SUPPLEMENT

This supplement provides additional detail on the large-scale alternatives evaluated for Elkhorn Slough, the interdisciplinary investigations conducted, and the decision-making process.

Large-scale alternatives

At a series of meetings in 2005, Tidal Wetland Project (TWP) stakeholders generated numerous potential restoration actions designed to address the rapid channel erosion and marsh loss that had been documented in the estuary [1, 2]. These were then winnowed down to a smaller set of options over the following year, during TWP fieldtrips and group prioritization exercises. In 2006, four large-scale restoration alternatives were selected. They were thoroughly characterized and evaluated from 2006-2010, with final selection of alternatives completed in 2012. The timeline, accomplishments, and roles of different stakeholder groups involved in this process are summarized in Table S 1.

The large-scale alternatives were developed as strategies to reduce the tidal prism and thereby slow current velocities and reduce tidal scour [3]. Three of the alternatives accomplished this by decreasing the size of the entrance channel into Elkhorn Slough, which also served to reduce the height of high tide and thereby potentially enhancing marsh health by decreasing inundation time. Two of these mouth alternatives, the Low Sill and High Sill, involved submerged tidal barriers under the Highway 1 Bridge near the mouth of Elkhorn Slough (A in Fig. S1). The third mouth alternative, the Mouth Re-route, entailed closing the current Elkhorn Slough entrance channel and creating a new ocean inlet to the estuary to the north, at the location of a historic estuary mouth (B in Fig. S1). A fourth alternative, Parsons Restoration (C in Fig. S1), consisted of the substantial reduction of tidal prism to one large wetland complex that had subsided considerably during a period of diking and drainage; this would result in a significant reduction of tidal prism in the estuary as a whole. A fifth alternative – taking no major estuary-wide action to address tidal scour– was also evaluated to serve as a baseline for comparison with the other four alternatives.

Hydrodynamic and geomorphic evaluation

A team of scientists and engineers conducted a hydrodynamic and geomorphic investigation of the large-scale alternatives [3]. The team developed a sophisticated tidal circulation model and used that to predict water levels and velocities in the slough and the erosion of the channel bed through time. The modeling was reviewed and refined with input from the Model Advisory and Geomorphology Working groups. Overall, the modeling demonstrated that the Mouth Re-route and High Sill would be by far most effective at reducing tidal erosion, because peak ebb tide currents that erode the channel would be significantly reduced. However, differences between these alternatives and No Action decreased over time in the model; tidal erosion would slow in all alternatives by Year 50 because a new equilibrium would be approached as the main channel of the estuary grew larger.

Habitat predictions

The modeling team provided predictions of estuarine habitat extent under the five alternatives, based solely on inundation times [3]. Salt marsh habitat, the loss of which had been a major original factor in motivating the development of these alternatives, was predicted to be most extensive under the Mouth Re-route and High Sill options in the short term. Over the long-term, however, similarly extensive salt marsh loss was predicted to occur under all alternatives due to accelerated sea level rise.

A TWP Marsh Sustainability working group was convened to further explore and come to consensus on marsh sustainability issues [4]. This group determined that there have been multiple contributing factors to interior salt marsh loss in undiked portions of Elkhorn Slough, all of which have contributed to excessive inundation, also called “marsh drowning”. Increased tidal range following the 1946 opening of the harbor mouth led to initial losses, and has made marshes vulnerable to any subsequent stressor by decreasing their elevation relative to tidal waters. However the working group indicated that the role of the harbor mouth in more recent interior marsh dieback was unclear. The working group also recognized subsidence of the marsh plain as an important factor. The marsh plain is currently not tracking sea level

