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Assessing California's bar-built estuaries using the California Rapid Assessment Method

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ABSTRACT

Bar-built estuaries are generally found at the mouths of smaller watersheds with seasonal precipitation, episodic streamflow and seasonal swell dynamics. Low streamflows and constructive wave forces form a sand bar at the mouth isolating the stream from the ocean, creating a ponded lagoon, and inundating the surrounding marsh plain. Bar-built estuaries are wide spread in California comprising over 50 percent of California's more than 500 estuaries. By connecting terrestrial, freshwater, and marine realms bar-built estuaries are complex and dynamic providing great habitat and ecosystem services. California has suffered some of the highest losses of wetland habitats, and the wetland habitats of bar-built estuaries continue to be threatened by further development, pollution, and climate related changes including diminished streamflows and sea level rise. Given this loss and threat we developed a California Rapid Assessment Method (CRAM) to assess the condition of California's bar-built estuaries. CRAM uses visual indicators to accurately reflect current wetland condition with regards to buffer habitat, hydrology, physical complexity, plant diversity and structure, and landscape influences. Here we validate this method by comparing results of CRAM for bar-built estuaries to other accepted measures of wetland condition that we simultaneously collected with CRAM including vegetative surveys, water nutrient levels, and GIS landscape scale measures of stress for 32 sites throughout California. CRAM correlated well with each of these three independent methods of assessing condition. Notably, the Environmental Monitoring and Assessment Program (EMAP) number of natives metric significantly correlated with CRAM Index and all Attribute scores. The strong correlations of CRAM to nutrient levels is particularly important considering the documentation of the negative impact of nutrients on fish populations, the use of bar-built estuaries by juveniles of commercially important species, and the nursery role of bar-built estuaries for maintaining imperiled populations of species such as steelhead. GIS measured percent impervious, percent agriculture, and percent dams all correlated well with expected CRAM Attribute scores at appropriate watershed scales relative to the area of inference for each CRAM metric. Further, CRAM for bar-built estuaries works well throughout California's diversity of environmental conditions and regardless of geography, timing, or whether the bar was open or closed during the survey. We hope that the availability of CRAM combined with available data repositories will enable local, state, and federal decision makers to better manage, restore, and conserve valuable bar-built estuaries in the face of continual threats like development, drought, and sea level rise.

1. Introduction

Connecting marine, freshwater and terrestrial ecosystems, bar-built estuaries are complex and dynamic coastal confluences that provide a great diversity of habitat and ecosystem services (Beck et al., 2001; Fisher and Acreman, 2004; Costanza et al., 2014). Bar-built estuaries, also known as seasonally closed, seasonally tidal, or intermittently open or closed estuaries, are generally found at the mouths of smaller watersheds in Mediterranean climates with winter precipitation, episodic streamflow and seasonal swell

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dynamics. Under a typical pattern for California, high streamflows coupled with strong swells keep the stream mouth open in the winter; during summer, with low streamflows and a concomitant shift in swell direction, a sand bar forms at the mouth isolating the stream from the ocean. As a result, water is impounded expanding the aquatic and inundated marsh habitat, during the otherwise dry time of year. Even when closed, waves may overtop the sand bar delivering salt water, habitat structure and sources of productivity to the impounded lagoon. Bar formation may occur seasonally, interannually or over decadal scales, and the bar may form subtidally or in the high intertidal giving rise to variability in mouth state. The resulting structural complexity and spatiotemporal variability of bar-built estuaries may thereby support a wide array of species from specialist and generalist plants, to resident and migratory birds, to aquatic species from both the freshwater and marine realms. For example, bar-built estuaries provide juvenile rearing habitat for populations of threatened and endangered salmon (Shapovalov and Taft, 1954; Bond et al., 2008), as well as commercially important marine species such as Dungeness crab and California halibut (Monaco et al., 1990; Emmett et al., 1991; Hughes et al., 2014). By providing nursery habitat, bar-built estuaries may be disproportionately important to the maintenance of populations of aquatic species from both the freshwater and marine ecosystems, as well as species such as salmon that migrate between the two (Beck et al., 2001; Bond et al., 2008; Nagelkerken et al., 2013). Although individual bar-built estuaries may be relatively small and associated with smaller streams, they are quite common throughout California's coast, comprising over 50% of California's natural coastal confluences (Heady et al., 2014), and may provide important nursery habitat across a wider geography to more species than previously thought (Hughes et al., 2014).

