Conundrum: Understanding Native Fish Functions of Emergent Tidal Marsh Restoration in a Highly Altered Landscape Largely Devoid of Tidal Marsh

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Tidal marsh restoration for years has been as a major strategy for upper estuary native fish recovery (CALFED ROD 2000, Delta Vision 2008, ERP Conservation Strategy 2011, BDCP 2014). Recently, the efficacy of tidal marsh restoration for native fish benefits has been called into question. The severe paucity of tidal marsh study sites in the upper estuary and limited studies of them severely constrain our local knowledge. Two large studies (Integrated Regional Wetland Monitoring Pilot Project, BREACH I-II-III), along with other smaller studies, provide some insight. Impediments to restoration success cannot be ignored, nor should benefits for overestimated. What can we say about tidal marsh functions for native fish? This session presents findings about potential functions. It considers historic and modern landscapes, physical processes, stable isotope-mapped tidal marsh food webs, carbon cycling, prey communities, and fish utilization. It considers landscape potential for restoring tidal marshes, open water, the upland transition, and "novel" landscapes. It concludes with restoration and science approach considerations for Suisun Marsh and the Delta based on current management programs. The limited data show tidal marshes provide native fish functions. Detrital- and invertebrate-based food webs. Trophic relays. Supporting variability in aquatic environmental parameters. Reducing surface water temperatures. Spawning and refuge habitats. Fewer invasive species. Critical interplay between hydrodynamics, biological processes, carbon and nutrient cycling, and associated ecological functions. Position along the estuarine axis and within subregions appears vital and informs limits. "Novel" landscapes may help support ecosystem functions. The time has arrived to "learn by doing" in a well-organized adaptive management framework that supports insight development. Location, variability in restoration types, landscape configurations, restorations as experimental study units, integration with modeling tools, and efficacy assessment are the ingredients to working through our current conundrum.

Keywords: tidal marsh, restoration, conservation, fish habitat, ecosystem function
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 1:00PM – 2:40PM Room 311-313

Value of Wetlands to Aquatic Foodwebs and Fish

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The San Francisco Estuary has undergone extreme urbanization and other anthropogenic changes over the last 170 years that have greatly reduced the quantity, diversity and variability of natural habitats. Future changes include intentional reconnection of shallow areas to aquatic access with the intent of benefiting valued biota, unintentional reconnections due to levee failure and floods, changes in the location of shallow areas, changes in the salinity regime and the tidal prism due to sea level rise, alterations of freshwater flow due to climate change and water management, and continued introduction of organisms suited to the changed environment. What are the limits and opportunities to protect and improve the values of wetland areas in the face of these changes and how do they interact with other human values?

Historical analyses give quantitative and qualitative guidance on the habitats the native fauna evolved in and the extremes of climatic variability they experienced. Large-scale restoration in the lower estuary and elsewhere illuminates the benefits to fish accrue mostly on site. Analyses in remaining wetland areas in Suisun Marsh and in scattered other wetlands in the upper estuary show that salmon and some other fish, including many introduced species, flourish in them. Other species, notably smelts, seldom use wetlands directly and likely benefit only in the immediate vicinity. Hydrodynamic and climatic models depict likely changes to the physical characteristics of the estuary in the next 100 years. Together the results and tools allow us to assess future scenarios and how humans can affect that trajectory. Such integrative work is crucial to formulate reasonable and achievable goals for protecting and restoring the aspects of wetlands that humans value.

Keywords: wetlands, fish smelt, salmon, baylands, marsh, export production, function, location
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 1:00PM – 2:40PM Room 311-313

Direct and Indirect Effects of Large-Scale Restoration and Implications for Science and Management

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Problem statement: Planned large-scale restoration profoundly changes hydrodynamics, shear stresses, and material transport in the channels and bays of the Delta, and the hydroperiod of restored tidal marshes. Tidal range and currents are modified at the Delta scale by each new restoration project, which in turn affects the trajectory of previous restorations. Successful large-scale restoration will require systematic scientific processes for understanding and managing the ecosystem effects of hydrogeomorphic change.

Approach: Hydrodynamics and transport models have been used over the years to plan restoration projects and study the effect of unplanned levee disasters. We draw upon the best of these analyses to propose several rules of thumb for staging, scaling, and judging restoration progress.

