual arts.

Anthropogenic Stressors:

The condition of a BBE is determined both by natural processes and land use activities in its watershed. Activities that affect watershed runoff quantity and reduce water quality are likely to have deleterious impacts on multiple measures of BBE condition. Stressors are the anthropogenic events or activities that impact the physical and ecological functions of BBEs in California.

Altered freshwater input: Human activities in upstream reaches of coastal confluences can alter critical components of estuarine hydrodynamics which may result in fundamental changes to the physical, chemical and biological characteristics of estuaries, and in turn lead to a reduction in estuarine health. Reservoirs and diversion structures such as dams and weirs, and direct pumping of water from the stream channel for domestic, industrial and intensive agriculture can directly alter the natural magnitude and variation of riverine flows (Flemer et al. 2006).

Channel Modification: Modifications to stream channels such as channel straightening for flood mitigation or channel dredging can also directly impact these systems causing significant decreases in estuarine volume and productivity (Hofstra et al. 1987). Additionally there can be impact on more subtle components of natural flow regimes such as the duration of high flow events.

Watershed Land Use: Land use and management practices, such as the removal of riparian buffers, clearing of native forests, and expansion of urban areas can change the natural timing, magnitude and duration of rainfall runoff and ultimately increase the volume of stormwater that is generated within a watershed. Land use practices in the watershed can also increase sedimentation rates.

Urban encroachment/loss of floodplain habitat: Encroachment by urban development in the lower watershed and in the estuarine floodplain can lead to direct loss of habitat (HDR 2008).

Mouth Management: Modification of the entrance of the bar-built estuary, either in the form of breaching or a permanent structure (bridge), can affect the volume and frequency of flood events and tidal flows, as well as the timing of annual breach events.

Contaminants and Nutrient enrichment: Excessive loads of contaminants nutrients can cause the eutrophication of coastal waterways. The general pattern of change involves a shift from large macrophytes (including seagrasses) towards fast-growing macroalgae and phytoplankton (including harmful species found in blooms) that can capture and use light more efficiently. High loadings of organic matter to the sediment promotes oxygen consumption through decomposition, and can potentially lead to anoxic or hypoxic events. Low dissolved oxygen concentrations (and toxic algae) can harm benthic invertebrates, fish, and other organisms. Nutrient enrichment can also compromise the ability of seagrass meadows and salt marshes to support fish and invertebrates even before a change in habitat areas occurs (Flemer et al. 2006).

Biological Invasion: Non-native plants and animals brought to California over the past several centuries can out compete and take away the habitats of some native species.

Inventory and Classification

California has a number of wetland classification systems in use including Cowardin, HGM, CMECS, NWI, and CRAM. Each of these classification systems provides unique methods to characterize a set of wetland types that exist along any definable linear scale. Many of these classification systems suggest a temporal uniformity that does not exist in the natural environment. The most useful classification methods reflect the seasonal, inter-annual and decadal fluctuations in hydrogeomorphic conditions. They also help to distinguish systems that still function in this natural temporal flux from those systems that have been altered through management, yet still exist within an acceptable subset of the natural conditions to maintain the original habitat classification. See Figures 1.5 and 1.6 for the inventory of BBEs.

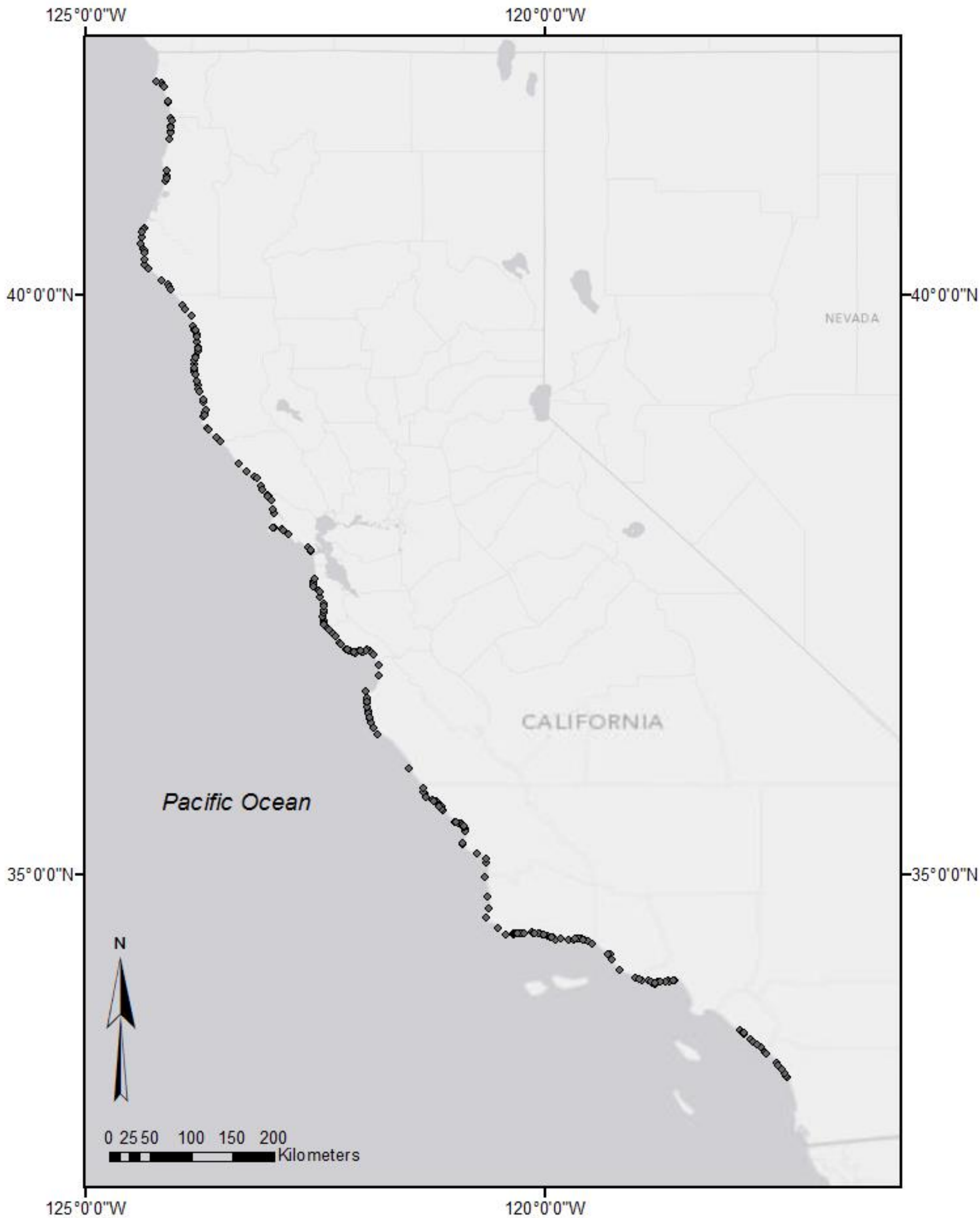


Figure 1.2: Inventory of all BBEs in California (N=276)

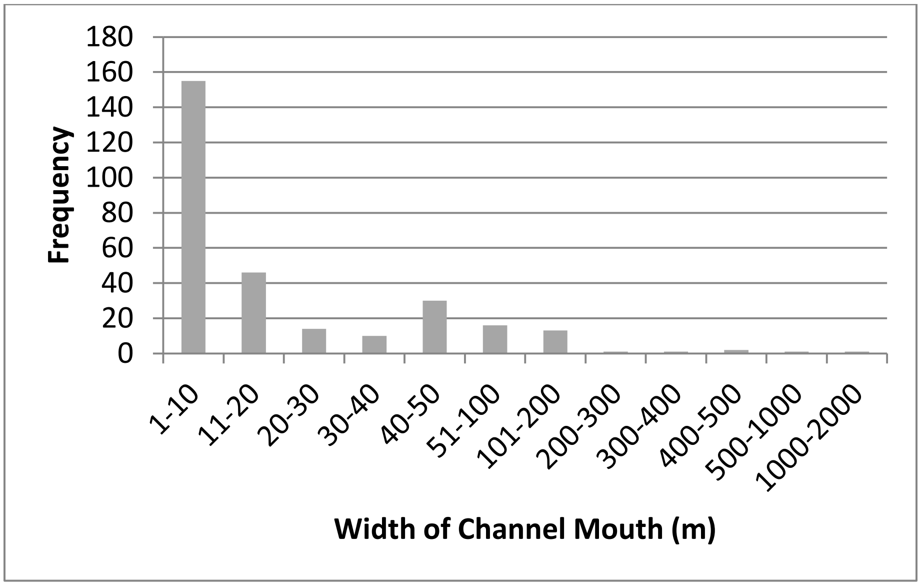


Figure 1.6: Results of surveying the width of BBEs throughout the State, displaying the prevalence of small systems and relatively few very large ones

CCWG Coastal Confluence Classifications

The following basic classification was developed by CCWG for an inventory of all coastal confluences in California. This was done to develop the sample frame from which sites were selected for the verification, validation of CRAM and ambient assessment of bar-built estuaries on the Central Coast. (Images taken from Google Earth and The California Coastal Records Project)

Bar-built estuary (BBE): In systems with a strong fluvial influence, there is sign of estuary mouth closure by the formation of a sand bar at some point during the year. A pond forms behind the bar and connection with the marine environment is reduced or severed.

Example: Santa Maria River

True Lagoon: Similar to bar-built estuaries, a sand bar forms across the mouth of the system creating a pond or lake with reduced or severed connection with the marine environment. However there is a very small watershed and little fluvial influence and the system (may) open infrequently.

Example: Stone Lagoon

Open River Mouth: A very large coastal confluence that does not close to the marine environment due to large freshwater flows or local geology, but shows some effect of a bar formation.

Example: Klamath River

Bay/Estuary: open bay with fringing estuarine wetlands or semi-enclosed estuary that is always open to tidal action.

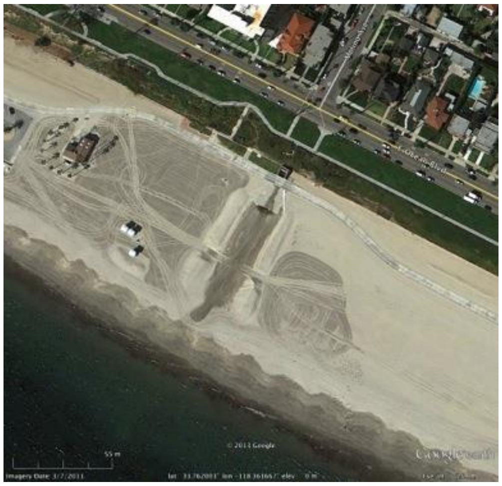
Example: Drakes Estero

Creek Mouth: a small coastal confluence that does not close off to the marine environment from the formation of a sand bar or form a ponded system. This may be due to natural reasons (steep gradient or large grain size on the beach), or anthropogenic in that it used to be a BBE but lost all habitat and ability to close.

Example: Big Devil's Canyon

Urban Drain: a coastal confluence in an urban setting with no obvious watershed area or historical drainage feature.

Example: Long Beach-Molino Ave.



2. CRAM Module Validation

Introduction

Efforts to restore and conserve wetland habitats rely on an understanding of the condition of existing habitats to better guide management actions (Solek et al. 2012; Allan et al. 2012). An estimated loss of more than 30% of bar-built estuarine habitat in California, and continual threats of further loss through human alterations, lends a certain urgency to the completion of a comprehensive inventory and assessment of BBE habitats (Ryan unpublished data). Recognizing that intensive assessment methodologies are not always practical or needed, the United States Environmental Protection Agency (USEPA) has recommended a three-tiered approach to wetland monitoring and assessment (Level 1-2-3; USEPA 2002). Accordingly, Level 1 refers to habitat inventories and landscape scale assessments, Level 2 refers to rapid assessment methodologies (RAMs), and Level 3 refers to intensive species or physical parameter specific assessment approaches (Stein et al. 2009; CWMW 2013) . Because of their relative cost- and time-efficiency, Level 2 or rapid assessment methodologies have been gaining popularity for assessing wetland habitats for a range of uses including ambient assessments, restoration monitoring, and the direction of regulatory and conservation management (Fennessy et al. 2007; Stein et al. 2009; Solek et al. 2012). Rapid assessment methods are intended to evaluate the ecological and functional condition of a wetland relative to the range of possibilities using a finite set of field indicators (Stein et al. 2009). Because rapid assessments are cost effective and use standard metrics to integrate the condition of multiple functional components of these systems, they provide an important tool for characterizing relative condition among the numerous systems within a region. Obtaining these data supports development and adoption of more standardized management objectives.

The California Wetland Monitoring Workgroup (CWMW) was established by the State of California and the USEPA to build tools such as the California Rapid Assessment Method (CRAM) to support the monitoring needs of various state agency programs and better meet the state's wetland protection and enhancement objectives (CWMW 2013). The development of RAMs for multiple classes of wetlands is particularly important for the state of California which hosts a wide range of wetland types (Cowardin 1979) but also has the highest loss of wetlands in the lower 48 United States at 91% (Dahl 1990). CRAM development has drawn from other assessment methodologies including the Washington State Wetland Rating System (WADOE), the Montana Wetland Assessment Method (Burglund 1999), the Ohio Rapid Assessment Method (Mack 2001), the Releve Protocol of the California Native Plant Society, wildlife and stream bio-assessment procedures of the California Department of Fish and Wildlife, and wetland compliance assessments of several regional water quality control boards (CWMW 2013). CRAM provides a cost-effective assessment tool for wetlands that can be used to assess the condition on a variety of scales, ranging from portions of individual wetlands to assessments of wetland condition throughout watersheds and climatic regions.

CRAM provides an Index score of the condition of a wetland relative to other wetlands of that type throughout the state. This Index score is calculated as a combination metrics scores based upon visual and easily measured indicators of ecological condition. The metrics assessed in CRAM are similar across various wetland classes but are adapted as necessary to fit the characteristics unique to each wetland type. Seven modules have been developed, or are being developed to assess different wetlands types under CRAM (Sutula et al. 2006). Of these, the riverine and estuarine CRAM modules have been "validated" (Stein et al. 2009) in order to establish their scientific credibility using the State-adopted a process for validation through comparisons with other independent measures of habitat condition (Sutula et al. 2006; Stein et al. 2009). Here we validate CRAM for bar-built estuaries following the validation approach described by (Stein et al. 2009).

Although individual bar-built estuaries may be relatively small, they collectively comprise a large area and provide the only estuarine habitat along large stretches of California's coastline. By definition, bar-built estuaries (BBE) alternate between tidally influenced estuaries and impounded river mouth "lagoons", disconnected from the ocean. As the interface between terrestrial freshwater and marine ecosystems, bar-built estuaries exhibit high levels of spatio-temporal complexity. This gives rise to ecological benefits including a diversity of habitat provisioning (i.e. backwater refuge and brackish water) to support species diversity, including species uniquely adapted to this variability.

The development of wetland class specific CRAM modules enables wetland practitioners to evaluate the "condition" of a number of classes of wetlands based upon its ecological functioning. Thus, to develop a module for bar built estuaries, it was important to ensure that the tool is: 1) responsive to the full range hydrologic dynamics and habitat complexity, and 2) able to evaluate the overall condition of these diverse systems based on the four standard CRAM Attributes. While the variability in water elevation due to temporal mouth dynamics may suggest a need for multiple repeat surveys, we instead sought to define a set of visual cues and indicators capable of assessing temporal dynamics regardless of closure status. We then confirmed that CRAM reliably characterized bar-built estuary condition along the 1100 miles of California's diverse coastline, by comparing CRAM and other indicators of condition throughout varying climatic and environmental conditions.

Methods

CRAM relies on visual indicators to reliably assess physical and biological complexity, which is then used to infer ecological functioning and benefits (i.e. condition). We developed the bar-built estuaries module specifically to assess the condition of the 276 coastal stream mouths BBEs in California (see chapter 1) that are seasonally closed by the formation of a sand bar. We classified bar-built estuaries as river confluences that exhibit strong fluvial influence characterized seasonally by directional surface flow between a distinct watershed inflow and ocean outflow, and that surface water connectivity to the ocean is seasonally interrupted by a sand bar (CCWG 2012). We defined the boundaries of bar-built estuaries for the purpose of this assessment to be the inland extent of impounded water dictated by the most extreme sand bar impoundment elevation. The frequency and duration of sand bar closure of these systems that leads to impoundment vary greatly along a continuum between (but excluding) open rivers, that never form a bar and true lagoons, that are do not have a strong fluvial influence and are commonly isolated from marine tidal exchange for long periods.

Table 2.1: CRAM attributes and metrics, and how they are assessed for bar-built estuaries.

Attributes	Metrics	Assessed by
Buffer and Landscape Context	stream corridor continuity	combined total length of non-buffer land cover segments within a distance of 500m upstream
	adjacent aquatic area	extent of aquatic habitat within four 500m transects parallel to the coast line
	marine connectivity	the extent of anthropogenic disruption of littoral and nutrient exchange with lagoon and adjacent beach (e.g. piers, seawalls, beach cleaning, excessive human visitation)
	percent area with buffer	percent of area surrounded by at least 5m of buffer habitat
	average buffer width	average of eight evenly spaced buffer width measurements up to 250m
	buffer condition	the quality (i.e. native) of vegetation cover, degree of soil disturbance, and degree of human visitation
Hydrology	water source	degree of anthropogenic influence on dry season water sources (e.g. extractions or inputs) within 2km watershed boundary of area
	hydroperiod	degree of anthropogenic alteration to opening / closure dynamics of lagoon mouth
	hydrologic connectivity	the ability of rising water to flow laterally across marsh plain unrestricted by levees or dikes
Physical Structure	structural patch richness	number of patch types observed from a pre-selected list of 27 possible
	topographic complexity	the degree of both micro- and macro-topographic features observed along multiple channel / marsh plain cross-sections
Biotic Structure	number of plant layers	number of five possible plant layers that each cover at least 5% of the area
	number of co-dominants	total number of living plants species that comprise at least 10% of any plant layer
	percent invasive species	the percent of the total number of co-dominants that are on the Cal-IPC invasive species list
	horizontal interspersion	the complexity of the plant zone mosaic
	vertical biotic structure	Assessed in two possible manners: 1) with dominance of a tall plant layer – the degree of overlap of vertical plant layers; 2) without dominance of a tall plant layer – the extent of dense vegetation and litter collected in the vegetative canopy

Overview of CRAM

We systematically selected 32 sites from throughout California encompassing a range of condition for which we applied CRAM and simultaneously collected Level 3 data commonly used to evaluate the condition of wetlands. We also conducted landscape scale (Level 1) assessments of the watersheds of the selected sites for a multitude of stressors using GIS interpretation of available base-maps. Then using correlation and multivariate analyses we followed and expanded upon validation methods described in Stein et al. (2009) for the bar-built estuaries of California.

The CRAM assessment area for bar-built estuaries may range from 0.1 to 2.25 ha and include either the entire system or a 2.25 ha portion within larger systems. To the extent possible, we strived to retain similar CRAM metrics among classes and focus on creating unique narrative descriptions for metrics specific to BBEs (CWMW 2013, Colins, Stein). Because bar formation and maintenance are unique drivers of condition within BBEs, we developed several "sub-metrics" that generate additional insight into bar driven condition elements. These sub-metrics are then averaged to generate a metric score (Table 1).

Study sites

This project represents the first systematic employment of the CRAM validation process described by Stein et al. 2009. We selected 32 BBEs distributed along the California coast to validate the CRAM module for bar-built estuaries (Figure 1). Sites were selected to equally represent three coastal regions: North, from Oregon to San Francisco Bay; Central, from San Francisco Bay to Point Conception; and South, from Point Conception to Mexico. Sites were selected to represent a wide range of condition to ensure that CRAM can properly assess the full range of bar-built estuary's condition across California's nearly 10^{o} of latitude.

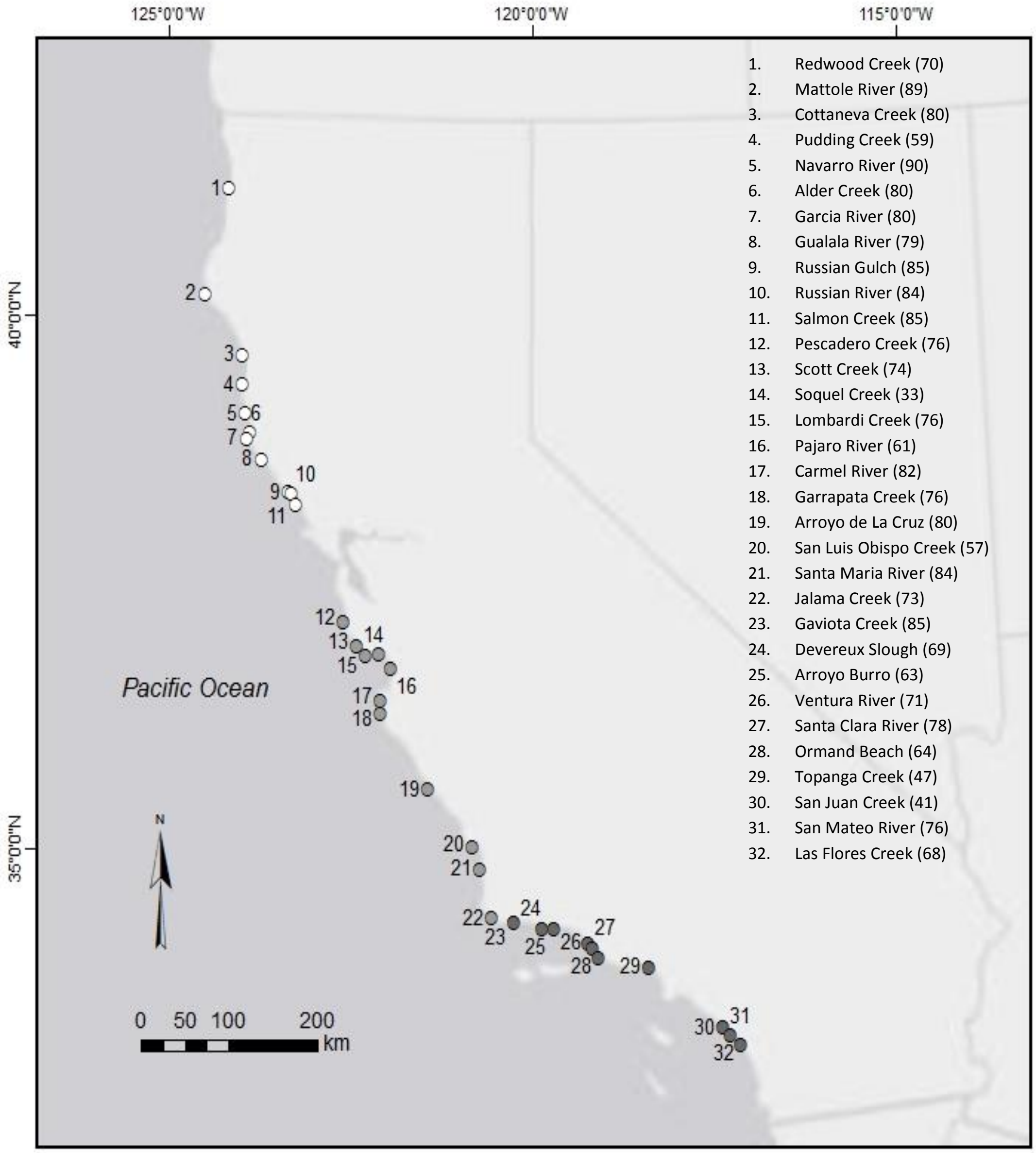


Figure 2.1: CRAM validation BBE locations

Validation of CRAM

Botanical surveys adapted from the Environmental Monitoring and Assessment Program (EMAP) were completed and used to evaluate relationships between CRAM condition scores and plant community structure. Plant surveys used point-intercept data from three transects along each bar-built estuary, stratified from the water's edge to the backshore of the marsh plain. Each transect had five quadrats randomly placed to document plant community complexity. From the botanical surveys we calculated five EMAP indices: 1) the percent cover of non-natives, 2) the percent cover of invasives, 3) the number of natives, 4) the percent cover of non-natives along the backshore, and 5) overall species richness.