rise because it is sinking at almost the same rate as it is accreting sediment [5]. This subsidence could be a result of eutrophication leading to lower below-ground investment by marsh plants or faster decomposition rates [6]. Eutrophication has been shown to lead to salt marsh die-back as well as channel widening and bank erosion [7]. If eutrophication increased under the large-scale alternatives that decrease tidal prism and thus tidal flushing, then the potential gain in marsh predicted [3] based solely on inundation time might be countered by increased subsidence rates. The importance of a sediment supply was also recognized by the Working group. Diversion of the Salinas River in the early 1900s may have resulted in decrease of an important sediment source. The Mouth Re-route alternative would further separate Elkhorn Slough from the freshwater and sediment inputs of the Salinas River and Tembladero Slough. The working group concluded that only through targeted sediment addition projects and/or restoration of a sediment supply to the entire estuary, could Elkhorn Slough marshes be sustained in the long-term.

Water quality assessment

Evaluation of water quality impacts of the large-scale alternatives was conducted by researchers at the Monterey Bay Aquarium Research Institute's Land-Ocean Biogeochemical Observatory (www.mbari.org/lobo; [8]). No Action ranked highest for all water quality parameters assessed (dissolved oxygen, ammonium, hydrogen sulfide, primary productivity) except nitrate concentrations. The Mouth Re-route as well as the Low and High Sills could lead to negative water quality consequences for the estuary, increasing the risk of extended periods of hypoxia by decreasing flushing and thus removal of algal mats. The Mouth Re-route alternative ranked highest for nitrate reduction, because it would separate Elkhorn Slough from the current major nitrate source (the Old Salinas River Channel, D in Fig. S1). This would likely decrease eutrophication in the estuary in the long-term -- but not in the short-term, due to high existing organic enrichment.

The ESNERR water quality team conducted analyses that complemented MBARI's investigations, assessing causes and consequences of eutrophication at 18 sites throughout the estuary [9]. They found

that most of the main channel of Elkhorn Slough was moderately eutrophic, but more peripheral sites with restricted tidal exchange were highly or even “hypereutrophic”. The best predictor of hypoxia (low oxygen) was tidal range; all sites in the estuary with extended low oxygen periods and “hypereutrophic” conditions were behind water control structures. The TWP Water Quality working group concluded that predictions regarding water quality impacts of the large-scale restoration alternatives remained uncertain, but that it was important to proceed with great caution because of the high risk of dissolved oxygen crashes given the highly eutrophic conditions in the estuary. They highlighted that the ultimate solution to eutrophication in the estuary lies with decreased nutrient inputs.

Key species evaluation

In order to provide decision-makers with information on biological responses to the large-scale restoration alternatives, reports were prepared about a suite of key estuarine species [10-17]. Eight taxa (pickleweed, eelgrass, oysters, selected large benthic infaunal invertebrates, selected flatfish, selected shorebirds, harbor seals, and sea otters) were examined. They were chosen either because they have strong ecological effects on other species (e.g. by altering habitat structure or providing food resources) or because they have socioeconomic importance (e.g. recreational or commercial value). Each report was written by a local investigator, and was reviewed by a working group of 5-8 experts for that taxon.

The rankings of the alternatives in terms of favorability differed by taxon. No Action was found to be the best alternative for most of the large invertebrates and migratory shorebirds assessed, as well as for flatfish, sea otters, and harbor seals. These species all peak in abundance in the western, marine-influenced portion of the estuary and have co-existed with the harbor mouth without undergoing declines in the past decades. The Low Sill was ranked highest for Olympia oysters, jackknife clams, and least sandpipers. These species peak in abundance in the mid-estuary, where marine influence is more moderate, and thus might expand in abundance in the western estuary if tidal energy were reduced and the marine influence was dampened. The High Sill ranked highest for pickleweed, due to reduction in tidal

inundation time, and the Parsons Restoration alternative ranked highest for eelgrass, due to decreased velocities in the western main channel while maintaining marine influence.