With a growing human population, often centered in coastal areas, estuaries experience varying and often extreme levels of alteration (Dahl, 1990; Zedler, 1996). Future alterations, flood control practices, increasing demand for freshwater, and climate and sea level changes all further threaten these habitats and the services they provide (Dahl, 2000; Griggs, 2005; U.S. National Research Council, 2012). Thus there exists a critical need to assess the condition of over 280 bar-built estuaries of California to aid the management and restoration of these unique coastal ecosystems.

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). A total loss to date of 51% of wetland habitat in the conterminous United States and continual threats of further loss and alteration lends a certain urgency to the inventory and assessment of wetland habitats (Dahl, 1990). Unfortunately, ample funding is not necessarily available for or directed toward this endeavor, thus development of a cost-effective approach to assess condition is needed (Fennessy et al., 2007; Solek et al., 2012). Recognizing that intensive assessment methodologies are not always practical or necessary, 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 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 selected area relative to the range of possibilities using a finite set of field indicators, with a goal of informing management (Stein et al., 2009).

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 et al., 1979) but also has the highest loss of original wetlands in the lower 48 United States (91%; Dahl, 1990). Drawing from many other assessment methodologies previously developed throughout the United States and abroad and supported by the State of California and the USEPA the California Rapid Assessment Method (CRAM) has been developed independently for seven different wetland types including, riverine, estuarine, lacustrine, vernal pools, depressions, seeps and springs, and here bar-built estuaries. 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 larger 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 from several metrics based upon visual and easily measured indicators of ecological condition. The metrics assessed in CRAM are standardized across the different wetland types but are adapted as necessary to fit the characteristics unique to each wetland type. Of the different CRAMs for each of the seven different wetland types, the riverine and estuarine CRAM modules have been validated (Stein et al., 2009).

It is important that any given assessment methodology be validated using independent accepted measures of habitat condition in order to establish scientific credibility (Sutula et al., 2006; Stein et al., 2009). Here we validate CRAM for bar-built estuaries. We systematically selected 32 bar-built estuary sites throughout California encompassing a range of condition for which we simultaneously applied CRAM, collected Level 3 data commonly used to evaluate the condition of wetlands, and conducted landscape scale (Level 1) assessments of the watersheds of the selected sites for a multitude of stressors using GIS analysis. Then using correlation and multivariate analyses we followed and expanded upon validation methods described in Stein et al. (2009) to assess and validate the *Range and representativeness*, *Responsiveness*, and *Reproducibility* of CRAM for the bar-built estuaries of California.

2. Methods

We classified bar-built estuaries as coastal confluences that seasonally exhibit a strong fluvial influence characterized by directional surface flow between a watershed inflow and the ocean, for which surface water connectivity to the ocean is seasonally interrupted by a sand bar; however, these seasonal cycles may vary in response to interannual or decadal climatic variability. We defined the boundaries of bar-built estuaries for the purpose of this assessment to be the most extreme upland extent of impounded water arising from sand bar formation, based on historical aerial photographs and visual cues such as fluvially deposited wood and vegetative communities.

2.1. Study sites

We selected 32 bar-built estuaries distributed along the California coast to validate the CRAM module for bar-built estuaries (Fig. 1). Sites were selected to equally represent three 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 encompass a wide a range of condition to ensure and validate that CRAM can properly assess a