Initial benthic invertebrate core data were inconclusive and costly, leading to a termination of that collection effort.

Nutrient concentrations within the BBE were collected simultaneously with CRAM assessments and used to validate CRAM. To evaluate water quality impacts from watershed specific land uses, we measured ammonia, nitrite, nitrate and phosphate levels in each bar-built estuary. At each site we collected unfiltered water samples from just below the surface. Frozen water samples were transported to Moss Landing Marine Laboratories, filtered through a 0.45µm filter and analyzed for dissolved nutrients using an ALPKEM Rapid Flow Analyzer.

A level 1 GIS landscape analysis studied the influences of land use stressors within the watersheds of the 32 estuaries assessed using CRAM. Data were derived using Watershed Delineation Tools in ArcGIS to quantify the percent cover and density of different land use alterations within each drainage. The degree of impact was calculated for four discrete geographic scales of influence (Figure 2): 1) the entire watershed of the bar-built estuary (ws); 2) a two kilometer radius area surrounding the bar-built estuary (2k); 3) within a 250 meter buffer paralleling all watershed streams of the bar-built estuary (wsbf); and 4) within a 250 meter buffers of all stream segments within the two kilometer radius area surrounding the bar-built estuary (2kbf).

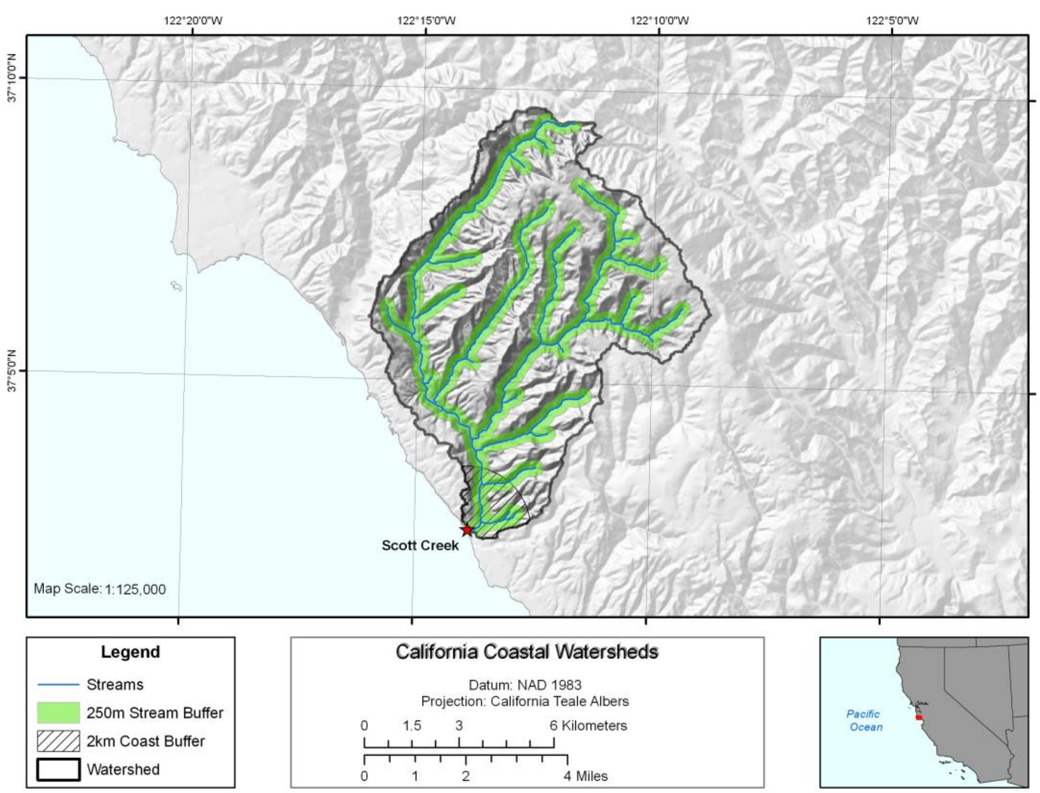


Figure 2.3: Example GIS watershed assessment of anthropogenic stressors with four scales of analysis

Validation analyses

The validation process includes quantification of three prescribed factors to meet the objectives of RAM Calibration. These factors include *Range and representativeness,* the ability of an assessment method to characterize the entire range of existing conditions; *Responsiveness* or the ability of an assessment method to discern good vs. poor condition; *Redundancy,* the degree to which multiple metrics measure the same elements of condition; *Integration,* the process of combining metrics to formulate Attribute scores; and *Reproducibility* or the minimization of user error relative to actual variation in condition.

Range and representativeness were assured through field assessments at selected good, fair and poor condition sites that successfully led to the selection of each scoring bin (a-d) for each metric. *Redundancy* was statistically analyzed using data from the 32 field assessments. *Responsiveness* was tested by comparing CRAM results to other data using more intensive field collection methods that evaluate specific functions. We utilized the methods described in Stein et al. 2009 to combine metric and submetric scores (Integration) to derive Attribute scores. *Reproducibility* was tested in the field via repeated CRAM assessments of the same BBE by multiple investigators.

Due to the dynamic nature of bar-built estuary habitats and the services they provide, the timing of data collection should be considered when assessing the condition of bar-built estuaries using any methodology. We therefore determine that CRAM assessments be conducted, as for all other modules, between the months of April and September to coincide with the botanical growing season. Because bar formation timing is inconsistent, we sought to devise a method that could properly characterize the spatio-temporally variable habitats regardless of mouth closure status. To confirm we met this objective, we assessed a subsample of our sites at various times within the field season to look at error introduced due to differences in the timing of assessments. We statistically tested whether CRAM for bar-built estuaries is responsive to the complete range of condition without bias from date, mouth closure status, region, latitude, or level of precipitation through correlations, regressions and multivariate analyses of CRAM scores across these gradients.

Range and representativeness

Range and representativeness describes the ability of an assessment method to characterize the entire range of conditions that exist in the real world (Stein et al. 2009, Hennesey 2007). Our first step to ensure representativeness of CRAM for bar-built estuaries was to select sites across as wide a range of condition as possible using our best professional judgment and guidance of the technical advisory committee and local experts. To investigate representativeness a posteriori we examined the range of CRAM metric, Attribute, and Index scores in comparison with the range of Level 1 & 3 data variables (plant community profiles, water quality, watershed stressors). We then compared distributions of CRAM metric and Attributes both within and among the three regions of California, and where necessary adjusted the thresholds of method's categorical bins to normalize distributions and better represent the distributions of Level 3 data (Stein et al. 2009).

Responsiveness

We tested responsiveness, a measure of the ability of an assessment method to discern good vs. poor condition (Stein et al. 2009), using Spearman's rank correlations and multivariate classification and ordination analyses. We examined correlations of all CRAM attributes to all Level 3 data and correlations among selected CRAM metrics and selected Level 3 indices. The direction of the predicted relationship depended upon the manner of measuring both CRAM and Level 3 data. For example, a high metric score for invasive species score in CRAM indicates few invasive species, whereas, in EMAP high non-natives scores are indicative of higher numbers or percent cover of non-native or invasive species. Thus, we predicted a negative relationship between EMAP metrics that measure non-native and invasive plant species and all CRAM Attributes and metrics (Table 2.2). We predicted positive relationships between EMAP number of natives and richness and all CRAM Attributes and metrics tested (Table 2.2). We also hypothesized negative correlations between all nutrients (NH_3, NO_2^-, NO_3^-, Total N and PO_4^{-3}) and CRAM Index, Attributes, and selected metrics (percent area with buffer, average buffer width, buffer condition, hydrologic connectivity, and water source).

Table 2.2: Expected relationships (positive +, or negative -) between tested EMAP metrics, water nutrients and CRAM attributes (capitalized) and selected metrics (lowercase). Blank cells indicate no correlation was tested.

	EMAP metrics					Nutrients
CRAM Attribute CRAM metric	Percent cover of non-natives	Percent cover of invasives	Number of natives	Percent cover of non-natives along backshore	Total species richness	NH3, NO2-, NO3-, Total N and PO4-3
Buffer and Landscape Context	-	-	+	-	+	-
percent area with buffer	-	-	+	-	+	-
average buffer width	-	-	+	-	+	-
buffer condition	-	-	+	-	+	-
Hydrology	-	-	+	-	+	-
water source						-
hydrologic connectivity			+			-
hydroperiod	-	-	+		+	
Physical Structure	-	-	+	-	+	-
topographic complexity			+		+	
structural patch richness					+	
Biotic Structure	-	-	+	-	+	-
number of co-dominants			+		+	
percent invasive species	-	-		-		
Index	-	-	+	-	+	-

To test responsiveness of CRAM to discern estuary condition we also investigated relationships between all CRAM Attributes and selected metrics and Level 1 landscape measures collected from GIS analysis. Landscape-scale measures of stressors were calculated at four scales but not all landscape stressors were calculated or available at each scale. Here we predicted negative relationships between each selected measure of landscape stressor and all CRAM Attributes and selected metrics. Significant relationships in expected directions were interpreted as indicating responsiveness (Stein et al. 2009). When similar indicators of watershed stress were significantly correlated we selected the indicator most used in the literature or most available across various scales of investigation (Table 2.3).

Table 2.3: Expected relationships (all were predicted to be negative -) between CRAM attributes (capitalized) and selected metrics (lowercase) and Level 1 landscape measures of human disturbances at four different scales (the entire watershed (ws), a 2km area surrounding the assessment area (2k), constrained to within a 250m buffer of all watershed streams (wsbf,), and constrained to within a 250m buffer for all streams within 2km surrounding the assessment area (2kbf). Blank cells indicate no correlation was tested.

	Level 1 landscape measures					
CRAM **Attribute** metric	Percent impervious surfaces	Density artificial channels**	Percent dams*	Percent agriculture	Density gravel mines***	Density CWIQS**
Buffer and Landscape Context	ws,wsbf, 2k, 2kbf	ws, 2k	ws	ws,wsbf, 2k, 2kbf	ws,wsbf,	ws, 2k
stream corridor continuity	2k, 2kbf	2k				
adjacent aquatic area	2k, 2kbf	2k		2k, 2kbf		
Hydrology	ws,wsbf, 2k, 2kbf	ws, 2k	ws	ws,wsbf, 2k, 2kbf	ws,wsbf,	ws, 2k
water source	2k, 2kbf			2k, 2kbf		
Physical Structure	ws,wsbf, 2k, 2kbf	ws, 2k	ws	ws,wsbf, 2k, 2kbf	ws,wsbf,	ws, 2k
topographic complexity	ws,wsbf, 2k, 2kbf	ws, 2k	ws	ws,wsbf, 2k, 2kbf	ws,wsbf,	
structural patch richness	ws,wsbf, 2k, 2kbf	ws, 2k	ws	ws,wsbf, 2k, 2kbf	ws,wsbf,	
Biotic Structure	ws,wsbf, 2k, 2kbf	ws, 2k	ws	ws,wsbf, 2k, 2kbf	ws,wsbf,	ws, 2k
Index	ws,wsbf, 2k, 2kbf	ws, 2k	ws	ws,wsbf, 2k, 2kbf	ws,wsbf,	ws, 2k

*Only available at the watershed scale
** Only available at watershed and 2k surrounding area scales
***Only available at watershed and watershed buffered scale

To account for such a large number of correlations and to control for Type-I error, we applied the false discovery rate (fdr; Benjamini and Hochberg 1995) statistical approach and present corrected p-values relative to $\alpha = 0.05$. Applying fdr independently to independent data sets controls for false discovery while increasing the power to detect true relationships (Benjamini and Hochberg 1995).We treated each Attribute within CRAM independently and each separate Level 1 or 3 data set independently and thus corrected p-values using fdr separately for each set of CRAM Attribute / Level 3 or Level 1 investigation (i.e. botanical profiles, nutrient concentrations, and landscape stressors).

Redundancy

Following Stein et al. (2009) we evaluated *Redundancy* using a Spearman's correlation matrix of CRAM Attributes and metrics to investigate relationships between metrics, and a Principal Components Analysis (PCA). As recommended by Stein et al. (2009), we did not eliminate redundant metrics but present results to maintain transparency of the method.

Reproducibility

We investigated *reproducibility* in the field via repeated CRAM assessments of the same BBE by multiple investigators. For metrics with discrepancies among investigators we worked to increase precision and reduce user error by clarifying metric descriptions and thresholds or simplifying metric methodology. We did not analyze this a posteriori because we did not have a large enough sample of repeat site sampling to properly assess this reflection of precision to meet objectives of *Standardization,* but instead relied upon the history of CRAM validation of *Reproducibility* on other similar systems from which this method drew upon.

Results

Range and representativeness

The 32 selected sites represent a wide range of BBE condition as estimated using CRAM, indicators of watershed stress and (Level 3) water quality and vegetation data. CRAM Index scores ranged from 33 to 90 statewide and showed similar range of Index scores among regions (North 59 to 90, Central 33 to 84, South 41 to 92; Figure 2.3). As was found in previous statewide inventories of estuary and river systems using CRAM, highest and lowest index scores are rarely obtained, because CRAM is an average of 16 metric scores. Good condition wetlands often received high scores for most but not all metrics. Field assessments documented that each CRAM metric option (a-d) was reported from at least one of the visited BBEs, indicating that the method appropriately describes the full range of condition; i.e. *Range and Representativeness*. Geographically however, all three regions reported maximum Attribute scores of 100, only the Central and South regions reported minimum Attribute scores of 25.

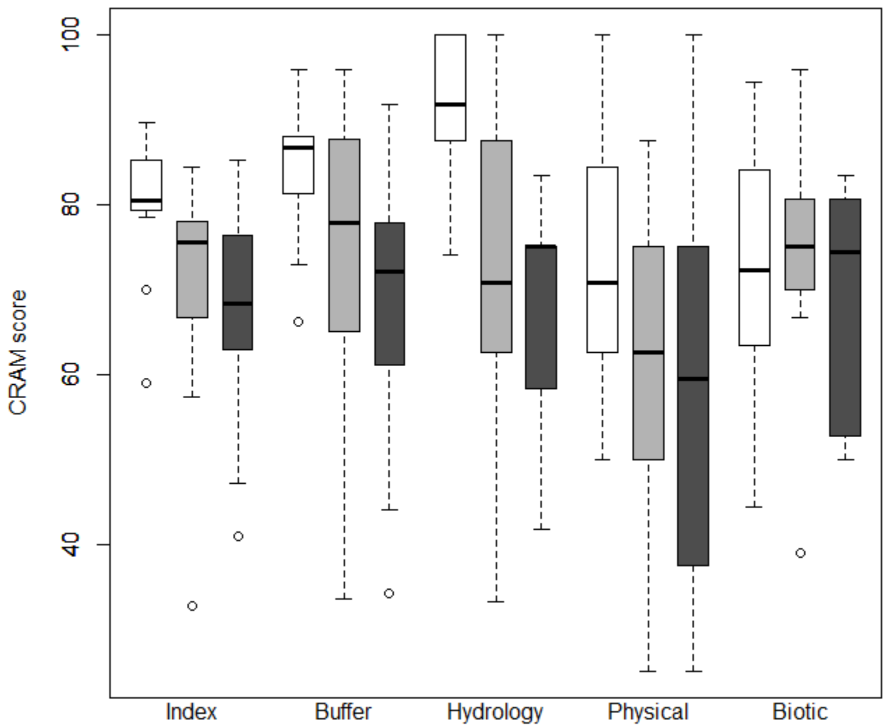


Figure 2.3: Box Plots depicting CRAM Validation Index and Attribute scores by region.

No relationship (regression p-value = 0.95) was found between date and Index score and multivariate classification analyses revealed no confounding effect of geographic region, date of assessment, mouth closure status, or state identified water quality impairments on CRAM metric, Attribute or Index score. Only the Hydrology Attribute was significantly correlated with latitude (ρ 0.42, p-value = 0.02).

Responsiveness

Numerous CRAM Attributes and selected metrics showed significant correlations as hypothesized with Level 3 measures (Table 2.2). All CRAM Attributes and the Index score were significantly correlated to EMAP plant data (i.e. number of natives) in the expected direction (Table 4, Figures 4a and 4b) and to the hydrologic connectivity ($\rho = 0.54$, $p = 0.0156$), topographic complexity ($\rho = 0.49$, $p = 0.0195$), and number of co-dominants ($\rho = 0.51$, $p = 0.0141$) CRAM metrics. The CRAM invasive plant metric was not significantly correlated to the EMAP percent invasives measure ($\rho = -0.31$, $p = 0.14$) but it was significantly correlated to EMAP percent non-natives and EMAP percent non-natives along backshore indices ($\rho = -0.50$, $p = 0.01$; and $\rho = - 0.42$, $p = 0.04$ respectively; Table 2.4). EMAP total plant species richness was significantly correlated to several physical and hydrological CRAM metrics including buffer width ($\rho = 0.55$, $p = 0.0105$) and hydroperiod ($\rho = 0.45$, $p = 0.260$).

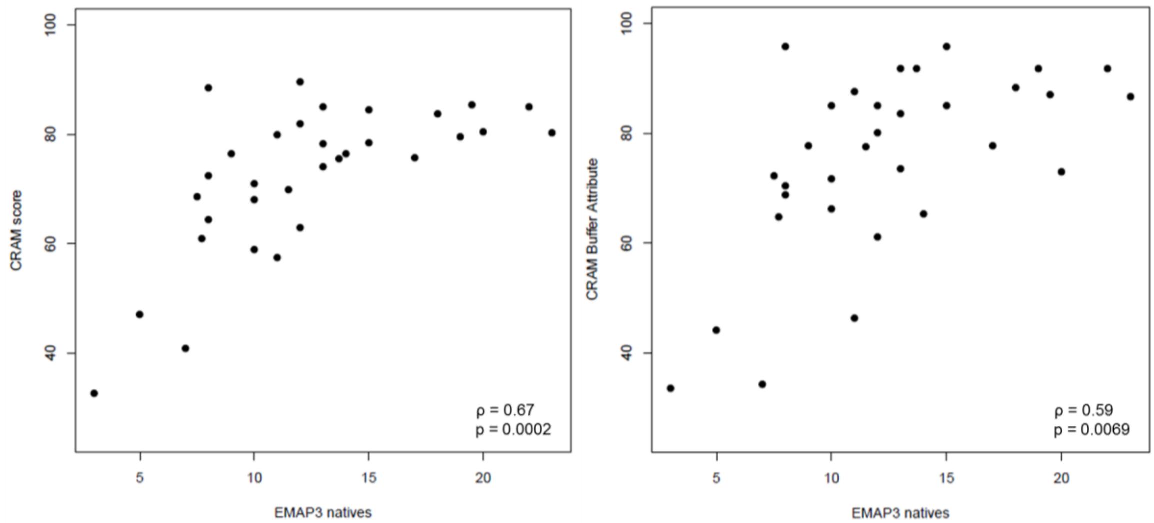


Figure 2.4: a) Significant correlation of CRAM Index score to EMAP number of natives. b) Significant correlation of CRAM Buffer and Landscape Context Attribute scores and EMAP number of natives.

Table 2.4: Spearman's rank correlation coefficients ρ, and false discovery rate corrected p-values (Benjamini & Hochberg, 1995; for α = 0.05) for correlations between CRAM and EMAP assessment metrics (total n = 49). CRAM attributes were treated as independent and thus false discovery rate corrections were made independently for each attribute / total EMAP investigation. All CRAM attributes (capitalized) and a priori selected metrics (lowercase) were tested against all EMAP metrics. The number of relevant metrics varied among attributes resulting in variation in the number of comparisons among CRAM attributes (Buffer and Landscape, n = 20; Hydrology, n = 6; Physical, n = 8; Biotic, n = 10; Index, n = 5).

CRAM	EMAP	ρ	p-value
Buffer and Landscape	Number of natives	0.59	0.0069
buffer width	Total species richness	0.55	0.0105
Hydrology	Number of natives	0.51	0.0135
Hydrology	Total species richness	0.46	0.0262
hydroperiod	Total species richness	0.45	0.0260
hydrologic connectivity	Number of natives	0.54	0.0156
Physical	Number of natives	0.53	0.0146
topographic complexity	Number of natives	0.49	0.0195
Biotic	Number of natives	0.51	0.0282
number of codominants	Number of natives	0.51	0.0141
number of invasives	Percent non-natives	-0.50	0.0117
number of invasives	Percent non-natives along backshore	-0.42	0.0397
Index	Number of natives	0.67	0.0002

Eight of the tested correlations between all nutrients (NH_3, NO_2^-, NO_3^-, and PO_4^{-3}), all CRAM Attributes, Index and selected metrics (percent area with buffer, average buffer width, buffer condition, water source, and hydrologic connectivity) were significant, and all in the expected direction (Table 2.5). The Hydrology Attribute was the only CRAM Attribute that showed significant correlations to nutrients; and was significantly related to ammonia (ρ = - 0.45, p = 0.0321), nitrite (ρ = - 0 .59, 0.0022), and nitrate (ρ = - 0.40, p = 0.0469; Table 2.5). The Hydrology Attribute was marginally significantly correlated to Phosphate (ρ = - 0.36, 0.0655). Only Hydrology metrics showed significant correlations; hydrologic connectivity was negatively related to nitrite, and water source was negatively related to all four nutrients (Table 5). Additionally, hydrologic connectivity was marginally significantly correlated to ammonia (ρ = - 0.37, p = 0.0634), and percent area with buffer was marginally significantly correlated to ammonia and nitrite (ρ = - 0.47, p = 0.0523; and ρ = - 0.49, p = 0.0681 respectively). Index was marginally significantly related to ammonia and nitrite (ρ = - 0.37, and p = 0.0729; and ρ = - 0.43, 0.0551 respectively).