Economic, policy and feasibility assessment

Social science evaluations of the alternatives were conducted so that the decision-makers could choose an alternative that would be likely to garner political support, be broadly favored by regional stakeholders, and be feasible in terms of policy, permitting and funding [18]. The analysis revealed that the Moss Landing Power Plant has the greatest economic impact in the estuarine region, followed by research/conservation organizations (MBARI, Moss Landing Marine Laboratories, ESNERR, Elkhorn Slough Foundation). Commercial and recreational fishing, harbor activity, and recreational tourism comprise smaller but important components. Because the Elkhorn Slough economy has developed around a strongly marine-influenced estuary, the study concluded that it was unlikely that current economic activity in the area would be affected detrimentally by the No Action alternative. Other alternatives, however, might negatively impact the local economy. For instance, number of days of hypoxia might increase if tidal prism were decreased, and preliminary results indicated that there might be a negative relationship between days of hypoxia in the estuary and subsequent offshore commercial fishery catch of some species.

The economic analysis also included surveys of visitors to Elkhorn Slough. Of those interviewed, 72 percent said they hoped to observe sea otters during their visit, and 41 percent listed birding as an activity that motivated their visit. While much of the focus of restoration at Elkhorn Slough is on salt marsh habitat, outdoor recreation in the estuary did not appear to be very affected by salt marsh extent. Recreation was concentrated in areas of greatest marine influence, including areas near the mouth of the estuary that lack extensive salt marsh. The Mouth Re-route or Sills would likely have negative impacts to kayaking by posing barriers to connectivity in navigation between kayak launching and wildlife viewing sites.

An extensive policy assessment [18] revealed an array of about 25 federal, state, regional, and local agencies/programs that have some authority or interest in what happens to Elkhorn Slough, and about 30 applicable laws or regulations. No Action was thus clearly the most straightforward alternative from a policy perspective. One of the most significant policy issues identified by the analysis was the absence of a single entity to coordinate legal oversight and accountability for the entire estuary, which would be required for the large-scale restoration alternatives at the mouth of the estuary. The policy analysis was augmented by a TWP Feasibility and Sustainability Working group. This group noted that pursuing a large-scale alternative at the mouth of Elkhorn Slough would require extensive federal, state, and local partnerships to meet the high costs of a project. Strong community support would be essential to generate the political will needed to generate this public investment. Such broad support appeared to be lacking, partly because many stakeholders were pleased with the status quo, and partly because of stakeholder concerns about unmitigated impacts and risks of large-scale projects at the mouth.

Decision-making process

Following completion of the evaluation of alternatives, the decision-makers charged the coordinating staff with drafting recommendations regarding large-scale alternatives. Ten recommendations were completed in September 2012. TWP participants provided written feedback on and scored level of agreement with these recommendations during September and October 2012. All ten recommendations were supported by TWP participants as indicated by the average scores they received, with support ranging from weak support to very strong support for different recommendations. The recommendations were discussed at a joint meeting of the TWP Science Panel and Strategic Planning Team in November 2012. Following the open meeting with all stakeholders, the decision-makers met independently to vote on the ten recommendations. All recommendations passed an initial straw poll with a 2/3 majority. Discussion ensued that led to minor modifications of the recommendations, increasing support for them. In the final vote, each recommendation received between 11-14 “yes” and 14-16 “passing” (yes + neutral) votes from the 16 voting decision-makers [1].