Table 2.5: Spearman's rank correlation coefficients ρ, and false discovery rate corrected p-values (Benjamini & Hochberg, 1995; for α = 0.05) for correlations between CRAM results and water nutrient data (total n = 36). CRAM attributes were treated as independent and thus false discovery rate corrections were made independently for each attribute investigation. All CRAM attributes (capitalized) and a priori selected metrics (lowercase) were tested against all nutrients (NH_3, NO_2^-, NO_3^-, and PO_4^{-3}). The number of relevant metrics varied among attributes resulting in variation in the number of comparisons among CRAM attributes (Buffer and Landscape, n = 16; Hydrology, n = 8; Physical, n = 4; Biotic, n = 4; Index, n = 4).

CRAM	Nutrient	ρ	p-value
Hydrology	NH_3	-0.45	0.0321
Hydrology	NO_2^-	-0.59	0.0022
Hydrology	NO_3^-	-0.40	0.0469
hydrologic connectivity	NO_2^-	-0.43	0.0385
water source	NH_3	-0.66	0.0003
water source	NO_2^-	-0.73	0.0000
water source	NO_3^-	-0.41	0.0453
water source	PO_4^{-3}	-0.48	0.0238

Results from correlations between CRAM Index, Attributes, and selected metrics and watershed stressors quantified through Level 1 landscape measures of human disturbances revealed salient patterns at four different geographic scales. Consistently significant landscape measure correlates included Percent impervious, Percent agriculture, Density of gravel mines, and Percent dams (Table 2.6). The CRAM Index scores and the Buffer and Landscape Context and Hydrology Attribute scores each showed significant correlations with Percent Impervious Surface watershed stressors across all four scales of investigation (Table 6). Additionally, the Hydrology Attribute was significantly related to Percent agriculture, Density of gravel mines, and Percent dams (Table 2.6). CRAM metrics that evaluate stream corridor continuity, adjacent aquatic area, and water source showed significant correlations to percent impervious surface and percent agriculture occurring within a 2km radius and within a 250m wide buffer along the stream within that 2km distance upstream.

Table 2.6: Spearman's rank correlation coefficients ρ, and fdr corrected p-values (Benjamini & Hochberg, 1995; for $\alpha = 0.05$) for CRAM Attribute and metric correlations with Level-1 landscape measures of human disturbances at four different scales: the entire watershed, a 2km area surrounding the assessment area, constrained to within a 250m buffer of all watershed streams, and constrained to within a 250m buffer for all streams within 2km surrounding the assessment area. CRAM attributes were treated as independent and thus fdr corrections were made independently for each attribute / scale investigation. All attributes (Buffer and Landscape, Hydrology, Physical, Biotic, and the Index score), and a priori selected metrics were tested against a priori selected Level-1 measures. Number of correlations tested for each respective Attribute are presented below the column for each watershed. Not all Level-1 data were available at all four scales and thus the numbers of comparisons vary. (Correlations not tested are denoted by --, blank cells imply non-significant correlations).

		Watershed		2km Boundary		Watershed stream buffer		2km stream buffer	
CRAM	GIS data	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
Buffer and Landscape	Percent Impervious	-0.61	0.0015	-0.68	0.0002	-0.58	0.0014	-0.69	0.0001
stream corridor	Percent Impervious			-0.49	0.0213			-0.44	0.0214
adjacent aquatic area	Percent Impervious							-0.40	0.0295
adjacent aquatic area	Percent Agricultural			0.47	0.0218			0.44	0.0299
Hydrology	Percent Impervious	-0.63	0.0006	-0.51	0.0110	-0.61	0.0007	-0.48	0.0232
Hydrology	Percent Agriculture	-0.44	0.0356	-0.47	0.0163	-0.44	0.0174	-0.40	0.0309
Hydrology	Percent Dams*	-0.42	0.0332	--	--	--	--	--	--
Hydrology	Density of Gravel Mines**			--	--	-0.42	0.0166	--	--
water source	Percent Impervious			-0.53	0.0115			-0.45	0.0211
water source	Percent Agricultural			-0.45	0.0175				
Index	Percent Impervious	-0.58	0.0032	-0.53	0.0070	-0.55	0.0030	-0.49	0.0085
*Only tested at the watershed scale		n=6,6,16,6,6		n=9,7,10,4,4		n=3,3,9,3,3		n=5,4,6,2,2	

** Only tested at watershed and watershed buffered scales

Redundancy

Correlations between Index and Attribute scores generally had high correlation coefficients as expected (0.72-0.90) but the various Attribute scores were not significantly correlated to each other (coefficients ranging from 0.33 to 0.68, mean = 0.53). As expected, correlations among metrics within Attributes were generally high but not excessive. Previous evaluations of CRAM attribute redundancy for riverine and estuarine systems found similar correlation coefficients for metrics within a CRAM attribute (Stein et al. 2009).

Reproducibility

According to *Standardization* efforts and continual evaluation of CRAM on other wetland systems from which CRAM for bar-built estuaries was derived from, CRAM is generally *Reproducible* within ± 4 CRAM Final Attribute points, and ± 2.5 CRAM Index score points meeting the respective CRAM objective of ± 10% and ± 6% error between assessment teams (Stein et al. 2009).

Discussion

Our results document that this cost-effective method can generate valuable information on the status of bar-built estuaries throughout California and is a useful new assessment tool, able to aid regional or statewide management of these systems. Considering the historic alterations and wide range of impairments pressuring these coastal confluences, as well as the varying and conflicting management objectives posed upon these coastal drainages, a rapid assessment tool, alone or in tandem with site specific data collection techniques, will better aid their management. This validated bar-built estuary CRAM module is now available (www.cramwetlands.org) to the numerous state agencies and local jurisdictions that manage river mouth systems. CRAM provides a valuable assessment tool that accurately reflects current condition with regards to hydrology, physical complexity and plant diversity; providing a robust index of condition that can help relate field conditions with multiple management objectives. We predict that the method will also enable resource managers to better articulate the full range of hydrologic functions and ecological services these systems provide, and subsequently, more completely describe the potential implications of proposed management strategies to these services. By repeating the established method for validating rapid assessment methodologies described in Stein et al. 2009, we have provided transparency into the *calibration, standardization,* and *evaluation* of this method and it's utility to assess the condition of bar-built estuaries.

Calibration and Standardization

Best professional judgment and posteriori results of Level 1 and Level 3 environmental data of the 32 sites selected to represent a wide range of natural and anthropogenically influenced conditions ensured CRAM's capacity to asses a full range of current BBE conditions. Among the 32 sites we recorded a full range of possible scores for each of the metrics (Figure 2.2b). The range of scores for Attributes represented a complete (Physical Structure), or near complete range of possible scores (Buffer and Landscape Context: 34-96; Hydrology: 33-100; Physical Structure: 25-100; and Biotic Structure: 39-96; Figure 2.2). With the exception of Hydrology, there was a general overlap in range of both Attribute and Index scores among the three regions of the State (Figure 2.2). The discrepancy in Hydrology Attribute scores quite probably represents a real difference in the degree of management and alteration to natural hydrology between the Northern and Southern regions of the state.

There were no significant correlations between latitude and other CRAM metric or Attribute scores. The presumed natural gradient in precipitation and resulting degree of aquatic habitat would instead be reflected in the adjacent aquatic area metric within the Buffer and Landscape Context Attribute (Table 2.1) which did not show a significant correlation to precipitation data ($\rho = 0.31$, p-value = 0.09). Using correlations and multivariate analyses we found no effect of precipitation, date of survey, or whether the stream mouth was open or closed on CRAM performance. Thus, CRAM appears to independently represent the condition of bar-built estuaries throughout California, free from bias resulting from natural climatic or geographic gradients.

Redundant metrics are not necessarily superfluous, but rather provide different pathways for sites to attain both Attribute and Index scores that properly represent a wide range of ecological condition and anthropogenic stress, and thus improve the *Range and Representativeness* and *Responsiveness* of the method (Stein et al. 2009). A principal components analysis revealed that the manner in which bar-built estuary CRAM Index scores are attained from Attribute scores and how each Attribute is calculated from metric scores reflects the overall variance in wetland condition across the entire state (Stein et al. 2009) and correlates significantly with Level 3 data variables.

Evaluation

In order for a rapid assessment methodology to be trusted to provide a reliable representation of condition, the Attribute and Index scores should correlate well with established trophic and species specific assessment protocols. CRAM was found to correlate as predicted with the USEPA's Environmental Monitoring and Assessment Program (EMAP) vegetation data. Notably, the number of natives EMAP metric significantly correlated with CRAM Index and all Attribute scores (Table 2.4) and confirms the ability of CRAM to evaluate wetland condition as depicted through plant communities, as was found with previous validation efforts.

EMAP estimates of natives plants also correlated well with CRAM metrics of hydrologic connectivity and topographic complexity, reflecting the importance of unrestrained inundation of the marsh plain by rising waters and hydrologic complexity provided by bar-built estuaries to native plants.

EMAP total species richness estimates were significantly correlated with CRAM buffer width, inferring the importance of ample buffers to the maintenance of ecological function and plant diversity. CRAM number of invasives was also significantly correlated to EMAP percent non-natives, further documenting the negative effects of invasive species on these sensitive aquatic habitats. Correlations between CRAM metric, Attribute, and Index scores and salient EMAP metrics provides strong evidence that CRAM properly evaluates the botanical function of bar-built estuaries.

Water quality within these aquatic habitats is of great concern to local, state and federal regulatory agencies. It is, however, often difficult to find correlations between nutrient levels and assessed ecological function. This is particularly true for stream habitats where water quality is transient and not necessarily related to adjacent land use. While bar-built estuaries are part of stream ecosystems, they exist at the lowest portion of a drainage basin resulting in containment of upstream discharge within still ponded lagoons. These unique aspects of bar-built estuaries justify the number of significant correlations between nutrients and CRAM scores. Not surprisingly, all of the significant correlations were between nutrients and the Hydrology Attribute and hydrology metrics. For example, each nutrient tested was significantly correlated to the CRAM water source metric (Table 2.5). This reflects the importance of anthropogenic alteration to water inputs of upstream drainages within 2km of bar-built estuaries. Impacts include reductions in flows, limiting dilution and export of nutrients, and increased pollution from urbanized non-point source pollution (e.g. storm drains). NO_2^- and NH_3 were the most strongly correlated nutrient constituents with the Hydrology Attribute and water source metric scores (Table 2.5). This implies that non-point sources such as runoff and animal waste led to quantifiable impacts to bar-built estuary habitats. Furthermore, NO_2^- was significantly correlated to the hydrologic connectivity metric likely signaling the importance of the ability of bar-built estuaries to flood the marsh plain and enable the microbial reduction of nutrients (Poe et al. 2003). Results are consistent with the literature regarding the ability of wetlands to filter nutrients (Garcia-Lledoa 2011, Beutel et al. 2009), and the importance of hydrologic connectivity to facilitate this filtration.

Increases in technology allow remote sensing of stressors to provide reliable and updatable data (Roth et al. 1996; Brown and Vivas 2005; Falcone et al. 2010) and are therefore valuable resources to validate field based assessment methodologies (Fennessy et al. 2007; Stein et al. 2009). As with the other analyses of this project, we correlated each GIS measured stressor to all four CRAM Attributes, however, only the Buffer and Landscape Context and the Hydrology Attributes showed any significant correlations to landscape stressors. This is a particularly salient result. While any local habitat quality (as measured by metrics within Physical Structure and Biotic Structure) may be affected by landscape processes the Buffer and Landscape Context, and Hydrology Attributes explicitly aim to assess landscape scale impacts (Table 2.1).

Percent impervious surface was the only landscape scale measure of stress that correlated to the CRAM Index score and all significant CRAM metric and Attribute scores (Table 2.6). It is widely agreed upon that percent impervious surface provides a reliable single GIS measure of stress on the environment (Brown and Vivas 2005). Thus, this work supports the assumption that the single Index score of habitat condition provided by CRAM showed highly significant correlations to this GIS based measure across all four scales investigated. It is also notable that CRAM metrics correlated with GIS based measures of stressors at the 2k and 2km stream buffer scales for which they focus, whereas Attributes were significantly correlated at all four scales including the entire watershed. These finding support the goal of CRAM method development that metrics assess specific indicators of condition and function whereas Attributes, through averaging multiple indicators assess broader measures of impact across broader scales is being attained.

The specific relationships between CRAM and GIS-based measures and the scale to which they were significant demonstrate that CRAM metrics and Attributes are able to discern site specific indicators of reduced condition that correspond well with watershed scale stress. Specifically, strong correlations to both Percent Agriculture and Percent Impervious surface metrics confirm that the Hydrology Attribute effectively assesses the degree of anthropogenic influence on the condition of bar-built estuaries. The density of gravel mines and percent dams within a watershed were significantly correlated to the Hydrology Attribute. The Buffer and Landscape Context Attribute, which also assess landscape scale stressors, was significantly correlated to Percent Impervious Surface across all four of the scales investigated (Table 2.6). Stream corridor continuity and adjacent aquatic area metrics showed significant correlations to GIS-based measures of stress (Table 2.6), implying efficacy of the metrics to measure degradation of condition due to hard structure (impervious) and interruptions to stream riparian and buffer habitats within 500m.

Measure of ecological function and habitat alteration are important to any habitat assessment, and thus the specific correlations between the adjacent aquatic area metric and GIS interpretations suggest that CRAM can integrate the ecological benefits provided by adjacent aquatic habitat and the potential for loss of connectivity and wetland habitats. The negative correlation to percent impervious surface supports the metric's ability to respond to the loss of habitat, connectivity and ecological function associated with increases in impervious surfaces and helps to quantify impacts of urban and industrial expansion in removing and altering wetland habitats, including bar-built estuaries.

Conversion of wetland habitat to anthropogenic uses leading to significant wetland habitat loss is well documented (Dahl 1990; Zedler 1996) . As a result, the unpredicted positive correlation between CRAM's adjacent aquatic area and percent agriculture at both 2 km scales was a surprise. However this result may be due to the fact that BBEs in confined river valleys have less potential to contain wide marsh plain features in the immediate adjacent area and often do not have room for agricultural land use, while BBEs located in broad valleys are more likely to harbor large floodplains with aquatic features. These broad floodplains are often converted to agriculture as well. Therefore, we found a correlation between increased % agriculture within 2 km of the BBE and the amount of adjacent aquatic area. However, the fact that percent impervious surfaces (which strongly co-varied with percent urban, and density of roads) was negatively correlated with the aquatic connectivity metric implies a measurable impact of anthropogenic degradation on bar-built estuary condition using the CRAM adjacent aquatic area metric. Further, percent agriculture could be regressed against other Level 3 measures of impact to investigate the relationship between percent adjacent agriculture and other measures of condition for bar-built estuaries.

3. Historical Assessment of BBE Change

According to the often cited US Fish and Wildlife Study (Dahl 1990), 91% of California's wetlands were lost between the 1780's and 1980's. Wetlands continue to be lost, and a recent report on the status and trends of wetlands showed a reduction in net wetland acreage on the Pacific Coast of 5220 acres between 2004 and 2009 (Dahl and Steadman 2013). While this bleak assessment is valuable on the whole, it does not specify whether this loss is evenly distributed among all wetland types, or if some types have lost more than others. As part of this project, CCWG decided to investigate whether the wetland loss for BBEs has been that high or whether coastal BBEs have been spared. Part of what is special about these systems is that within a BBE there are multiple habitat types that each provides unique beneficial services. Not only did we want to know the total wetland loss, but also the habitat conversion within the wetland. We did this by developing a methodology that can be used throughout the State to assess the entire suite of BBEs, and then implemented the methodology on 30 sites. Our goal is to be able to answer the following questions:

- What loss (entire wetland and habitat specific) has been estimated for each region of the state? Have there been any overall increases in habitat?
- What are key causes of loss (filling, diking, urbanization etc.)?
- What are key watershed impacts on lagoons by region?
- What, if anything, does this tell us about how systems should be managed on an individual or regional level?

We started with the 19th century T-sheets, which were brought into ArcGIS, and rectified when necessary. Current imagery came from the 2012 NAIP maps. At each site, a polygon shapefile was drawn to encompass what we determined was the maximum extent of the specific lagoon for both the current and historical condition. Inland extent was determined considering several factors including: 10 foot elevation, narrowing of channel, change in vegetation type, and in some cases, extent of T-sheet (especially larger systems). Lateral extent was determined by looking at topographic indicators and the presence of surface waters that are physically/hydrologically connected to the channel. The polygon was copied with one version named "current" and one "historic."

Using the "cut polygon features" tool, the polygons were cut by tracing habitat boundaries for both the current and historic maps until each specific habitat zone had been separated (Figure 3.1). One of the biggest challenges was to craft the labeling system that would best characterize these systems and encompass the value of all the habitats, without overloading the attribute table with too much information. We also wanted to ensure confident and consistent habitat identification, with the understanding that the T-sheets were made by different people with different expertise over several decades. Each individual habitat type was classified and the area was calculated in ArcGIS.

The classification was broken down into four levels (see Table 3.1 and Figure 3.2). Level 1 partitions wetland from not wetland. We did not map anything that was "not-wetland" in both the current and historic settings, but there were many instances where a site was historically wetland but currently not. Level 2 is the highest level of accuracy we felt we could offer in classifying the actual habitats. It provides the general information necessary for a comparison. Level 3 is more descriptive but has higher potential for error based on the quality of the t-sheets, the detail included in the drawing of the sites, the ability of the non-biologist mapper to classify what he saw, and our ability to interpret everything (including current condition). Level 4 categorizes sites that had been hydrologically connected but are now isolated and therefore are still "wetland" but not "lagoon". A separate document is being prepared with a complete description of the GIS methods used. See Table 3.1 for definitions of the terms in Figure 3.2.

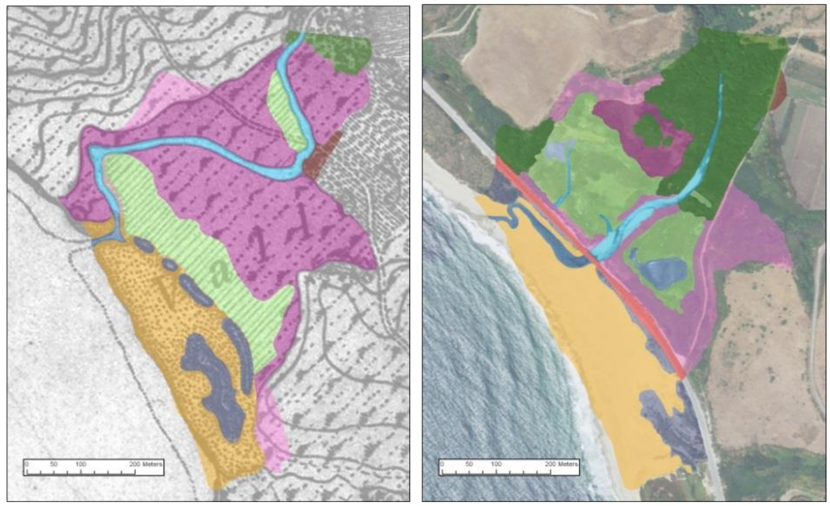


Figure 3.4: Scott Creek with habitats showing coloring for Level 3 analysis.

Table 3.1: CCWG BBE habitat classification system

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Wetland (W): Regularly or occasionally wet, or with a high water table that supports wetland vegetation. Depending on the salinity gradient these systems would be classified by **NWI** as Riverine, Estuarine or Palustrine.	**Beach/Berm/Inlet (B):** Sandy shoreline between the lagoon mouth and the ocean. At times, the lagoon can pond on this shoreline creating a distinct habitat type. **NWI:** Unconsolidated Shore (US), typically Sand (2).	**Beach (Be):** Non-vegetated, exposed sand.	
		Beach Channel/Inlet (I): Area of the beach that contains open water communication between ocean and lagoon. **NWI:** Marine (M) Intertidal (2)	**Hydrologically Connected (HC):** or **Hydrologically Isolated (HI):** Project specific descriptor for whether existing wetlands are still hydrologically connected to the lagoon, or whether they have been isolated by management actions.
	Wetable Lowland: Low lying land that is potentially inundated by lagoon dynamics. **NWI:** see our Level 3	**Periodically Inundated (P):** Surface water only present during situations with especially high freshwater flows, high tides, or unusually high inundation. Vegetation likely to be a mix of hydrophilic and upland vegetation. **NWI:** Scrub Shrub (SS) or occasionally Emergent (EM) with modifier Intermittently Flooded (J). *Note: Historical T-sheet sites that do not define the habitat type but are topographically low lying are put in this category by default.	
		Mash Plain (M): ground that is regularly, seasonally, or intermittently wetted with either surface water or saturated soils. Supports wetland species of plants. **NWI:** Emergent (EM) with possible modifiers Temporarily Flooded (A), Saturated (B), Seasonally Flooded/Saturated (C/E), Regularly Flooded (N)	
		Flats (F): Non-vegetated sand or gravel flats, not including the beach or channel area that are maintained in this state by episodic flows. **NWI:** Unconsolidated Shore (US) which could be Cobble-Gravel (1), Sand (2),	
	Open Water (O): Areas experiencing standing or flowing water that are not vegetated. The extent and elevation of actual water may vary within or among days (tidally), seasonally (seasonal tides and stormflows), and interannually. **NWI:** see our Level 3	**Channel: (C)** unvegetated areas of water conveyance. **NWI:** Riverine or Estuarine (R or E) Tidal (1)	
		Pond (P): Off-channel areas of still water. **NWI:** Lacustrine (L), Estuarine (E) Intertidal (2) Unconsolidated Shore (US), or Palustrine (P) Unconsolidated Bottom (UB)	
		Bars (Ba): Non-vegetated sand or gravel flats, not including the beach, within the greater channel area, that are maintained in this state by episodic flows. **NWI:** Unconsolidated Shore (US) which could be Cobble-Gravel (1), Sand (2),	
	Altered, Developed or Disturbed (D): Areas that show signs of human disturbance, but inundation is at least partially maintained. NWI: depending upon the level of disturbance **NWI** may not classify these as wetland.		
	Vegetated Woody (VWo): Vegetated land covered by trees and shrubs that are typically hydrophilic such as willows. **NWI:** Forested (FO)		
Non-Wetland (NW): generally upland or developed land with either impervious or well drained soils, is thereby only wet from storm events, and dries relatively quickly. **NWI** does not subcategorize these; they are typically defined as "Upland."	**Developed (D):** Highly impacted by people, often with hardened or compressed surfaces, and thus the area does not fit the Level 1 definition of "Wetland." It may or may not have been Wetland prior to disturbance.	**Transportation Corridor (TC):** Paved and dirt roads, railroad tracks and heavily trafficked paths.	**Not-Applicable (NA):** The issue of hydrologic connectivity is not applicable in non-wetland settings
		Agriculture (A): farmed agricultural land including grapes, row crops, grains and orchards	
		Grazing (G): Land used for grazing, including cows, sheep and horses.	
		Urban (Ur): developed land with a high percentage of impervious surface including residential, commercial and industrial uses.	
		Parking Lot (PL): Land adjacent to the site that is used solely for parking.	
		Other (Ot): Non-wetland land that doesn't fit into other categories. NOTE: this could include fallow ag land that is disced, undeveloped bare ground.	
	Undeveloped (UD): Non-wetland that is allowed to remain in a natural or semi-natural state.	**Vegetated Upland (VUp):** Upland land that is typically vegetated with non-wetland species	
		Dune (Du): Sand dunes, could be vegetated or bare.	

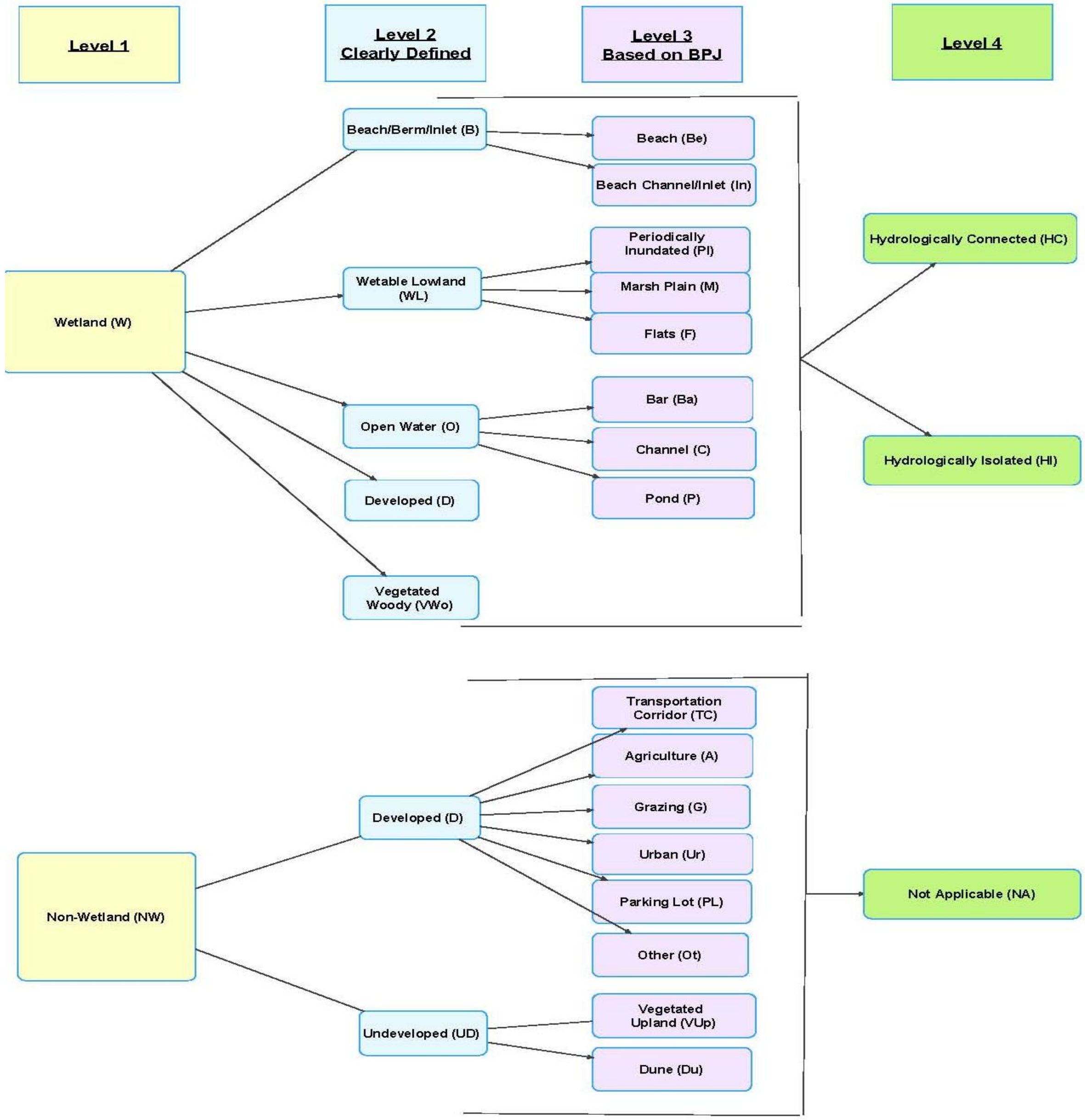


Figure 3.5: Flowchart showing levels of attributes

Once the classification of each of the 30 validation sites (two less than the original set of validation sites because Pudding Creek and Redwood Creek were omitted due to problems with the T-sheets) was complete for both the current and historic condition, we copied the attribute tables into one large Excel spreadsheet and then uploaded it to R for analysis. We calculated absolute and percent change of habitat for Level 1 and Level 2 for each site individually, for each region of the State, and for the State as a whole. Below is a summary of some of the main results.

Statewide Assessment

Overall California's wetlands have seen a loss of 25% of BBE habitat from the T-sheets (ranging from the 1850s-1890s) to the present day for the sites we studied (Figure 3.3). This alone is valuable because it shows that these habitats have been impacted to the point that there is an overall significant reduction in wetland habitat for the State. However, on its own this information does not provide enough detail to determine priorities for management actions.

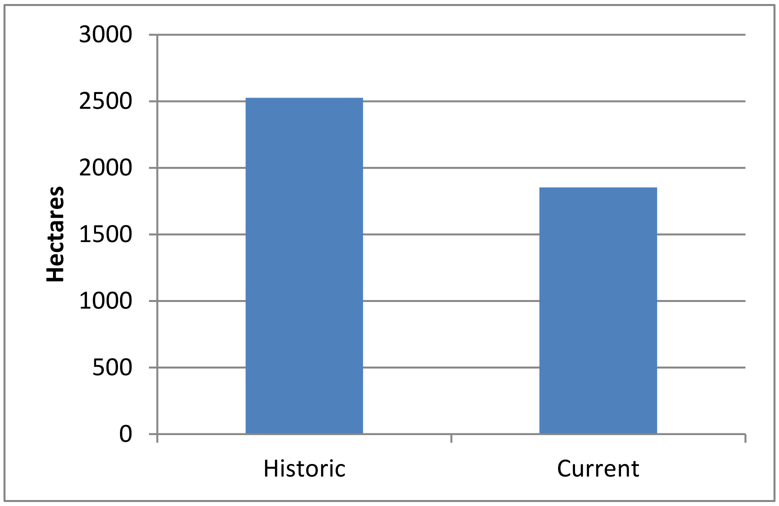
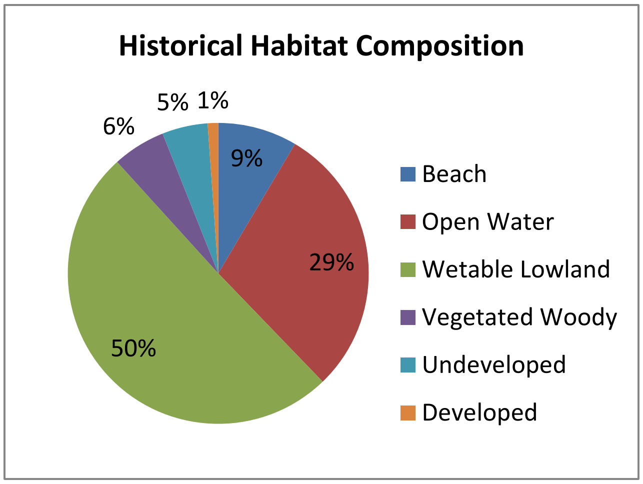


Figure 3.6: Statewide wetland habitat change

We get a clearer picture of the wetland loss shown above, as well as an understanding about which habitats have been the most vulnerable, when the data are analyzed by Level 2 Habitat type (Figure 3.4). From these two graphs it is clear that the most vulnerable habitat is wetable lowland – marsh and periodically inundated landscapes that provide some of the habitats and functions that make lagoons such a vital wetland type. We also see that open water, including both channels and ponds, has been reduced. The total reduction of wetland habitat for these two types is 30%. This is greater than the overall reduction in wetland habitat we see for the State. This is possible because not all natural habitats are being reduced - undeveloped upland and beach have stayed relatively the same and vegetated woody habitats have actually increased. The biggest change is a drastic increase in developed non-wetland. This encompasses all anthropogenic land uses including transportation corridor, urban development, parking lots and agriculture. In the 19th Century these landuses were only 1% of the studied BBEs, but now they are 27% of the BBE area. Level 3 landscape analyses has not been conducted yet, but will highlight which major categories of development are the primary drivers behind this increase in developed non-wetland land use.



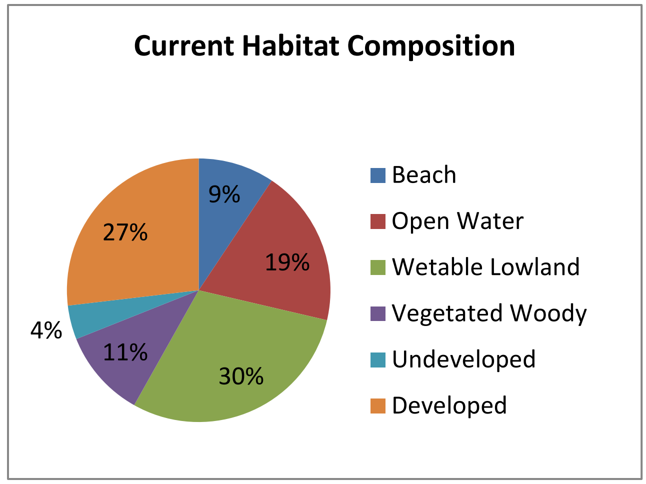


Figure 3.4: Statewide change in habitat area

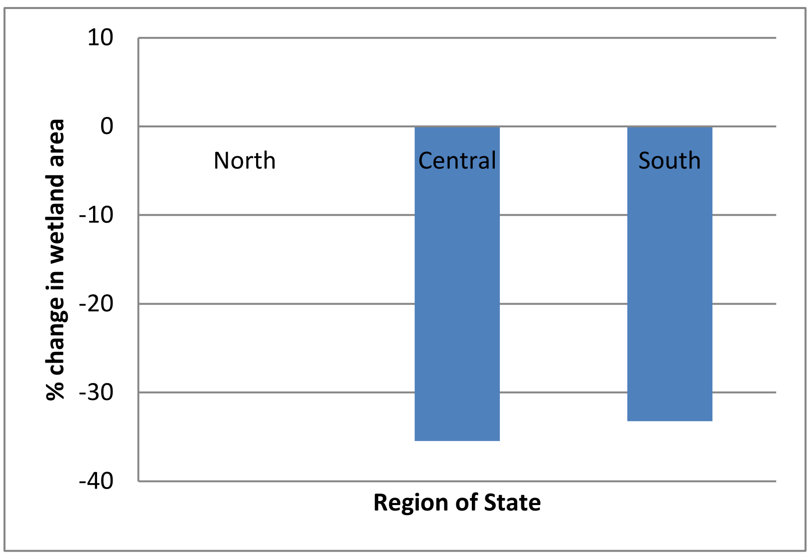


Figure 3.7: Regional change in wetland area

Regional Assessment

Viewing habitat loss on a statewide level is extremely important for determining future policy, but is less helpful in determining what actions each region should take and how to prioritize them. In order to help regional managers compare their region to the others in California, and to help them view their local sites as a suite of systems working together to provide services, we looked at the results regionally. The State was broken into 3 regions: North, Central and South. Nine sites were studied on the North, eleven on the Central and ten on the South Coast. Total wetland area was calculated for each of these regions for both current and historic analysis, as was done for the entire state. The results are shown in Figure 3.5. Both Central and Southern California sites have lost around one third of their BBE wetland habitat, while Northern California remains almost unchanged.

Like the Statewide analysis, we get a different picture when we look at the breakdown by Level 2 analysis (Figure 3.6). We see that although the wetland loss along the North Coast has been minimal, habitat conversion has still been prevalent, particularly with a shift from open water habitat to vegetated woody. As expected, the Central and South Coasts show trends similar to the whole State including loss of open water and wetable lowland, and increase in developed non-wetland. This could lead land managers on the North Coast to decide to invest in habitat conservation efforts, whereas, when appropriate, managers on the Central and South Coasts may decide it is worth investing funding in the restoration of open water and wetable lowland habitat instead. We were initially surprised that the Central Coast showed a higher proportion of developed land than the South Coast. However, this is due to the specific sites selected in this study which include several reference sites with relatively high condition in Southern California. We anticipate that as we add additional sites, we will see an increase in the developed non-wetland category for the South Coast.

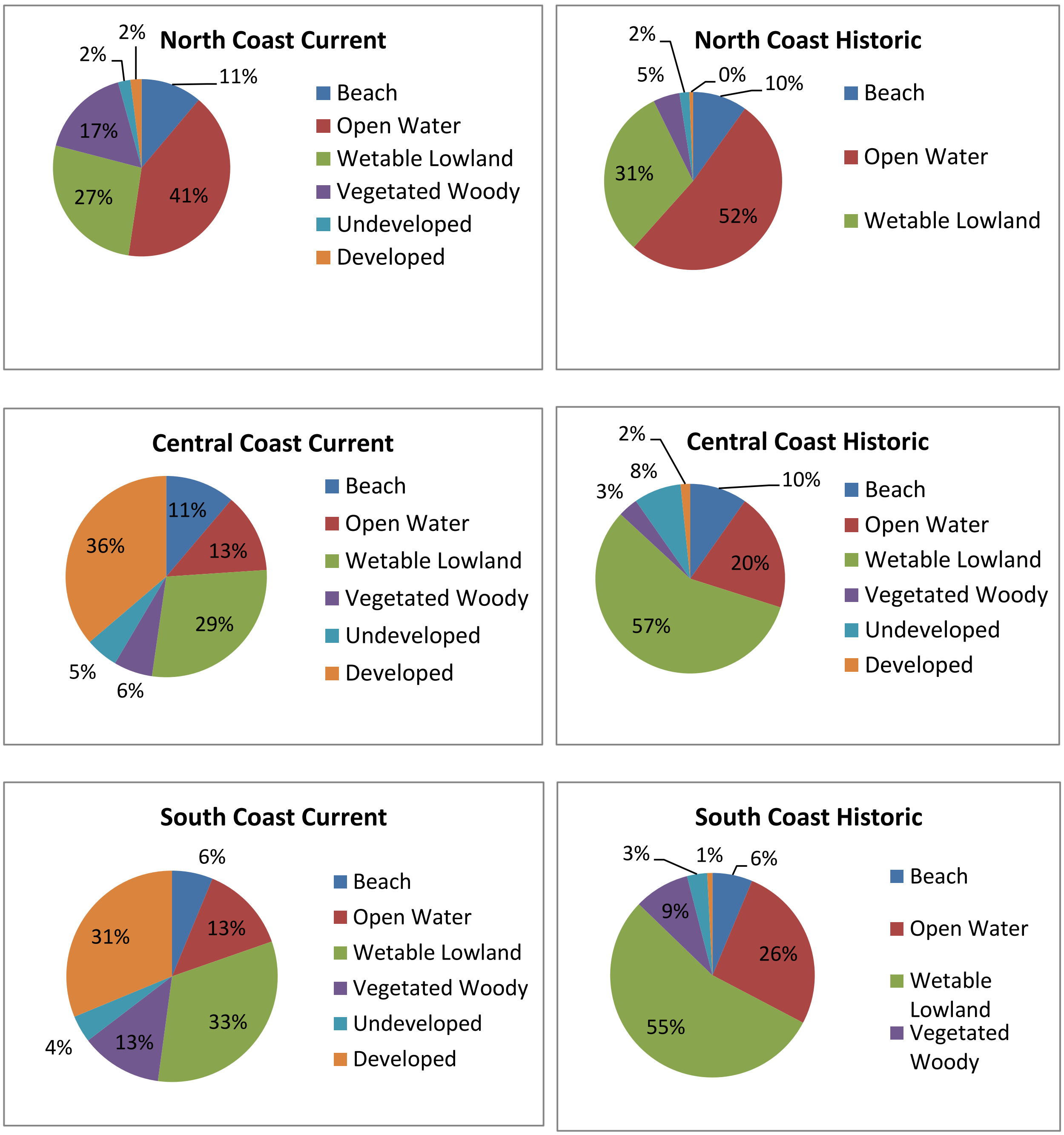


Figure 3.8: Habitat change by region

Site Specific Assessment

Even within a region, the trends we see at the regional level are not always consistent with each individual site. For example, Scott Creek and Soquel Creek (Figure 3.7) are less than 20 miles from each other on the Central Coast. Their historical habitat breakdowns are similar; however they have both been altered in the subsequent century. Scott Creek still has a lot of intact marsh habitat, though with a different breakdown of habitat types than it did in the past. Soquel has been altered for flood control and urban development in the floodplain, although the remaining remnant still provides important habitat for migrating steelhead. Scott Creek provides a broader suite of functions due to the access to the floodplain and lack of development. For a manager with only a few sites, or even just one, the individual site breakdown is the most important.

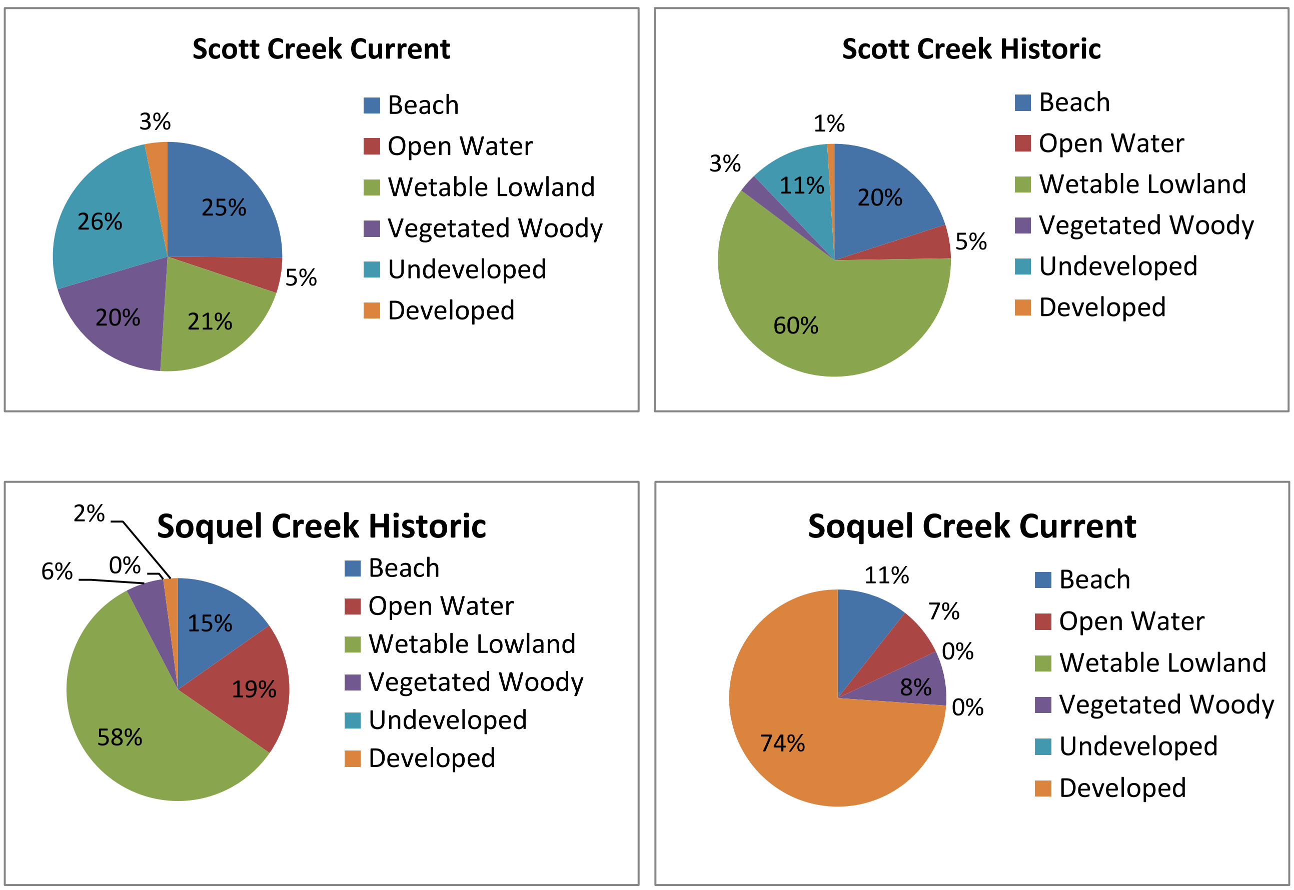


Figure 3.9: Habitat change by site, two examples from the Central Coast.

Conclusion

While some useful data has come out of this process, one of the most valuable outcomes is the development of the method as a foundation for continuing this work for the suite of BBEs in the State. The next step will be to add more sites to the analysis to get a broader understanding of these systems. CCWG also intends to do additional multivariate analyses to investigate which wetland habitats (e.g. periodically inundated, marsh plain, or flats) or classifications of development (e.g. parking lot, urban, agriculture, grazing, etc.) influence any groupings we see in BBEs.

4. Bar Built Estuary Condition Assessment

Sample description

To evaluate the utility of the CRAM assessment tool and to investigate the current condition of Bar Build Estuaries along California's 1100 mile coastline, we completed a field data collection exercise that assessed the condition of 32 sites along the California Coast (Figure 4.1). Sites were selected that represented a wide range of conditions for each of the three regions of the coast (North, Central and Southern). We selected sites of varying condition and that were situated in a variety of landscape contexts (natural and human environments). Sites were selected using input from local experts that included systems in urban and rural settings, systems of good, fair and poor condition and systems that ranged in size from small drainages to some of the largest watersheds along the coast. All systems were assured to meet the definition of a Bar-Built Estuary prior to their inclusion on the draft list of sites. Several systems were later removed from the sample frame because field visits led to reclassifying the confluence as coastal creek mouths rather than functioning BBEs (they did not form season beach bars that close the systems to tidal influence).