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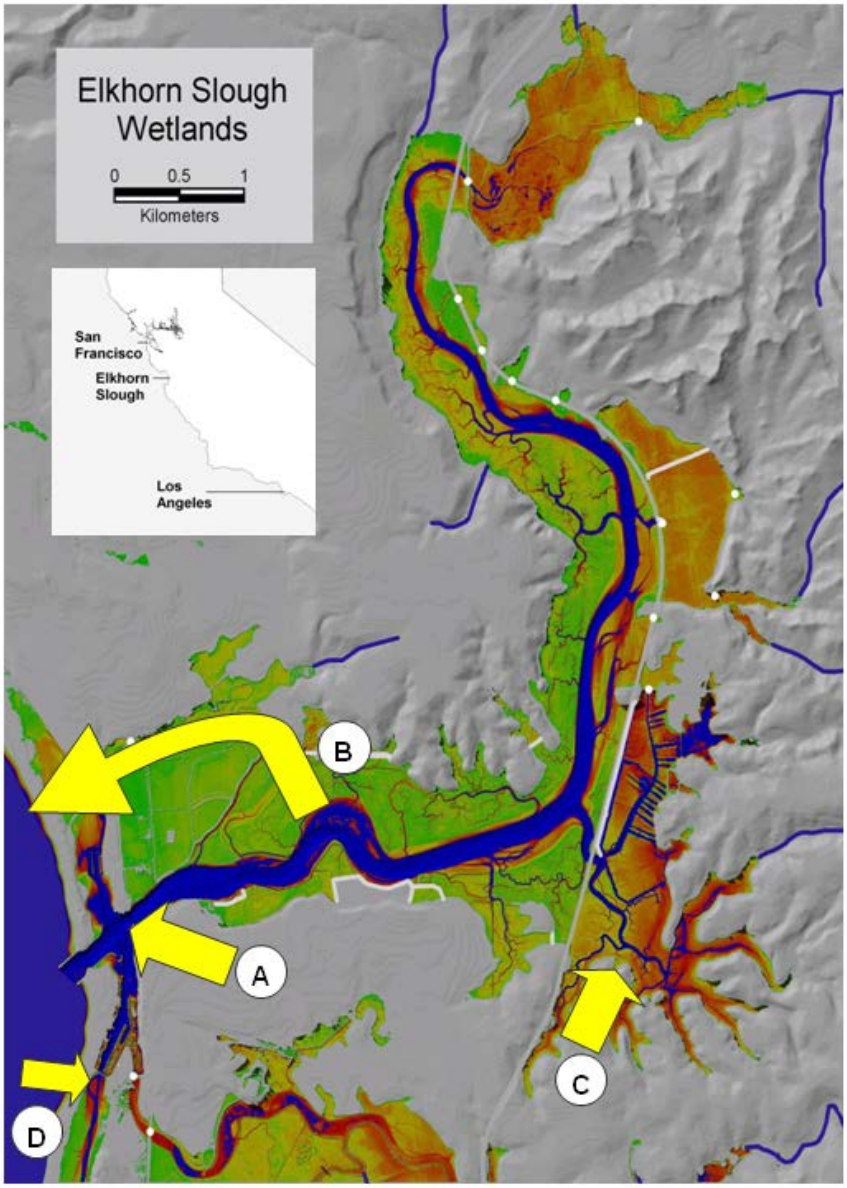
Figure S1. Map of Elkhorn Slough. **A:** The Low Sill and High Sill alternatives would be constructed near the Highway 1 Bridge at the entrance to Elkhorn Slough. **B**: The Mouth Re-route alternative would open a new inlet between the ocean and the main channel of Elkhorn Slough; the current entrance channel would be dammed under the Highway 1 Bridge. **C**: The Parsons Restoration alternative would substantially reduce the tidal prism of the entire Parsons Slough Complex. **D**: The majority of nitrate inputs to the estuary arrive in Elkhorn Slough via the Old Salinas River Channel. Colors correspond to elevations: green areas are above Mean High Water, of sufficient elevation to sustain salt marsh. Red and yellow elevations support intertidal mudflats. Blue areas are subtidal channels that are permanently submerged.