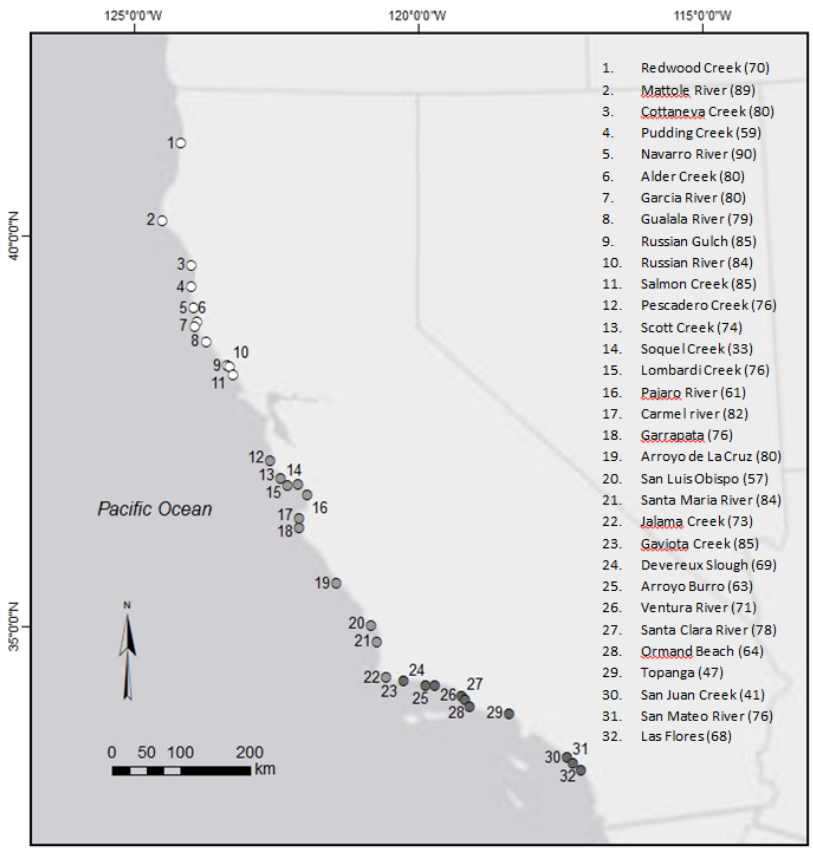


Figure 4.1: Map of 32 BBEs assessed with associated CRAM Index score

The bar-built estuaries surveyed for this project are owned and managed by a variety of different entities (Table 4.1). Because these systems are quite frequently associated with public beaches, 19 of the 32 sites visited are managed by State Parks. Six of the BBE systems are managed by cities and counties, 4 systems are managed by federal entities (National Parks, military bases and Bureau of Land Management), one system is managed by the University of California and two are in private ownership. One of the BBEs beach bar was managed to increase and decrease the amount of time the system is open to the ocean.

The marsh habitats of the 32 BBEs supported a wide range of native plant species ranging from 3-23 different species found within survey transects. Of the 32 lagoons surveyed, all but one of the systems (Gaviota Creek) were reported to support one or multiple special status species (Cojo, Steelhead, Tidewater Goby) (California Natural Diversity Data Base and local reports and knowledge). Nineteen of the BBEs supported off channel marsh habitat that provides a number of special and unique ecological services (see Chapter 1).

Changes in wetland area were often caused by “reclamation” for agriculture, grazing and urban use. Such landuse changes have led to a loss in BBE wetland area of up to 75%. The Percent loss of Wetable Lowlands were often much greater with three of the BBE having all Wetable Lowlands (marsh plain) lost (Table 4.1). Field Surveys included evaluation of adjacent land use impacts through completion of a CRAM Stressor Checklist. Sites were noted to be impacted by zero to 18 unique anthropogenic stressors.

Many coastal confluence mouths are managed by local entities, but many of these management efforts lead to a type change (i.e. perennially open) and were therefore no longer appropriate for this assessment. Because many of these systems are located in urban areas, more than half of the systems have been modified artificially constrained from meandering or flooding (14 systems) or have mouth constrictions (8 systems) limiting the amount of lateral movement of the beach mouth. In addition to structural modifications to the mouth of these systems, a number of sites were reported to be artificially breached periodically (through sand excavation) to protect adjacent structures and land uses and to manage water quality concerns (Figure 4.2). However, six of the 13 sites assessed for water elevation and temperature were found to have significant marsh plain inundation during the spring to fall non-rain and storm seasons (Table 4.2).

Figure 4.2: Active beach berm management at Carmel River mouth

Table 4.1: Habitat and Management data for 32 selected sites

Site Name	Index	Ownership	Numer of Native Plant Species	T&E Fish Species	off-channel/backwater habitat	Percent Change of Wetland Acreage	Percent Change of Wetable Lowlands
Redwood Creek	69.9	State/Federal	12	3	yes	NA	NA
Mattole River	88.5	BLM	8	2	yes	0.0	-74.7
Cottaneva Creek	79.9	Private	11	2	no	0.0	NA
Pudding Creek	58.9	State	10	2	yes	NA	NA
Navarro River	89.6	State	12	2	yes	20.1	22.7
Alder Creek	80.3	State	20	2	no	3.9	554.4
Garcia River	80.4	BLM	23	1	yes	9.3	-31.6
Gualala River	78.5	County	15	1	yes	7.1	-17.6
Russian Gulch	85.1	State	22	1	no	0.0	-94.1
Russian River	83.7	State	18	2	no	-4.9	9.7
Salmon Creek	85.3	State	20	2	yes	-9.6	2.9
Pescadero Marsh	75.5	State	14	3	yes	-5.4	4.4
Scott Creek	74	State	13	1	yes	-19.9	-65.5
Lombardi	76.4	City	14	2	no	-48.7	-92.1
Soquel Creek	32.7	State	3	3	yes	-73.3	-100.0
Pajaro River	60.9	State	8	1	yes	-60.9	-75.9
Carmel River	82	State	12	1	yes	-5.4	253.4
Garrapata	75.7	Private	17	1	no	8.9	-21.2
Arroyo de la Cruz	79.5	State	19	1	yes	-7.5	NA
San Luis Obispo Creek	57.4	State	11	1	no	-64.2	-97.7
Santa Maria River	84.4	County	15	1	yes	18.1	6.8
Jalama Creek	72.5	County	8	2	no	-14.2	-46.7
Gaviota Creek	85.1	State	13	0	no	-40.3	-70.0
Deverough Slough	68.6	University California	7.5	1	yes	-47.6	1503.1
Arroyo Burro Creek	62.9	County	12	2	no	-34.4	-96.3
Ventura River	71	State	10	2	yes	-54.1	-49.5
Santa Clara	78.2	State	13	1	yes	-38.8	-47.8
Ormand Beach	64.4	City	8	1	yes	-10.9	-21.9
Topanga	47.1	State	5	1	no	-50.9	-100.0
San Juan Creek	40.9	State	7	2	no	-77.1	-100.0
San Mateo	76.4	State	9	1	yes	-35.5	-93.8
Las Flores Creek	68.1	Military	10	1	no	-1.3	-37.6

Table 4.2: Land use and stressor data for 32 selected sites

Site Name	Index	Adjacent land use	Percent Impervious (2km radius from mouth)	Percent Ag (2km radius from mouth)	Artificially Constrained	Mouth Constriction	Total Number of CRAM Stressors	Innundation Periodicity Index
Redwood Creek	69.9	Grazing	8.6	25.4	Yes		8	
Mattole River	88.5	Open Space	1.0	0.0			3	3.0
Cottaneva Creek	79.9	Open Space	7.0	0.0			3	
Pudding Creek	58.9	Urban	72.4	0.0			6	
Navarro River	89.6	Open Space	17.8	0.0			4	
Alder Creek	80.3	Grazing	13.1	0.0			5	2.0
Garcia River	80.4	Open Space	4.2	15.4	Yes		5	
Gualala River	78.5	Urban	21.3	0.0			4	3.0
Russian Gulch	85.1	Open Space	9.6	0.0			0	
Russian River	83.7	Mixed	8.0	0.0		Yes	0	
Salmon Creek	85.3	Urban	8.1	0.0			5	3.0
Pescadero Marsh	75.5	Open Space	3.6	15.6	Yes	Yes	8	
Scott Creek	74	Open Space	3.4	2.2	Yes	Yes	6	
Lombardi	76.4	Agriculture	11.0	16.8			16	2.0
Soquel Creek	32.7	Urban	97.9	0.0	Yes	Yes	17	0.0
Pajaro River	60.9	Agriculture	15.0	69.2	Yes		19	2.0
Carmel River	82	Urban	57.7	4.8			14	3.0
Garrapata	75.7	Open Space	5.3	0.0			4	
Arroyo de la Cruz	79.5	Open Space	8.0	2.7			0	2.0
San Luis Obispo Creek	57.4	Urban	21.2	5.7	Yes		12	0.0
Santa Maria River	84.4	Mixed	3.5	3.7	Yes		11	
Jalama Creek	72.5	Parking	5.2	0.0			8	3.0
Gaviota Creek	85.1	Parking	11.5	0.0	Yes		7	3.0
Deverough Slough	68.6	Urban	48.9	0.0			15	
Arroyo Burro Creek	62.9	Urban	52.2	0.0	Yes		11	
Ventura River	71	Mixed	55.6	6.0	Yes	Yes	15	
Santa Clara	78.2	Mixed	7.8	42.4			12	
Ormand Beach	64.4	Mixed	64.0	26.7	Yes		17	
Topanga	47.1	Parking	16.6	0.0	Yes	Yes	9	0.0
San Juan Creek	40.9	Urban	92.5	0.0	Yes	Yes	18	
San Mateo	76.4	Open Space	44.6	30.6		Yes	0	
Las Flores Creek	68.1	Open Space	25.1	0.0			10	

Condition Assessment Results

CRAM Scores ranged from a low of 33 to a High of 90 points for the 32 sites throughout California, with a median score of 76 (Figure 4.3). This score distribution does not reflect ambient condition of California systems but rather reflects the range of obtainable scores. No sites were found to have a CRAM index score higher than 90, indicating that none of the selected sites possesses optimal indicators for every metric. Among the 32 sites, at least one site was reported be of each of the four alternate condition categories for each of the 16 CRAM Metrics, suggesting that CRAM adequately represented the full range of condition for each Metric condition categories.

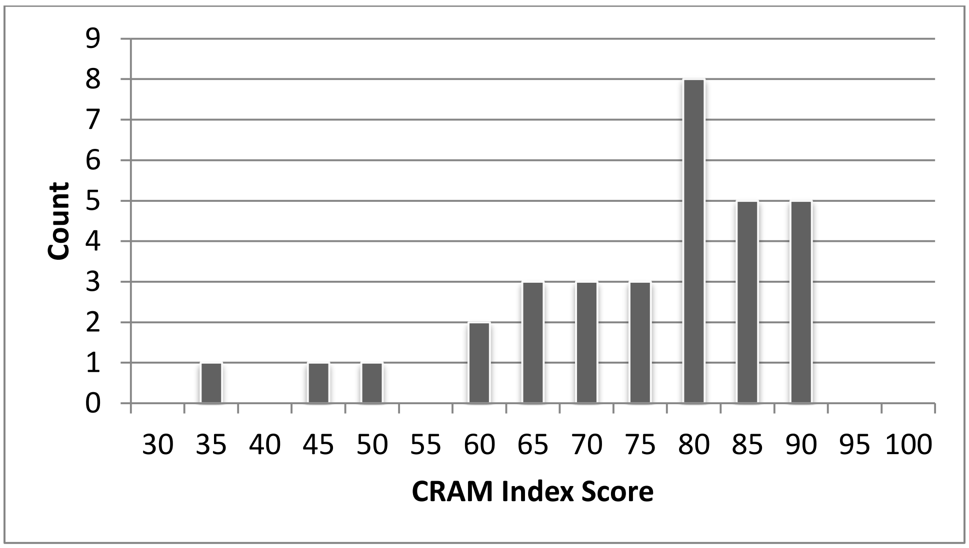


Figure 4.3: Histogram of CRAM index scores for all 32 sites

Range of Scores by Region

The range of scores within each geographic region varied with the North Coast having the highest index score of 90 within California. Central California had the lowest CRAM Index Score of 33 (Figure 4.4).

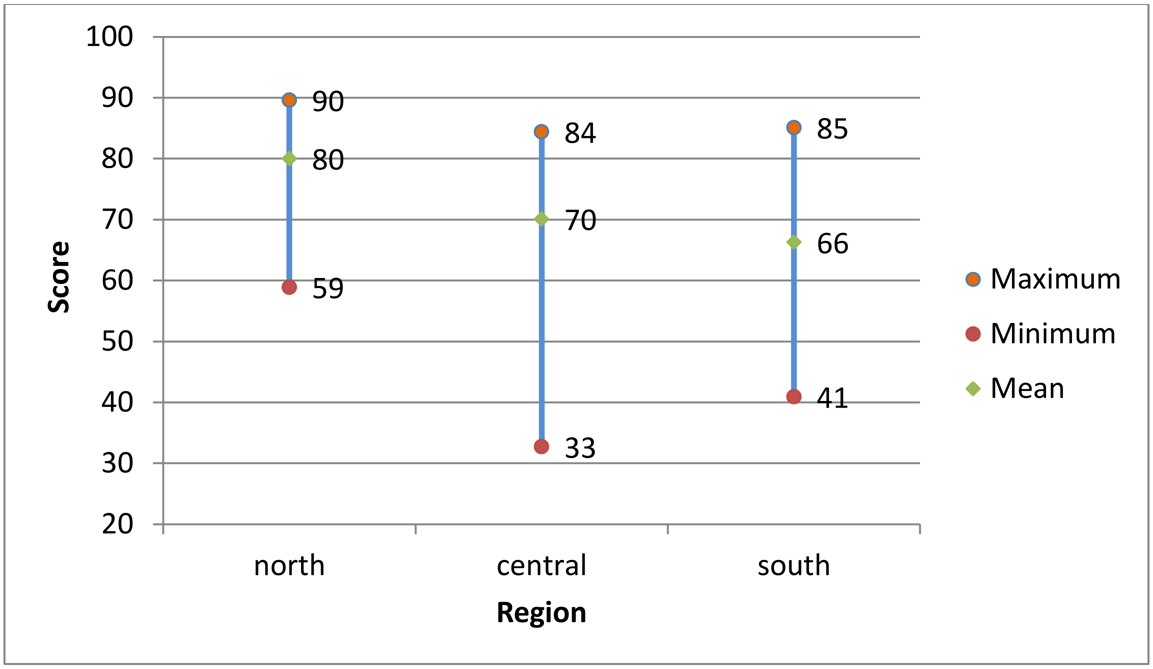


Figure 4.4: Maximum, minimum, and mean CRAM Index Scores by region

Sites were originally selected to reflect good, fair and poor condition (aka Best Professional Judgment, BPJ). Sites on the North Coast selected to represent poor condition BBEs scored much higher than low condition sites within Central and Southern California. While sites that were suggested to be of good and poor condition by local experts reflected a distinct difference in condition using CRAM, medium/fair condition sites spanned a large portion of both Good and Poor condition sites (Figure 4.5). This suggests that while local and regional experts can characterize high and low condition estuaries (with a wide variance), estimating the condition of less than optimal and greater than minimal condition sites becomes difficult and practitioners ability to estimate condition cannot be done effectively for over a third of the systems. Local experts, however, classified systems of “medium” condition that in retrospect spanned a wide portion of the entire range of conditions of BBE. This finding supports an initial observation that the condition of many BBE systems are often characterized by resource managers based on focused set of specific indicators of health rather than the more comprehensive evaluation of condition achieved through use of the CRAM tool.

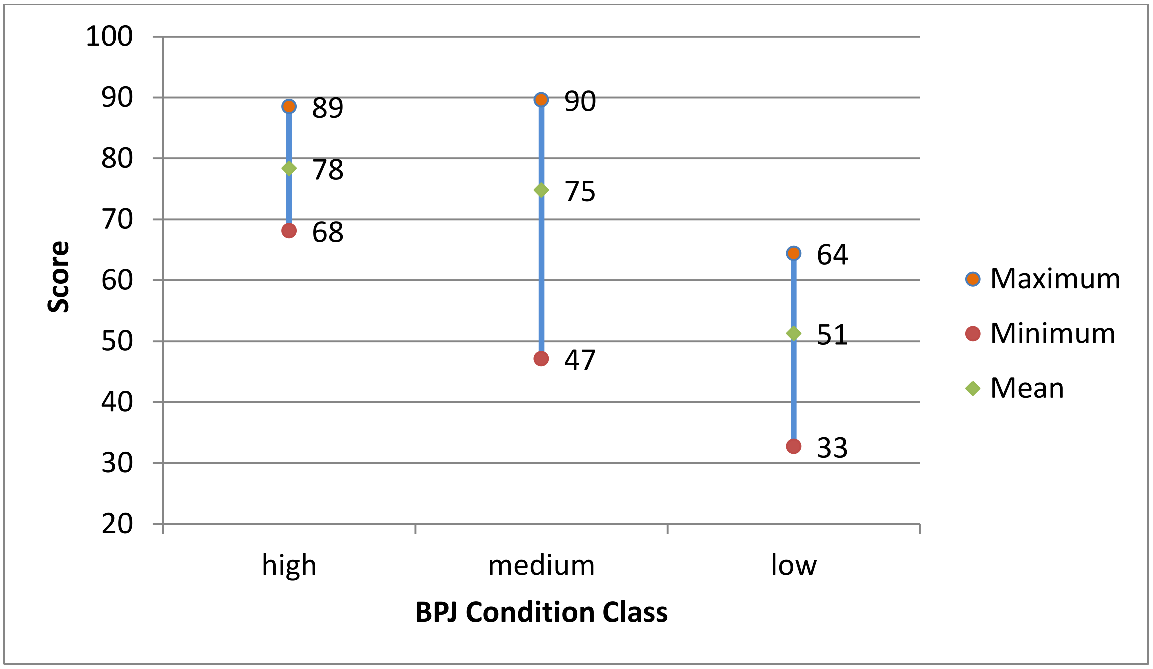


Figure 4.5: Maximum, minimum, and mean CRAM Index Scores by BPJ

Average Attribute scores were found to be higher in the north coast than central or southern California for all but the Biotic Structure Attribute (Figure 4.6). All supporting data demonstrates that Northern California Lagoons are less impacted from adjacent land uses and subsequently exhibit higher average condition scores. Invasive plants (*Ammophila* and *Spartina*) were found to be responsible for low biotic structure of some North Coast Estuaries.

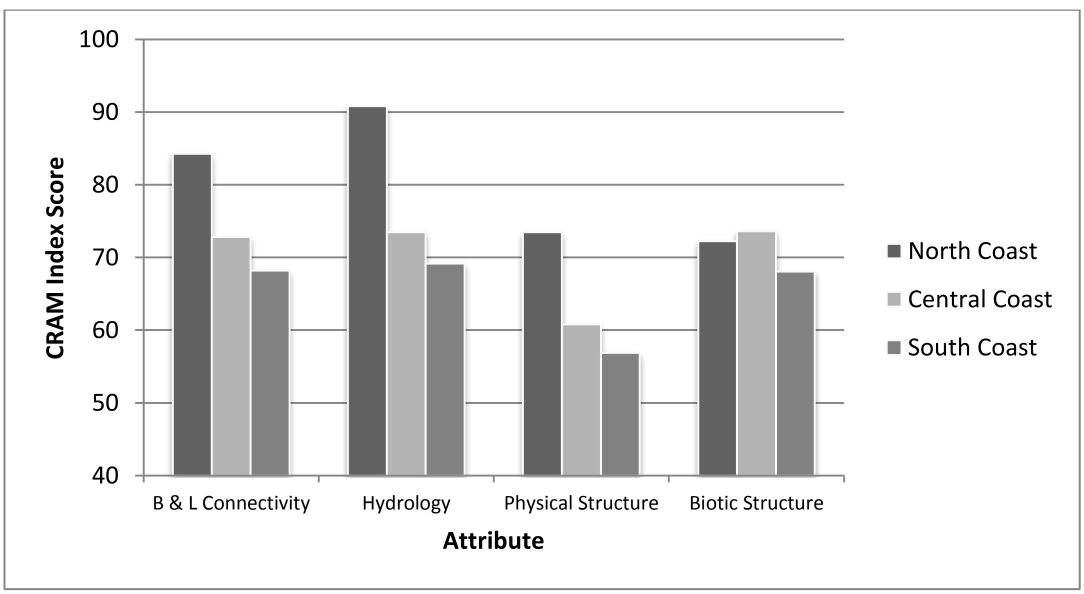


Figure 4.6: Average CRAM Attribute Scores by region

Comparison of CRAM Metric Results

The most noteable diffferences among regions for metric scores were greater average condition for hydrology metrics and Physical complexity of the lagoons in northern areas (Figure 4.7). Metrics that pertain to plant species abundance and dynamics are very similar among regions and invasive species in north coast systems (*Ammophila*) has led to lower average invasive species condition scores.

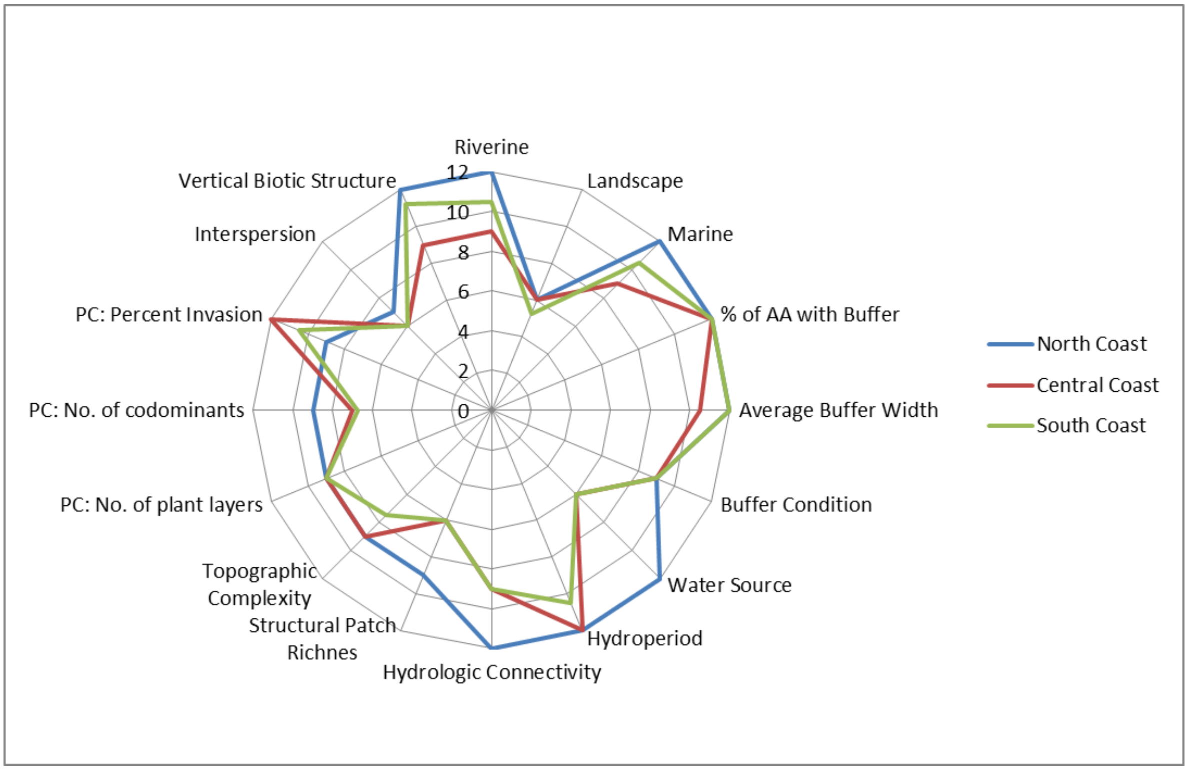


Figure 4.7: Average CRAM Metric Scores by region

Wetland Condition Groups

A statistical correlation analysis on all metric scores for all 32 sites was conducted to bin sites into groups based on their overall similarity. We felt this type of analysis would provide more insight than simply basing groups of sites on the CRAM Index score.

The result was a dendrogram depicting six unique clusters of sites that fit into 4 "condition categories", i.e. good, fair, poor, and exceptionally poor (Figure 4.8). Scores range for from 84-90 for groups A and B (good condition sites), 68-82 for Groups C and D (fair condition), 57-70 for E (poor condition) and 33-47 for F (exceptionally poor condition) sites.

Group A represents a group of five high quality sites distributed throughout California. Group B includes two sites with very high condition scores for all metrics other than biotic metrics which are lowered because of invasive *Ammophila* and *Spartina* infestations. Groups C and D represent two distinct groups of sites with CRAM scores that are less than optimal (medium condition sites). Groups E and F represent poor and very poor condition sites respectively. To note, each statistical condition Group includes BBE from each region of the coast except for Group B.

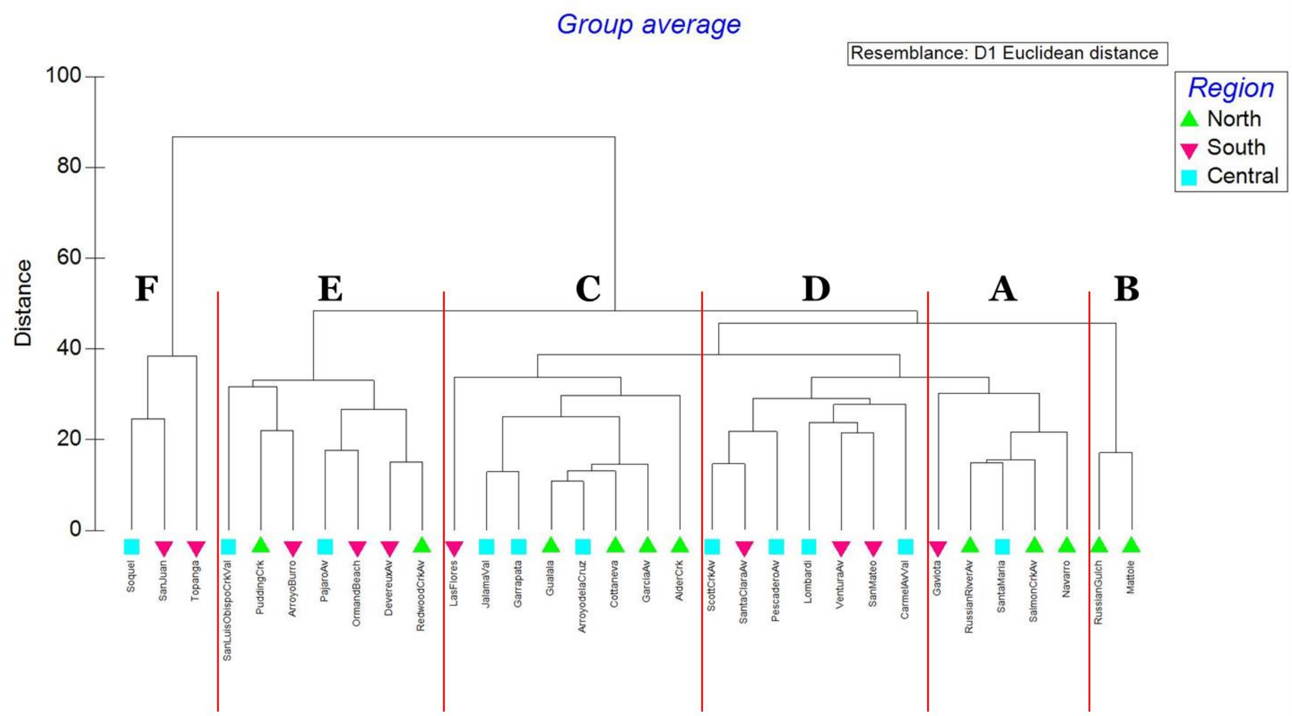


Figure 4.8: Dendrogram depicting six unique groups of sites that fit into 4 "condition categories"

For our analysis of differences in condition between Good, Fair and Poor, we combined Categories C and D together to represent overall fair condition BBEs. Category B exhibited optimal condition for hydrology and most buffer metrics but had uniquely poor biotic condition scores. Conversely, Group F exhibited the lowest overall score for all metrics with sites in central and southern California (Figure 4.9).

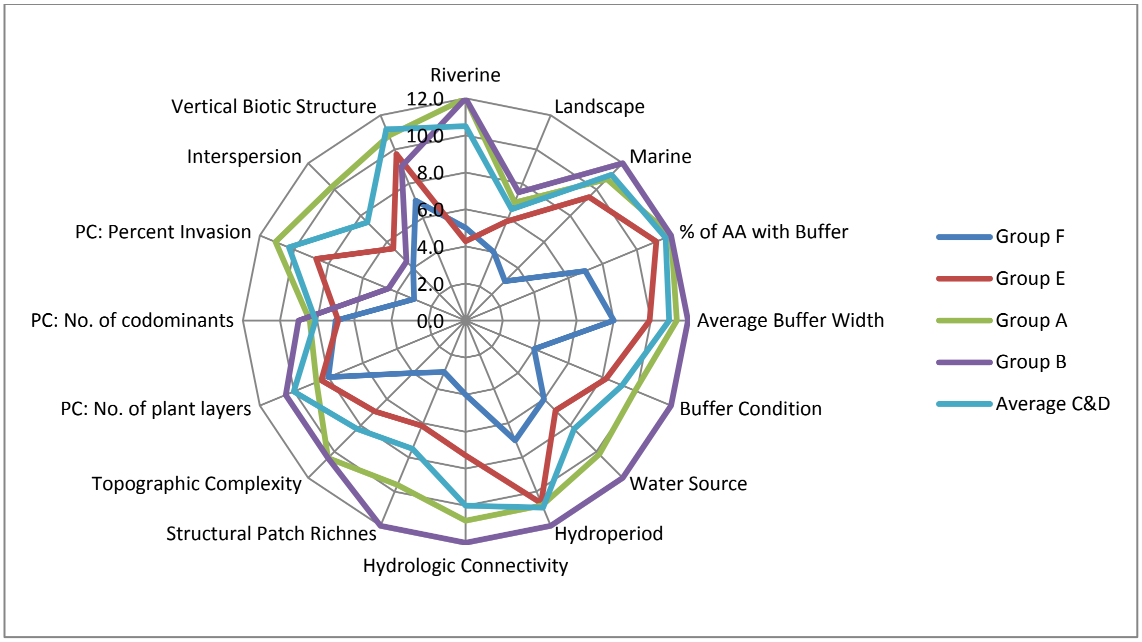


Figure 4.9: Graph comparing average CRAM Metric Scores for each Dendrogram Group

Specific differences in metrics driving score reductions are still being investigates, but both groups represent fair condition BBEs. Comparison among sites within Groups C&D suggest that Group D is impacted by hydrolic stresses (as supported by stressor checklist data) and Group C has lower biotic and physical complexity (Figure 4.10).

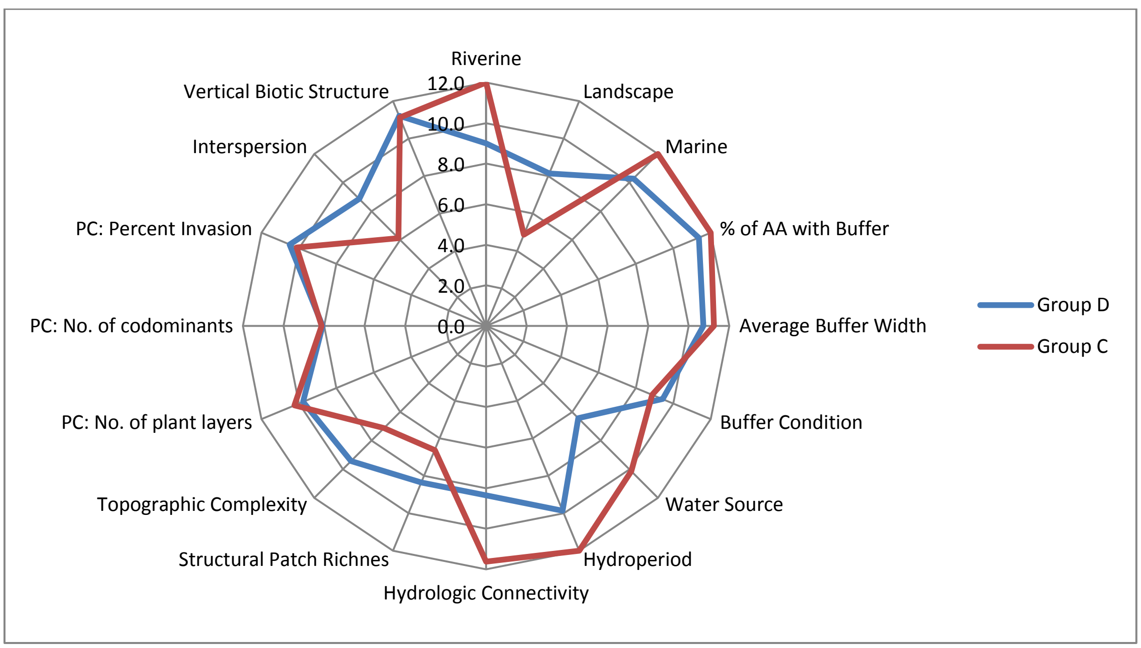


Figure 4.10: Graph comparing average CRAM Metric Scores for Groups C & D

Adjacent Land Uses and Anthropogenic Stresses

Percent Cover of Agriculture and Impervious Surfaces were found to be significantly different among CRAM condition categories (A-F) (Figure 4.11). Lower Condition Sites (categories D-F) were found to have higher percent cover of Agriculture and Impervious Surface. Lowest condition sites (F, CRAM Index <47) were reported to have greater than 65% impervious surface within the 2km radius around the BBE.

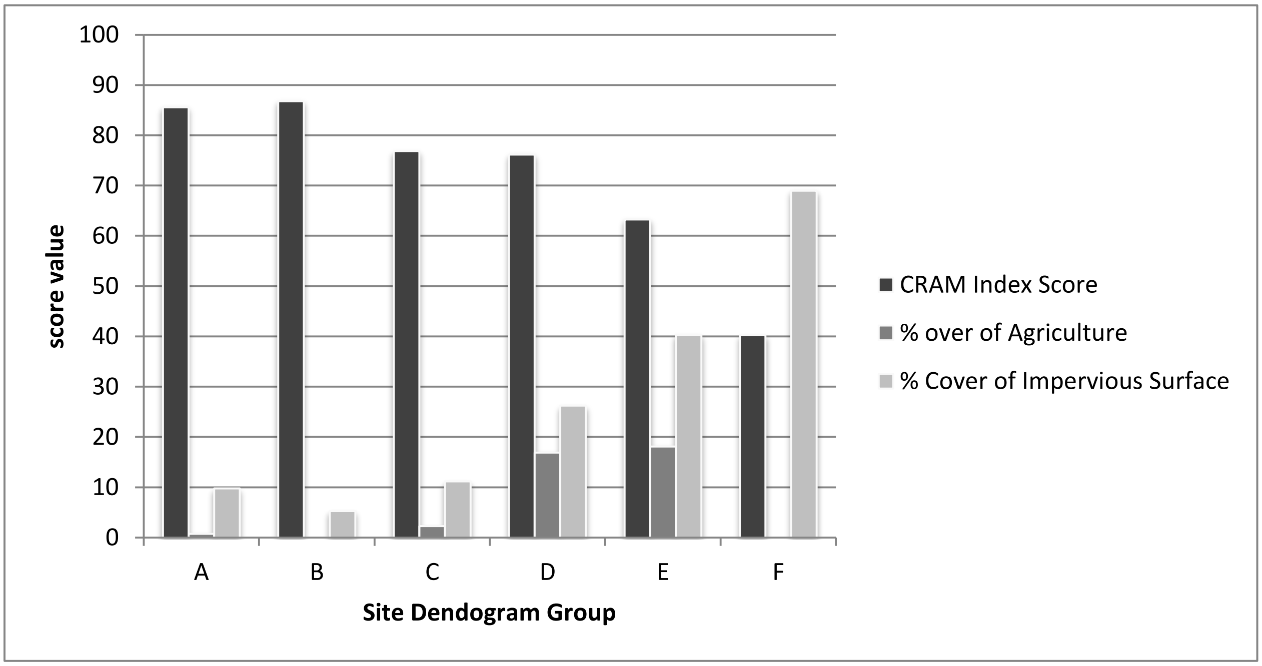


Figure 4.11: CRAM Index score compared to % cover of anthropogenic land uses by Dendrogram Group

Anthropogenic activities adjacent to the BBE or within the watershed draining to the lagoon were tallied for each site using the CRAM stressor checklist. A number of common land uses and human activities were noted that could be assumed to potentially reduce the condition of a site for one of the four attributes. Total numbers of noted stressors for each attribute group were tallied and analyzed to infer causal relationships with CRAM attribute and index scores. Average number of stressors found at a site by attribute for each region of the state was calculated (Table 4.3). North Coast sites were noted to on average be impacted by one hydrologic stress and 3 stresses from adjacent land uses. Central and Southern California Sites had on average far greater numbers of total stresses with two or more stresses within each category and four indicated from adjacent land uses. Anthropogenic stresses from within the wetland systems and adjacent land uses that present at more

Table 4.3: Average number of CRAM stressors for each system by region

	North	Central	South
Buffer and Landscape Context Attribute	3	4	4
Hydrology Attribute	1	2	3
Physical Structure Attribute	0	3	3
Biotic Structure Attribute	0	2	2

than half of the sites in each region are reported in Table 4.4. Stressors found at more than half the sites within each region include passive recreation and transportation corridors (Highway 1) within all regions of the state. Central and Southern California sites however had significantly more stressors found at more than half the systems and include water pollution inputs, and urban development. Southern California also included dikes and levees and other hydraulic management at more than half of the systems.

North Coast		Central Coast		South Coast	
Stressor	Total Number	**Stressor**	Total Number	**Stressor**	Total Number
Passive recreation (bird-watching, hiking, etc.)	9	Passive recreation (bird-watching, hiking, etc.)	10	Transportation corridor	9
Transportation corridor	5	Transportation corridor	8	Excessive human visitation	8
		Trash or refuse	7	Passive recreation (bird-watching, hiking, etc.)	8
		Excessive human visitation	7	Non-point Source (Non-PS) discharges (urban runoff, farm drainage)	7
		Lack of treatment of invasive plants adjacent to AA or buffer	7	Engineered channel (riprap, armored channel bank, bed)	7
		Non-point Source (Non-PS) discharges (urban runoff, farm drainage)	6	Dike/levees	7
		Nutrient impaired (PS or Non-PS pollution)	5	Nutrient impaired (PS or Non-PS pollution)	6
		Pesticides or trace organics impaired (PS or Non-PS pollution)	5	Trash or refuse	6
		Urban residential	5	Industrial/commercial	6
				Grading/ compaction (N/A for restoration areas)	5
				Urban residential	5
				Sports fields and urban parklands (golf courses, soccer fields, etc.)	5
				Active recreation (off-road vehicles, mountain biking, hunting, fishing)	5

Table 4.4: CRAM stressors present at more than half of the total sites in each region

Relationship between adjacent land use stressors and CRAM Index score

A significant relationship was found between the presences of greater numbers of Stressors and lower CRAM index scores ($p=0.0002$, $R^2 = 0.3666$) (Figure 4.12).

Because some CRAM metric scoring procedures reference watershed stressors and adjacent land uses, some correlations are expected but autocorrelation relationships are expected to be minimized by aggregating metric results into an Index score.

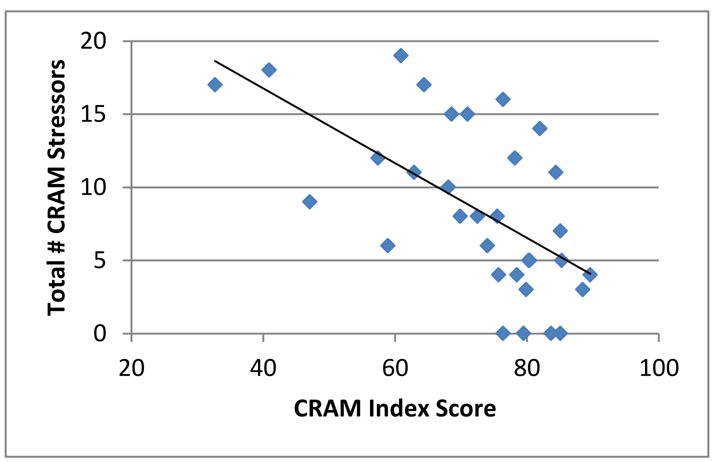


Figure 4.12: Correlation of CRAM Stressors and CRAM Index Score

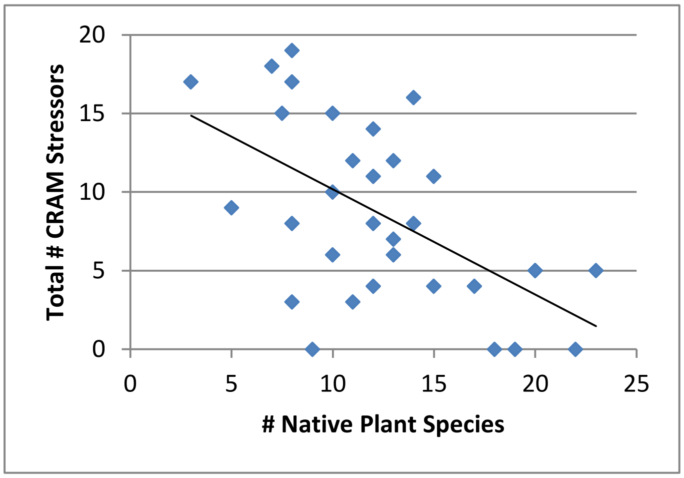


Figure 4.13: Correlation of CRAM Stressors and number of native plant species

To better test this expectation, we compared CRAM Index scores to other indicators of condition (specifically Native Plants). Larger numbers of stressors was found to correlate with lower number of native marsh plain plant species (p=.0006, R^2 =0.327) which were surveyed to represent a secondary and independent indicator of condition (Figure 4.13). Sites with more than 15 plant species were found in sites with less than five external stressors.

Indicators of Marsh Plain Degradation

The marsh plain and off channel pools and ponds provide unique ecological services due to their unique inundation periodicity and the resulting variability in water chemistry. Changes to beach bar formation and retention, accessibility to flood plain due to constructed hydrologic features such as dikes and levees, and modifications to upstream hydrology can all modify and potentially degrade marsh plain services and dynamics.

Loss of Wetland Area

While a few systems were found to have an increase in wetland area (usually small systems with small increases in channel width), many BBEs were found to have significant loss of wetland area. These losses in wetland area resulted in a significant reduction in CRAM Index scores ($p < 0.001$, R^2=0.4961) (Figure 4.14). Similarly, loss of wetland area was found to correlate with lower number of native plant species documented within field surveys ($p < 0.001$, R^2= 0.34) (Figure 4.15).

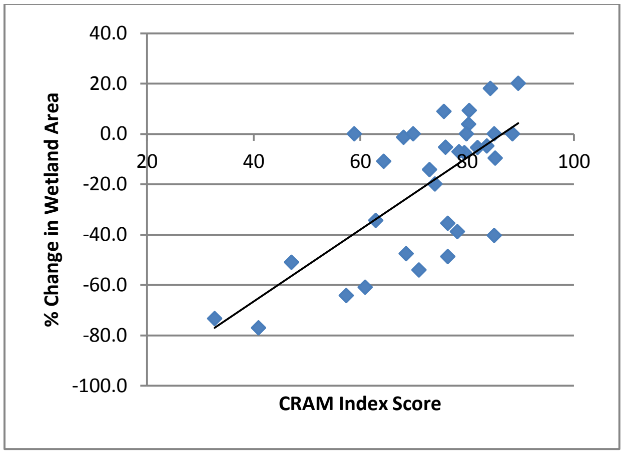


Figure 4.14: Correlation of change in wetland area to CRAM Index Score

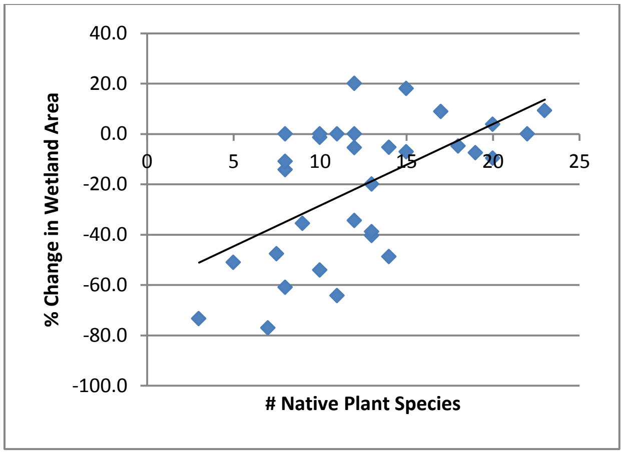


Figure 4.15: Correlation of change in wetland area to number of native plant species

Mouth Management and Resulting Impacts on BBE Hydrology

The sites with artificial channel restrictions and some form of mouth management routinely scored lower CRAM Index scores (Figure 4.16). Sites where hydrology was restricted or modified in both the channel and at the mouth had significantly different CRAM Index scores (Kruskal-Wallis T-statistic: 8.526, $p = 0.0362$). The number of sites with mouth constrictions was low and they were located in otherwise high quality northern sites. Low numbers of mouth constriction sites likely reflects that mouth management practices often coincide or follow channelization of the marsh plain itself. Similarly, many mouth management practices may lead to a type change in wetland class because the modifications made at the mouths restrict natural bar formation processes.