Supplementary Table 1. Milestones accomplished by different stakeholders

Quarter	COORDINATORS: TWP/ESNERR Staff	SCIENTIFIC STAKEHOLDERS: Science Panel/Joint SP/SPT Meetings	DECISION-MAKERS: Strategic Planning Team	EXPERTS: Working Groups	BROADER STAKEHOLDERS: Public
Spring 2004	**ESNERR and TWP Staff**: Received NOAA CIAP grant to launch the Tidal Wetland Project				
Summer 2004	**ESNERR and TWP Staff**: Identified key decision-makers and scientific expertise required to guide strategic planning	SP created	SPT created		
Fall 2004	**ESNERR and TWP Staff**: Coordinated first SP/SPT meetings	**SP/SPT:** Provided a critical review of the potential causes behind estuarine habitat change and hydrological trends in Elkhorn Slough	**SPT Meeting**: Amended and adopted the structure of the decision-making team and planning process, and began discussing the overall vision for TWP	**Historical Ecology Working Group**: Evaluated concepts for the historical ecology consensus statement **Ecological Characterization and Changes Working Group**: Revised estuarine habitat document	
Winter 2005	**ESNERR and TWP Staff**: Laid groundwork for decision and planning processes		**SPT Meeting**: Approved a consensus decision-making strategy, planning process framework, and strategy for public involvement		
Spring 2005	**ESNERR and TWP Staff**: Pursued funding for evaluation of five large scale alternatives for restoration of the estuary		**SPT Meeting**: Reached consensus that No Action alternative is not an acceptable course for Elkhorn Slough		Discussed TWP with the Friends of Moss Landing in a public seminar
Summer 2005		**Joint SP/SPT Meeting**: Refined list of Large Scale Alternatives and preliminary evaluation	**SPT Meeting:** Reached consensus on vision, goals and guiding principles for estuarine habitats in Elkhorn Slough		
Fall 2005	**ESNERR Research**	**Joint SP/SPT Meeting**:			

	Coordinator: Conducted correlative study looking at effects of tidal exchange on estuarine habitats and species	Revised list of alternatives and projected funding needs			
Winter 2006	**ESNERR and TWP Staff**: Received funding from Packard and Resources Legacy Fund Foundations to support evaluation of large-scale alternatives	**Joint SP/SPT Meeting**: Characterized effects of tidal exchange on habitats and identified potential causes of marsh loss	**SPT Meeting**: Developed and approved draft timeline of TWP actions for 2006-2011		
Spring 2006	**ESNERR and TWP Staff**: Drafted TWP Strategic plan	**Joint SP/SPT Meeting**: Developed a prioritized list of research and monitoring to inform TWP planning and restoration efforts			Presented and discussed major threats to Elkhorn Slough and potential efforts to conserve and restore these habitats
Summer 2006	**ESNERR and TWP Staff**: Drafted TWP Strategic plan	**Joint SP/SPT Meeting**: Discussed and recommended restoration strategies for tidal wetlands behind water control structures			
Fall 2006	**ESNERR and TWP Staff**: TWP strategic plan revised	**SP/SPT:** Modified TWP Strategic Plan	**SPT Meeting**: Adopted TWP Strategic Plan to provide shared consensus on context, goals, and approach		
Winter 2007	**ESNERR and TWP Staff**: Completed TWP Strategic Plan; coordinated development of reports on key species by taxonomic experts	**Joint SP/SPT Meeting**: Provided feedback on approaches for interdisciplinary characterizations of Large Scale Alternatives and scope of work for modeling different scenarios		**Key Species Working Groups**: Organized separate working groups with local and national taxonomic experts for each key species	Hosted community tour to learn about marsh loss and bank erosion in Elkhorn Slough; provided feedback on TWP Strategic Plan
Spring 2007	**ESNERR and TWP Staff**: Coordinated key species working groups and support			**Key Species Working Groups:** Reviewed reports summarizing factors that	