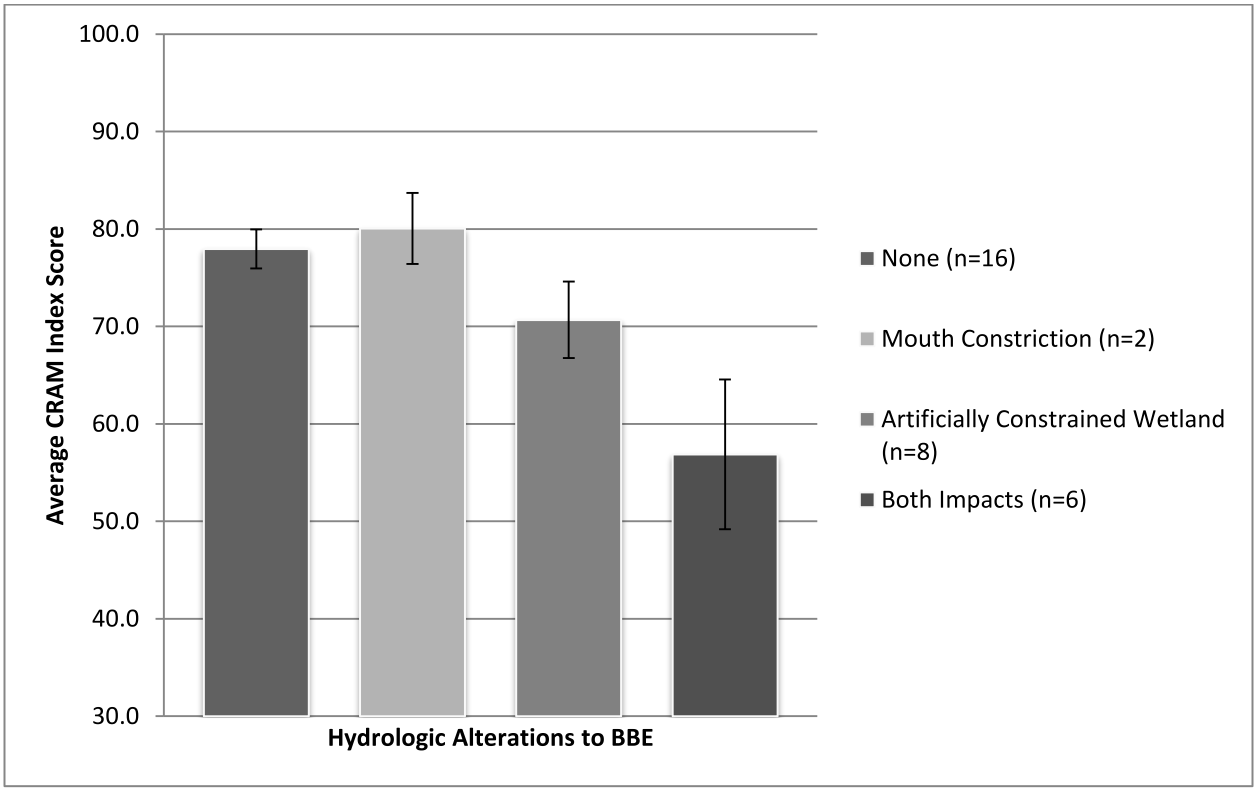


Figure 4.16: Average CRAM Index Score by various levels of hydrologic alteration to BBE systems

Marsh Plain Innundation

Hydrologic interactions (innundation) between the BBE channel and marsh plain were estimated at 13 sites along the California Coast. Hydrologic linkages between the main channel and the existing marsh plain were enumerated through the use of a Marsh Plain Inundation Periodicity Index. The index was generated through analysis of Hydrograph data collected at the 13 BBE where pressure transducers were deployed over one growing season. The relative elevation of the transducers in relation to the beach berm, marsh plain and adjacent wrack lines were surveyed. The devices were collected, water elevation was calculated and the periodicity at which water levels were high enough to support marsh plain inundation was recorded. Six of the 13 sites were found to have significant marsh plain inundation (number and length of flooding indicated by water elevation at or above marsh plain) during the spring to fall non-rain and storm seasons.

The frequency at which the Marsh Plain was innundated was quantified through the creation of a Marsh Plain Innundation periodicity Index. Sites were tallied to have no interaction with their marsh plain, infrequent interactions (1), infrequent but significant interactions (2), or frequent and signficant interactions with the marsh plain (3). CRAM Index scores were found to correlate with the calculated Parsh Plain Innundation Index ($p<0.001$, $R^2 = 0.68$) (Figure 4.17). This correlation further support other findings (native plant species correlations with mouth management) that reductions in marsh plain flooding associated with management of flooding and mouth closure dynamics leads to a reduction in ecological services including native plant species and CRAM Index scores.

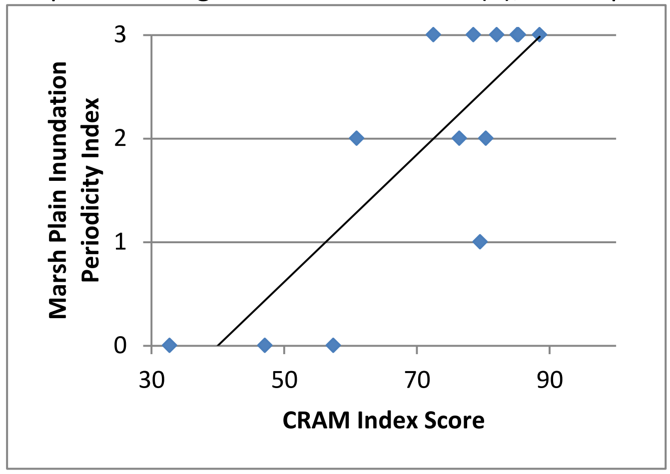


Figure 4.17: Correlation of Marsh Plain Inundation Periodicity Index and CRAM Index Score

While the six sites with high Marsh Plain Inundation Periodicity Index scores were found to have water levels above the marsh plain on numerous events throughout the season, other systems like Alder Creek had water levels well below the marsh plain for long periods of the summer (Figure 4.18). Bar formation corresponding with increased wave energy within the fall lead to increased water elevation within the BBE, resulting in some late-season flooding of the marsh.

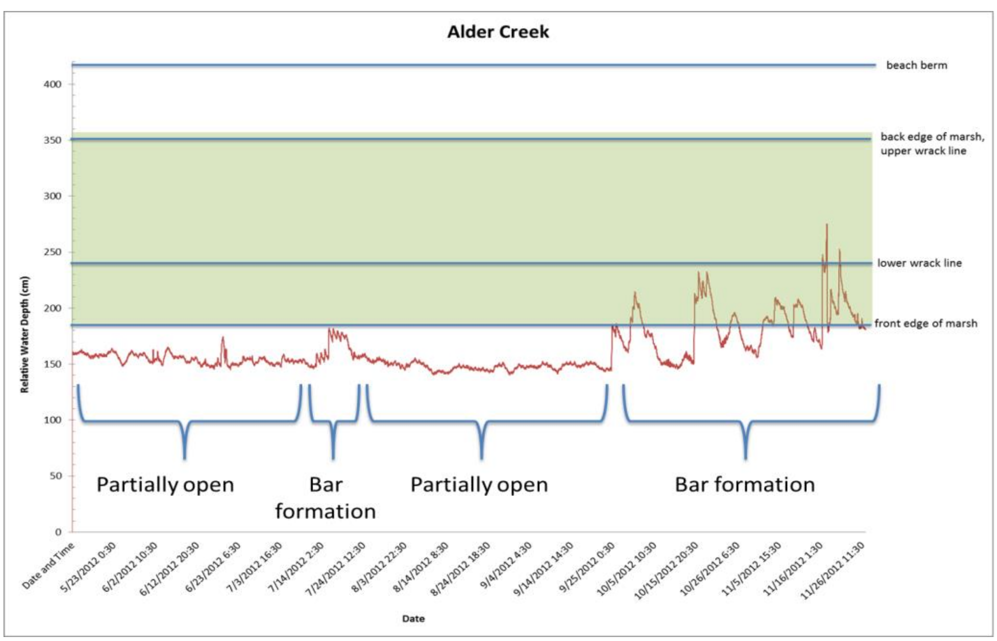


Figure 4.18: Hydrograph of BBE water elevation and mouth status in Alder Creek in 2012

Still other systems (Lombardi) were seen to have closed mouths, restricting tidal action for much of the summer but did not lead to ponding behind the berm except on specific high tide events when wave overtoping flooded the lagoon (Figure 4.19). Pooled ocean water quickly migrated through the berm, leading to a short period ponding and marsh plain interactions.

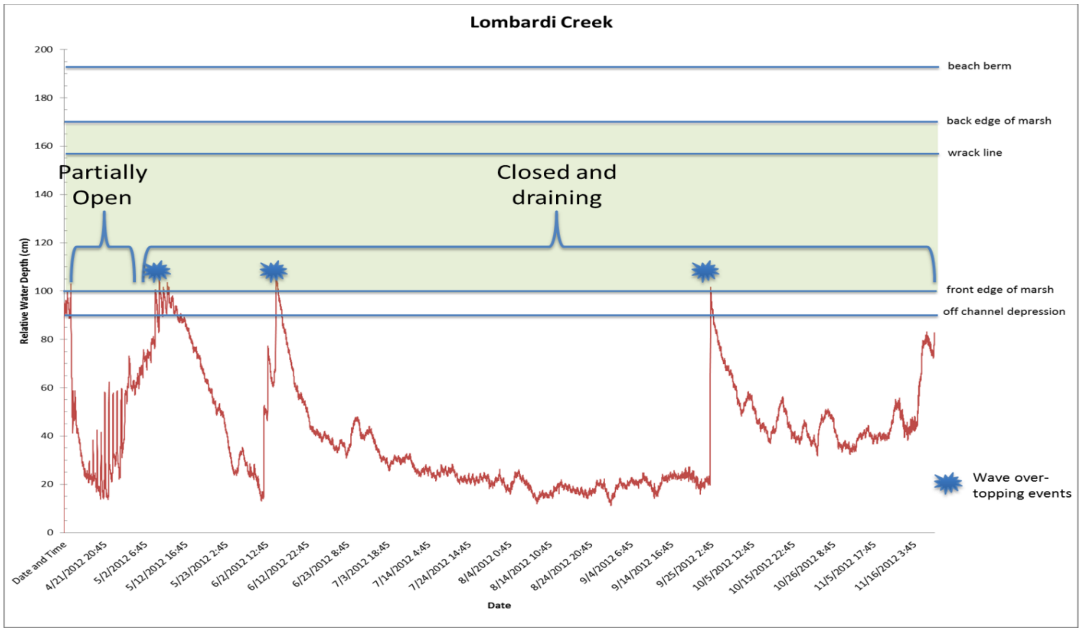


Figure 4.19: Hydrograph of BBE water elevation and mouth status in Lombardi Creek in 2012

Marsh Plain Vegetation

The average number of native plant species identified in plant surveys showed a significant increasing trend within BBEs with a higher CRAM Index score (Figure 4.20).

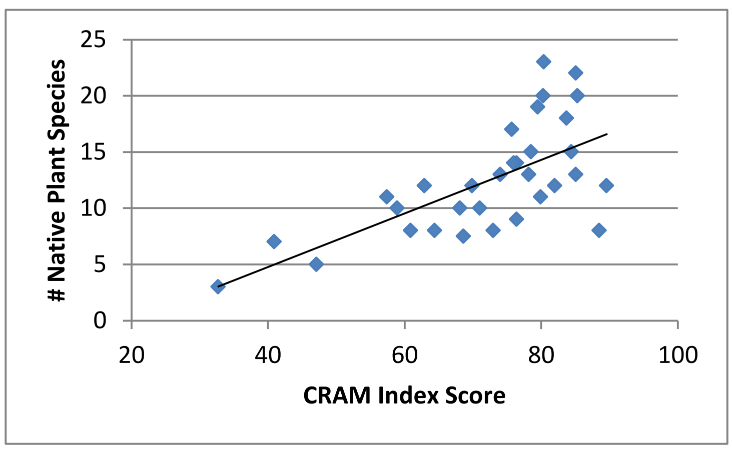


Figure 4.20: Correlation of number of native plant species to CRAM Index Score

The 50 most abundant plant species cataloged at the 32 BBE throughout Calfiornia are listed (Table 4.5). Fourteen of the 50 species are non-native species including the European Dune Grass, *Ammophila arenaria*. Common species included both salt tollerant plants including *Frankenia*, *Jaumea*, and *Sarrcoconia* as well as fresh water spcies genus including *Alnus*, *Juncus* and *Salix*. This diversity of plant species further documents the wide variety of salinity gradients common within these dynamic systems.

Table 4.5: Fifty most common plant species observed during plant surveys at 32 BBEs

scientific name	Common Name	Native Status
Ammophila arenaria	European Dune Grass	Non-native
Arundo donax	Giant Reed	Non-native
Brassica nigra	Mustard	Non-native
Carprbrotus edulis	Iceplant	Non-native
Digitaria sanguinalis	Crabgrass	Non-native
Euphorbia peplus	Petty Spurge	Non-native
Holcus lanatus	Velvet Grass	Non-native
Melilotus indicus	Yellow Sweet Clover	Non-native
Myoporum laetum	Ngaio Tree, Myoporum	Non-native
Parapholis incurva	Sickle Grass	Non-native
Paspalum dilatatum	Dallis Grass	Non-native
Pennisetum clandestinum	Kikuyu Grass	Non-native
Plantago coronopus	Cut-leaf Plantain	Non-native
Rumex acetosella	Sheep Sorrel	Non-native
Alnus rubra	Red Alder	Native
Ambrosia chammisonis	Beach Bur	Native
Ambrosia psilostachya	Western Ragweed	Native
Atriplex lentiformis	Quail Bush	Native
Atriplex triangularis	Spearscale	Native
Baccharis pilularis	Coyote Bush	Native
Baccharis salicifolia	Mule-fat	Native
Bolboschoenus fluviatilis	River Bulrush	Native
Bolboschoenus robustus	Saltmarsh Bulrush	Native
Carex barbarae	Santa Barbara Sedge	Native
Carex obnupta	Slough Sedge	Native
Carex sp.	Sedge	Native
Elymus glaucus	Blue Wild Rye	Native
Epilobium ciliatum	Willow Herb	Native
Frankenia salina	Alkali Heath	Native
Grindelia stricta	Gumplant	Native
Jaumea carnosa	Fleshy Jaumea	Native
Juncus balticus	Baltic Rush	Native
Juncus effusus	Common Rush	Native
Juncus lescurii	Salt Rush	Native
Leymus triticoides	Creeping Wild Rye	Native
Oenanthe sarmentosa	Water Parsley	Native
Persicaria lapathifolium	Curlytop Knotweed	Native
Persicaria punctata	Dotted Knotweed	Native
Potentilla anserina	Silvertip	Native
Rubus ursinus	California Blackberry	Native
Salix lasiolepis	Arroyo Willow	Native
Sarcocornia pacifica	Pickleweed	Native
Schoenoplectus californicus	California Bulrush	Native
Scirpus microcarpus	Panicled Bulrush	Native
Scirpus pungens	Common Threesquare	Native
Toxicodendron diversilobum	Poison Oak	Native
Trifolium wormskoldii	Cow Clover	Native
Typha dominguensis	Southern Cattail	Native

Central Coast Ambient Assessment

Introduction

In 2012 we conducted an ambient CRAM assessment of California's Central Coast bar-built estuaries in order to identify the overall condition of BBE's in the region. Thirty sites were randomly selected from all BBE's along the Central Coast. Selected sited spanned from Montara Beach in San Mateo County to Jalama Creek in Santa Barbara County (Figure 4.21). The study took place during the Fall of 2012. Field work consisted of the collection of CRAM data along with level 3 data including water quality, beach berm slope measurements, and mouth condition.

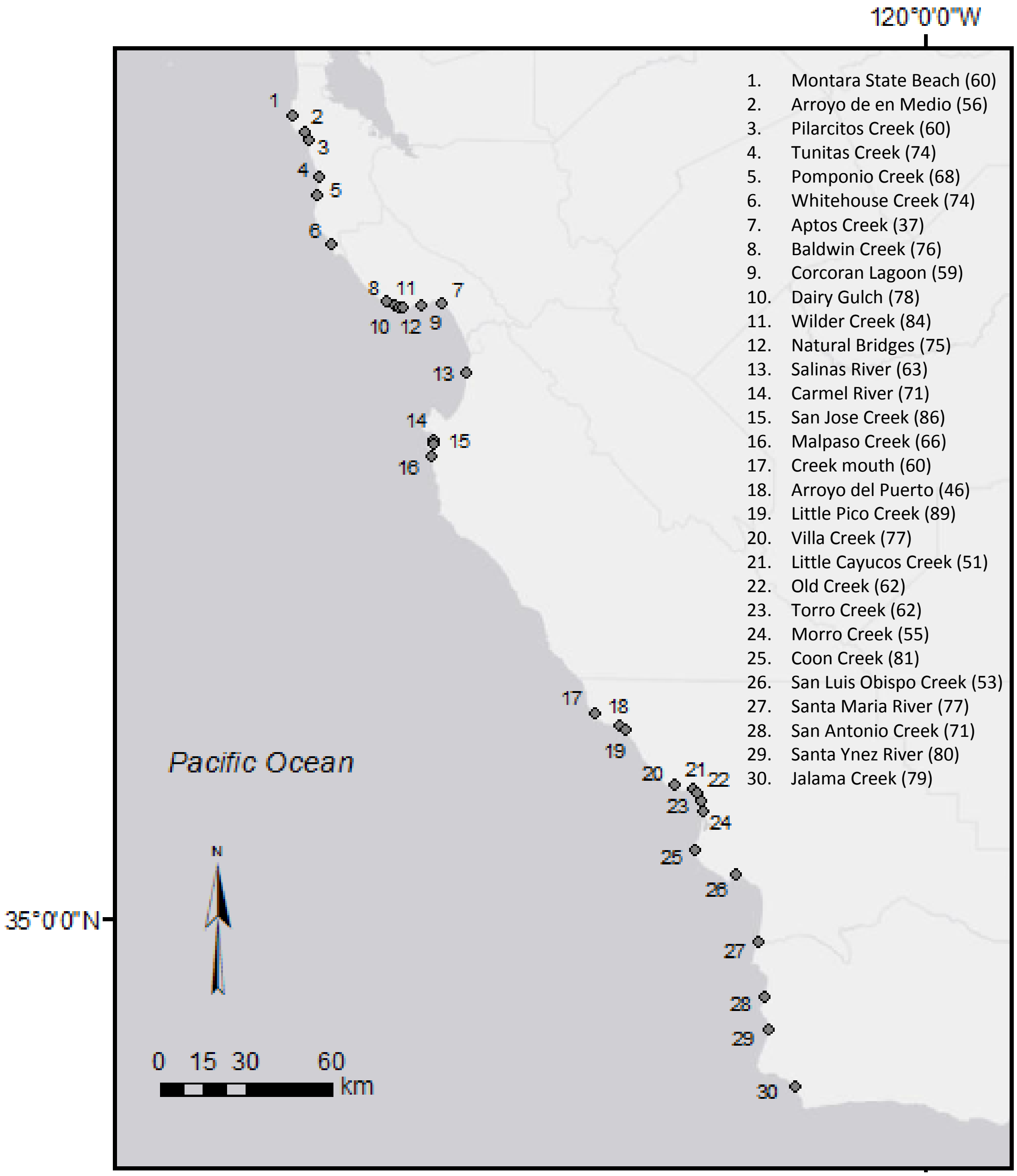


Figure 4.21: CRAM Ambient Study BBE locations

Data Collected

CRAM: Due to their smaller size, most systems only required a single CRAM assessment. At larger systems we conducted 2-3 representative assessments and averaged the CRAM scores to get the overall score for that BBE (Figure 4.22).

Water Quality: Water quality was collected simultaneously with CRAM assessments. At each estuary we used a YSI meter to collect measurements for salinity, dissolved oxygen, PH, temperature and conductivity at three locations at the water surface and bottom of water column. We also used a secchi disc to measure water clarity at each of the three water quality monitoring locations.

Anoxic soils: The depth to anoxic layer was assessed at each water quality monitoring location

Algae: The presence/absence of algae in the BBE was noted for each site

Beach berm slope: We used a stadia rod, site level and rangefinder to measure the slope of the beach berm on both the ocean side and lagoon side of the berm.

Adjacent Land use: Google Earth was use to classify each site according to the dominant adjacent land use.

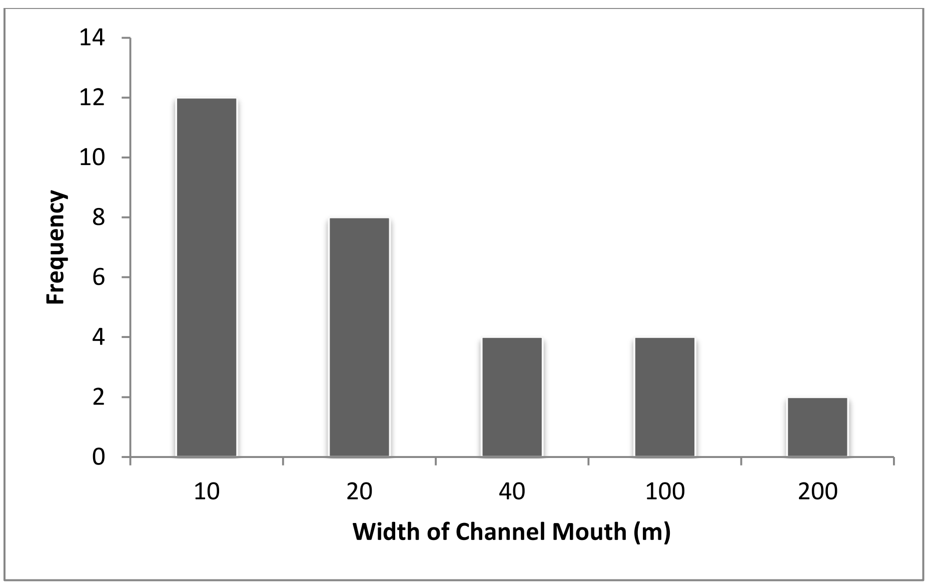


Figure 4.22: Size distribution of the width of the main channel mouth for the 30 BBEs assessed during the Ambient Study, displaying the prevalence of small systems and relatively few very large ones.

Results

CRAM: The 30 randomly selected sites represent a wide range of BBE condition using CRAM. CRAM Index scores ranged from 37 to 89, with a mean Index Score of 68 (Figure 4.23). Of the four CRAM Attributes, Hydrology on average scored the highest (78) and Physical Structure scored the lowest (52).

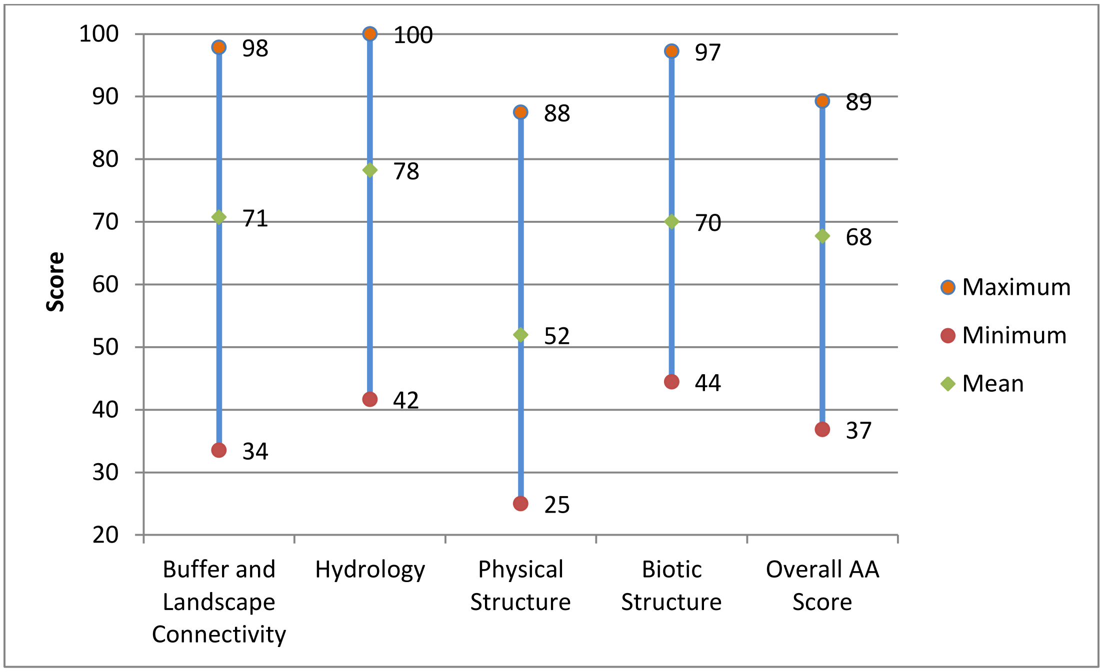


Figure 4.23: Maximum, minimum, and mean CRAM Attribute and Index Scores for 30 ambient study sites

The Cumulative Frequency Distribution (CFD) of CRAM scores for the central coast ambient assessment showed that 50% of systems have a CRAM score of 68 or higher (Figure 4.24). It also showed that the sites we selected for validation on the central coast were evenly spread throughout the curve, with seven sites located above the 50th percentile and 3 located below. This CFD will provide a regional context for all BBE CRAM assessments into the future, providing valuable insight into the relative condition of other BBEs, restoration projects and impacted wetlands.

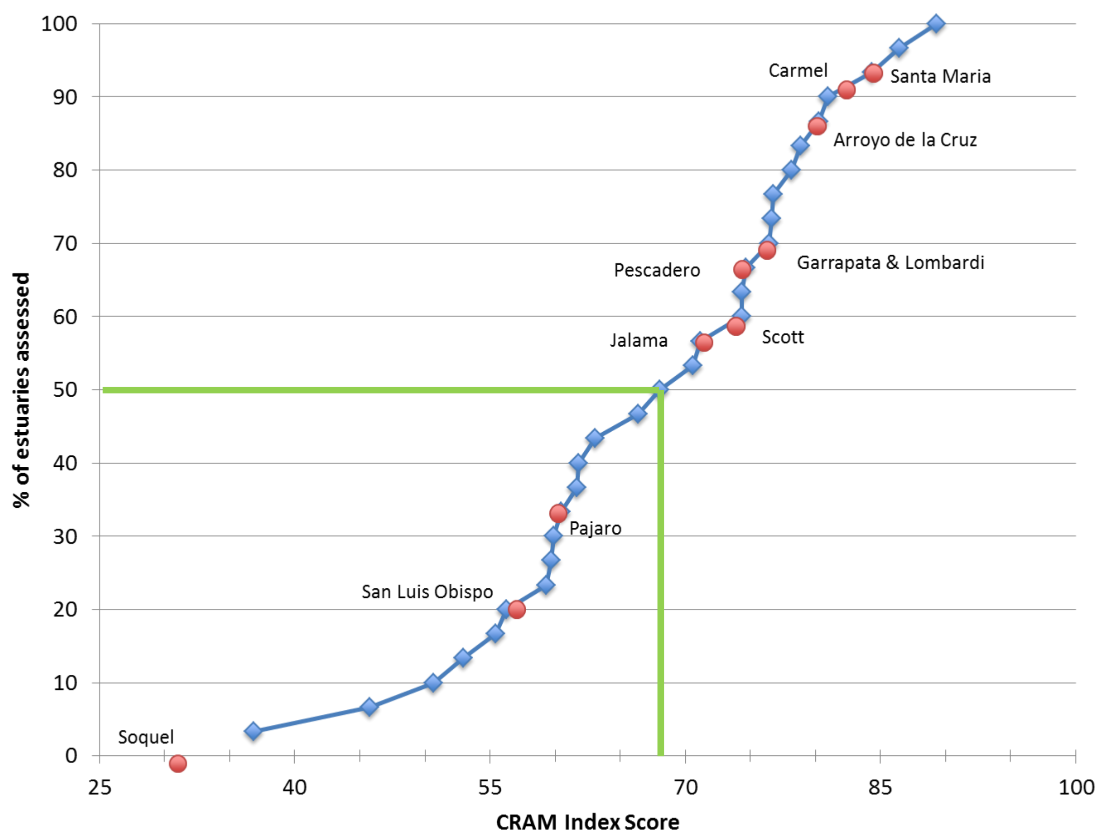


Figure 4.24: Cumulative Frequency Distribution of CRAM Index Scores for 30 ambient study sites

Adjacent Land use: In general, site that we located in an urban setting had a lower CRAM Index Score than site surrounded by open space or mixed uses (Figure 4.25). The four sites that were surrounded by agriculture scored higher than all other sites most likely due to being located in State Parks (Wilder Creek, Baldwin Creek, Dairy Gulch) or a National Wildlife Refuge (Salinas River) and having established management plans.

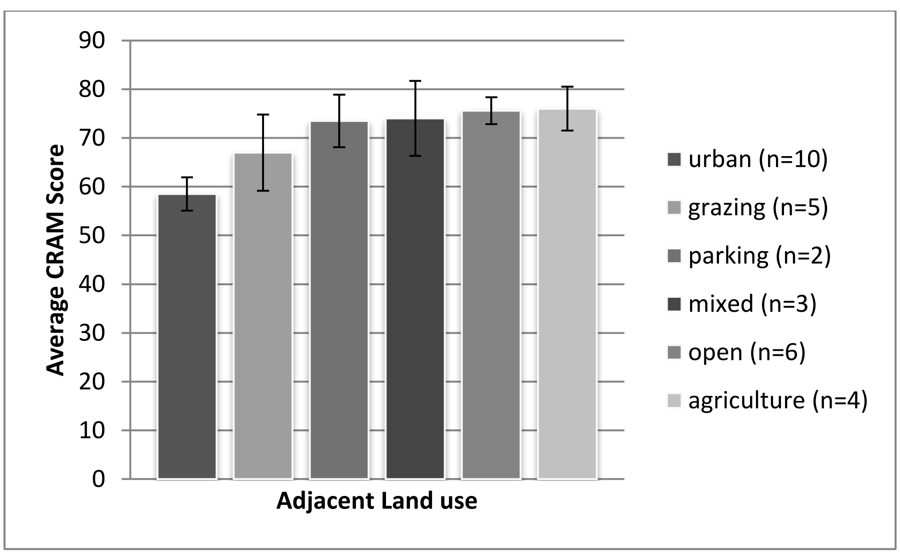


Figure 4.25: Average CRAM Index Score grouped by adjacent land use for 30 ambient assessment sites

The following data will be analyzed prior to publication. We will look at relationships between these Level 3 measures of condition and the CRAM scores for each BBE system.

- Water quality
- Anoxic soils depth
- Algae presence
- Beach berm slope

5. Outreach and Education

We conducted the following outreach and education during this grant:

- An exhibit on coastal lagoons was displayed at the Santa Cruz Museum of Natural History

- Various presentations were given at numerous professional conferences. Additional presentations were given to technical advisory committees and work groups, and high schools, colleges and universities.

Museum Exhibit

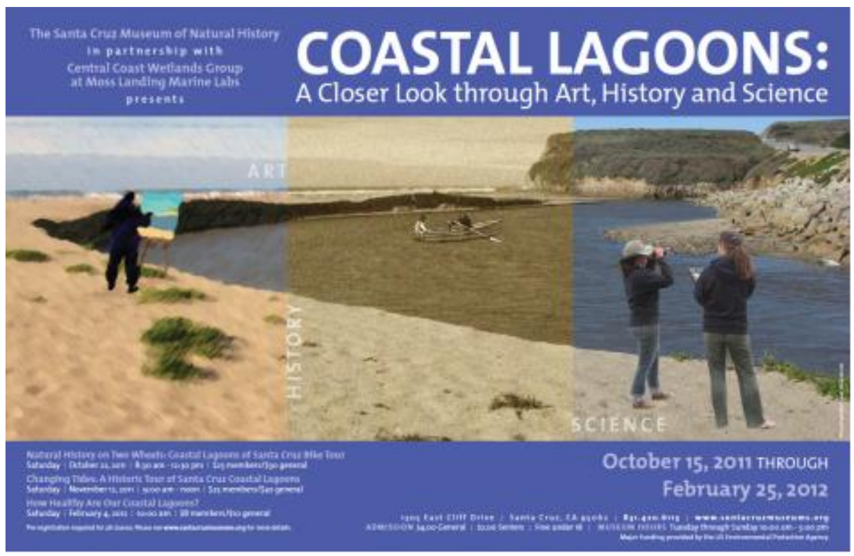


Figure 5.1 Publicity postcard for exhibit

As a large part of our education and outreach component, CCWG designed and coordinated a successful exhibit entitled "[Coastal Lagoons, a Closer Look through Art, History and Science]" which was displayed at the Santa Cruz Museum of Natural History (Figure 1.). Typically our outreach efforts are based on disseminating information through the CCWG website and sharing technical reports which are aimed at the scientific community. However, we believed that the BBE research would appeal to a wide audience. We reached out to the Santa Cruz Museum of Natural history after hearing that their reduced budget (due to the recession) made it difficult for them to make creative new exhibits and they agreed to do an exhibit featuring research from the grant.

To take advantage of both organizations areas of expertise, CCWG was in charge of text and visuals, coordination with collaborators, and construction and layout (through a contractor). The Museum was in charge of the publicity campaign, the content revision, education and school programs, space and setup, and activities. The exhibit was designed with an emphasis on attracting and educating people with a wide range of interests and education levels.

The exhibit contained background information on coastal lagoons, site specific information on seven central coast lagoons, and several additional eye catching displays (Figure 5.2).

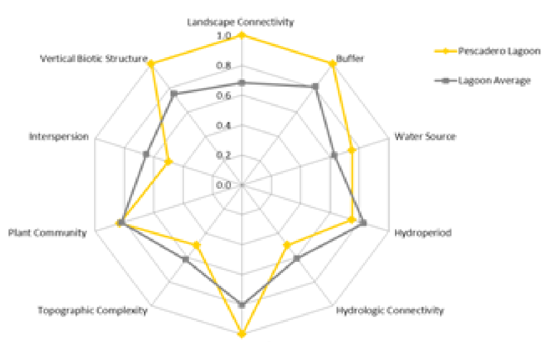
Background information panels were written with the take-away message featured in the panel title:

- "Lagoons are important"
- "How are our lagoons doing?"
- "A report card for lagoons" (CRAM)
- "Phases of lagoons and their functions"
- "Lagoon Plants: Natives and Invaders"

Figure 5.2 Exhibit display

The featured sites were seven locally recognizable lagoons, each looked at through a local artists rendering, a historical analysis and scientific research. Artists ranged from amateur to well-known professionals and one second grade class. Each site included:

- Historical T-sheet with habitat types highlighted, current aerial with habitat types highlighted, table of overall habitat loss and conversion over time.
- CRAM scores from the data sheet and a spider graphs comparing that site to the other featured sites (Figure 5.3).
- One historical photograph of each site
- Artist's rendering of the site



The above spider graph compares the condition of Pescadero Creek Lagoon (yellow) to the average of 16 Central Coast Lagoons (gray) by looking at the metrics used in CRAM. The closer the points to 1.0 (outer web) the higher the condition.

Pescadero Lagoon	
Attributes and Metrics	Grade/Score
Buffer and Landscape Context	
Landscape Connectivity	A
Buffer	A
Hydrology	
Water Source	B
Hydroperiod	B
Hydrologic Connectivity	C
Physical Structure	
Structural Patch Richness	A
Topographic Complexity	C
Biotic Structure	
Plant Community	B
Horizontal Interspersion and Zonation	C
Vertical Biotic Structure	A
Overall Score	78

Figure 5.3: Report card and spider graph represent the "science" component of the individual sites

Elements to catch the eye included:

- Videos: One video telling about how the history of landuse impacted local lagoons, and one discussing the exhibit which was aired on the Public Access channel. Both can still be watched on the CCWG website. The history video in particular was very popular and has been requested by other groups such as Save the Waves and the California Coastal Commission.

- 3D Cabinet Display: One with animals and one for CRAM "tools of the trade"

- Mural: Interactive mural that highlights the unseen wildlife living in lagoons. The mural was created by a local artist, who painted the mural at the museum so tourists on their way to the beach would walk past her while she worked. Since the exhibit closed, the mural has been used many times by CCWG for outreach events.

The Museum held several events and did additional publicity for the exhibit including:

- Exhibit grand opening
- Bike tour of lagoons (Figure 5.4)
- History walk
- Lecture
- Classroom tours
- Newspaper articles

Figure 5.4: Lagoon CRAM lesson during the bike tour

CCWG was very pleased with the partnership with the museum. While it was more challenging than our typical outreach, we think it was much more effective at informing and educating the public than our website and report would have done on their own. This exhibit resulted in three broad outcomes:

- CCWG presented their research to a broad audience of all ages. A total of 6,167 people visited the exhibit during the 5 months it was on display. CCWG still has the mural and videos to take to public events when needed, and the educational panels are on display at Moss Landing Marine Labs.

- The Santa Cruz Museum of Natural History featured a new, locally relevant exhibit that brought them higher than average attendance and publicity.

- The public learned the value of their local resources through varying perspectives. Based on the comments received by the Museum, attendees really appreciated the subject area: "I love the combination of art, history and science! Well done!" "Amazing exhibit on coastal lagoons. So much information. So beautifully presented. Congrats!"

Presentations

The following presentations were given about research conducted during this grant:

- Ross Clark: *Historical loss and current condition of Central Coast bar-built estuaries*. Salmonid Restoration Federation Conference, April 2012, Davis
- Ross Clark: *Historical loss and current condition of Central Coast bar-built estuaries.* Headwaters to Oceans, May 2012, San Diego
- Ross Clark: *Results of a newly developed rapid assessment tool for describing the condition and ecological services of California lagoons*, California Estuarine Research Society Conference, September 2012, Long Beach
- Ross Clark: *Results of a newly developed rapid assessment tool for describing the condition and ecological services of California lagoons*, Western Society of Naturalists Conference, November 2012, Marina
- Walter Heady: Guest Lecture to Moss Landing Marine Laboratories Mapping Class, 2012
- Walter Heady: Guest Lecture at San Lorenzo Valley High School, 2013
- Walter Heady: Guest Lecture at Cabrillo College, 2013
- Walter Heady: Guest Lecture at Monterey Institute of International Studies, 2013
- Walter Heady: Guest Lecture to AmeriCorps , 2013
- Walter Heady: *Validation of the California Rapid Assessment Methodology for bar-built estuaries*, Presentation to L2 Committee, May 2013, Richmond
- Walter Heady: : *Validation of the California Rapid Assessment Methodology for bar-built estuaries*, Presentation to CWMW, August 2013, Sacramento
- Walter Heady: *Validation of the California Rapid Assessment Methodology for bar-built estuaries*, Presentation to 401 Roundtable, September 2013
- Walter Heady: Presentation to Pescadero Science Advisory Committee, September 2013
- Walter Heady: *Landscape and Local Influences on the condition of California's bar-built estuaries*, Coastal and Estuarine Research Federation Conference, November 2013, San Diego
- Sierra Ryan: *Using innovative partnerships to bring current scientific research to a broad public audience*, Headwaters to Oceans, May 2012, San Diego

- Sierra Ryan: *Study of habitat loss and conversion over the past 150 years in 30 bar built estuaries throughout California*, California Estuarine Research Society, September 2012, Long Beach
- Sierra Ryan: *Using innovative partnerships to share scientific research with the public*, North American Association of Environmental Educators Conference, October 2012, Oakland
- Sierra Ryan: *Study of habitat loss and conversion over the past 150 years in 30 bar built estuaries throughout California*, Coastal and Estuarine Research Federation Conference, November 2013, San Diego

6. Conclusions and Future Research

Bar-built estuaries are incredibly complex and dynamic systems. While we do know that a significant loss of these coastal wetlands has occurred, we continue efforts to better understand the full extent of the services they provide and how previous and future alteration to these systems may impact these services. Results of our study highlight the specific needs to research the spatio-temporal complexities of functions and services bar-built estuaries provide, as well as the resulting effects of adjacent land use and management approaches on these services. Basic research into the ecological functioning of bar-built estuaries as a community of systems that spans the California coast will provide the foundation of understanding to better direct management to protect individual and regional populations of bar-built estuaries and the multiple services they provide.

The significant correlations between expected CRAM metrics and GIS measures of stress across expected scales raises the potential for use of CRAM in combination with GIS analyses to further inform links between landscape scale processes and habitat condition. Combining watershed- scale GIS analyses of stress with CRAM assessments of riverine habitat stratified throughout the watershed and assessment of bar-built estuary condition will inform resource managers on the ecological function of riverine habitats, overall watershed processes, and resulting reductions in the condition of downstream bar-built estuary habitats. Because the GIS analysis of watershed stressors has been found to correlate with specific CRAM metrics and Attributes, resource managers may now have corroborative evidence of the environmental cause and effects of adjacent land uses on the condition of these systems. We will continue to explore the utility of such approaches to help guide restoration and conservation efforts within the watersheds of central California coast in collaboration with the USFWS in 2014.

Bar-built estuaries are frequently plagued by single factor management strategies. Local governments and resource agencies often identify specific stresses (i.e. nutrient loading) and the resulting reduction in a specific function or component of condition (i.e. fish kills from low dissolved oxygen) from which management actions are proposed. CRAM for BBEs can evaluate multiple indicators of condition and has been shown by this work to capably quantify the impacts of watershed and adjacent land use stresses on these systems as well as quantify the environmental values these systems still possess. The documented correlations of the four CRAM attributes with multiple indicators of condition and stress help define a more comprehensive understanding of current functions provided by bar-built estuaries and may enable resource managers to better weigh the costs and benefits of specific management alternatives in the future. Further work examining the capacity of CRAM condition scores (Attribute and Index) to quantify the multiple services provided by these systems would benefit from additional correlations with other indicators of condition and function. A better understanding is needed of how various metric and attribute scores represent specific services valued by the multiple endemic species that rely on these systems.

Through this and other research, it is apparent that mouth management and channel alterations such as levees and hard structures negatively affect the extent, complexity and diversity of services provided by bar-built estuaries. Previous research has demonstrated the importance of bar-built estuaries to species such as the threatened steelhead trout (Bond et al. 2008; Hayes et al. 2011). This benefit, however, is dependent upon both the seasonal closure of the mouth, and the dynamic interactions with the ocean that provide periodic inputs of food, leading to an increase in productivity. The implications of aggressive mouth management by local municipalities (shown to be more common in sites to the south where protection of adjacent urban development is more often needed) only compounds the impacts of watershed stressors on habitat quantity and quality. Our field studies suggest that the marsh plains of bar-built estuaries are inundated less frequently when systems are impacted by upstream watershed effects (e.g. decreased streamflow), habitat alteration (e.g. levees), and mouth management efforts. Frequently, management efforts aim to reduce the temporal and special variability of marsh inundation, which results in habitat homogenization, reducing the complexity that defines these systems. Further research into the specific impacts of different management actions on ecosystem services and how these impacts can be ameliorated through modified management strategies and habitat restoration is warranted.

With a growing human population and associated environmental stress within coastal areas, it is critical to provide local governments with effective tools to more systematically mange these resources and curtail future degradation of condition. Local, state, and federal agencies each have goals of increasing the quantity and quality of California's wetlands (California's No-Net Loss policy for wetlands, California Coastal Act). However, until recently, California had yet to fully inventory its wetland resources through the National Wetland Inventory mapping program, nor begin the systematic evaluation of their condition (California Natural Resources Agency 2010). Work presented here is an example of successful collaborations between regional research institutions and local, state and federal agencies to increase state capacity to inventory and assess the extent and condition of California's wetland habitats. With the advent of rapid assessment methods such as CRAM, online inventorying resources such as the EcoAtlas website, and Multi-Agency leadership through the California Wetland Monitoring Workgroup, the State now possesses the tools to properly characterize California's wetlands. Work presented here documents the approach taken to validate this assessment tool and the resulting sample of the condition for California's bar-built estuaries. CRAM provides a valuable standardized tool that will provide agencies with the capacity to manage California's 276 BBEs more uniformly. Further research into the hydrologic complexities and dynamics of bar-built estuaries and the habitat and ecosystem services these dynamics provide will greatly aid the management these important coastal habitats.

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