	report authors		limit distribution and abundance of species in estuaries, and causes of Elkhorn Slough trends	
Summer 2007		**Joint SP/SPT Meeting**: Provided feedback on preliminary results of characterizations of water quality, key species, marsh dynamics and socioeconomics		
Fall 2007	**ESNERR and TWP Staff**: Hired new TWP director after a few months of vacancy of the position			
Winter 2008		**Joint SP/SPT Meeting**: Provided feedback on hydrodynamic and geomorphic change predictions presented by modeling team	**Model Advisory Team and Geomorphic Working Group:** Worked closely to oversee the hydrodynamic and geomorphic model predictions	Held community meeting
Spring 2008		**Joint SP/SPT Meeting**: Review of final results of the analysis of hydrodynamics and geomorphic change under the different restoration alternatives		
Fall 2008	**TWP Director**: Drafted report of hydrodynamics impacts of different restoration alternatives	**Joint SP/SPT Meeting**: Gave feedback on presentation about impacts of large scale alternatives on water quality	**Water Quality Working Group:** Created group to predict likely water quality outcomes under different alternatives	
Winter 2009	**ESNERR and TWP Staff**: Began planning for a medium-sized restoration project, Parsons Slough Restoration Project			Distributed newsletter to stakeholders; held community meeting about the TWP Strategic Plan
Spring 2009	**ESNERR Research Coordinator**: Coordinated			Distributed newsletter to public and stakeholders

	drafting of predictions for key species under alternatives, by taxonomic experts. **TWP Director:** Developed new plan for funding following end of Packard EBM grant program; shifted focus to restoration implementation to align with grant opportunities				
Summer 2009	**ESNERR Research Coordinator:** Coordinated completion of key species reports			**Key Species Working Groups:** Reached consensus on likely changes to estuary-wide abundance of species under each restoration alternative	Distributed newsletter to stakeholders; held community meeting and hike
Fall 2009	**ESNERR and TWP Staff**: Received funding from the CICEET to examine past, present, and future marsh sustainability				Distributed newsletter to public and stakeholders
Winter 2010					Distributed newsletter to public and stakeholders; held public meeting
Spring 2010	**ESNERR and TWP Staff**: Worked to permit a medium-sized restoration project, Parsons Slough Restoration	**Joint SP/SPT Meeting**: Reviewed draft decision process for selecting Large-Scale Alternatives	Approved new decision process		Distributed newsletter to public and stakeholders; held public information meeting.
Summer 2010		**Joint SP/SPT Meeting**: Provided feedback on presentations of result of water quality, key species and socioeconomic characterizations of alternatives		Convened three additional working groups to fill knowledge gaps for large-scale alternatives: Feasibility & Sustainability Geomorphology, and Regional Context	Distributed newsletter to public and stakeholders
Fall 2010		**Joint SP/SPT Meeting**:	**SPT**: Tasked ESNERR staff	**Water Quality Working**	Distributed newsletter to

		Marshes Past, Present and Future – a review of CICEET funded research into Elkhorn Slough marshes	with developing draft recommendations for the large scale alternatives	**Group** met to form a consensus statement about likely outcomes of the different alternatives to water quality	public and stakeholders
Winter 2011	**ESNERR and TWP Staff:** Implemented a medium-sized restoration project, Parsons Slough Restoration				Distributed newsletter to public and stakeholders
Spring 2011		**Joint SP/SPT Meeting**: reviewed other accomplishments and planned to complete large-scale decision process			
Fall 2011		**Joint SP/SPT Meeting**: Reviewed and provided feedback on new research on marsh sustainability at Elkhorn Slough, past, present and future			
Summer 2012	**ESNERR and TWP Staff:** Hired new TWP Director; developed draft recommendations for Large-Scale Alternatives			**Marsh Working Group:** Created a consensus statement on factors affecting marsh dieback in the Slough	
Fall 2012	**ESNERR and TWP Staff:** Incorporated feedback from SP/SPT into draft recommendations; summarized scores and comments and shared with SP/SPT	**SP**: Completed survey to score agreement with and provide feedback on draft recommendations **Joint SP/SPT Meeting**: Reviewed recommendations, and scores and comments received in survey; further discussed recommendations	**SPT**: Completed survey to provide feedback on draft recommendations. **SPT Meeting:** Reviewed recommendations regarding the Large Scale Alternatives and additional restoration strategies for Elkhorn Slough		