Findings: Restorations initiate hydrodynamics and transport process changes that have short, medium, and long-term effects. Wetted area, tidal currents, water levels, temperature regimes and residence times change immediately. Within days to months, sediment erosion and deposition is changing local bathymetry, sediment physiochemistry, primary production and plant and associated invertebrate communities. The adjacency of shallow water or intertidal marsh to more energetic and deeper channels drive scalar fluxes both ways. With years to decades, the energetics of tides, sediment, and vegetation have transitioned the biogeomorphology to a new dynamic state. Each of these processes mediates the other through non-linear feedbacks and thresholds, making predictions about outcomes difficult.

Conclusions: Making restorations relevant to native species resilience is not a matter of accumulating levee bordered restoration projects up to acreage goals. Rather, we should expect restoration of scaled-up functional landscapes to be messy, transitional, and surprising. We need new organization structures that support routine interdisciplinary interaction and use advanced data and modeling tools to manage the complexity of purposeful landscape change.

Keywords: Hydrodynamics, restoration, effects, landscape-scale, native species
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 1:00PM – 2:40PM Room 311-313

Conceptual Model of Fish Benefits of Tidal Marshes, Food Webs, and Linkages to Adjacent Habitats

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Problem. The vegetated intertidal zone with a meandering dendritic channel network is the defining feature of a tidal marsh. Fishes may use tidal marsh for foraging, refuge and spawning and they may access marsh-derived prey resources outside the marsh itself. Its role in supporting native fishes in the San Francisco Estuary remains unclear, however. *Approach.* We developed a conceptual model based on our hypothesis that the physical interaction between tide and geomorphic structure mediates food web production and fish usage in vegetated intertidal zones. The notion is that spring tides, especially those large enough for overbank flooding of the marsh plain, mobilize decaying plant matter and benthic invertebrates, thereby driving benthic food web production; neap tides facilitate in-situ phytoplankton production and advect and accumulate zooplankton, thereby driving pelagic food web production; and these patterns are reflected in behaviors of benthic and pelagic fishes. *Results.* We tested our hypothesis in First Mallard Slough in Suisun Marsh. This slough retains its natural meandering dendritic geomorphology, is subtidal at its mouth and intertidal at its head, and functions as a fish nursery grounds. Early results indicate that the benthic forager Sacramento splittail (*Pogonichthys macrolepidotus*) typically moves into and out of intertidal habitat during peak tides when water inundates stands of emergent vegetation. It is likely that the interaction of tide and channel bank structure provides increased foraging opportunities or predator refuge to benthic fishes. *Conclusions.* There appears to be considerable spatiotemporal variation in resource use within tidal marshes, highlighting the importance of dual food web pathways, heterogeneous channel structure, marsh plain elevation, and connectivity among diverse hydrogeomorphic features within the estuarine landscape.

Keywords: Tidal marshes, native fishes, food webs, invertebrates, zooplankton, hydrology, biogeochemistry
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 1:00PM – 2:40PM Room 311-313

Unraveling Sources of Food Web Support in the Sacramento-San Joaquin Delta's Marsh Ecosystems Using Fatty Acid Biomarkers and Multiple Stable Isotopes

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The current physical, biological, and chemical environment of the Sacramento-San Joaquin Delta little resembles historical conditions. A century of human alterations has dramatically transformed the Delta from a dynamic ecosystem dominated by riverine inflow, high turbidity, and vast marsh landscapes to one characterized by muted hydrodynamic variability, low productivity, and minimal marsh habitat. Adverse effects emanating from this transformation have been well documented for fishes, birds, and terrestrial wildlife reliant on natural ecosystem conditions, but ill-equipped to thrive in the current landscape configuration of the Delta. One major stressor for the Delta's organisms may be food limitation. Phytoplankton has decreased dramatically since the 1987 introduction of *Potamocorbula amurensis* and is thought to be related to the recent pelagic organism decline. Additionally, it is likely that the detrital food web is limited, as areas of internal, non-phytoplankton primary production are extremely limited within the Delta. Food limitation in the detritus-based food web, however, has received little attention in the region.

Given the historical landscape of San Francisco Bay and Delta, we hypothesize that non-phytoplankton detrital material plays an important role in supporting secondary production and that estuarine fish and invertebrates are well adapted to take advantage of this resource. We therefore focus on the detritus-based food web of the Delta, using stable isotope and fatty acid biomarkers to identify origins of food web support for important prey organisms and larval fishes. Preliminary evidence suggests detrital pathways are being utilized in tandem with algal sources. The results of this study may allow restoration planners to more broadly consider the role of vegetated areas, as these areas may not only provide shelter and spawning habitat, but may bolster food web support as well.

Keywords: Food web, Liberty Island, Stable Isotopes, Fatty Acid Biomarkers, Marsh
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 1:00PM – 2:40PM Room 311-313

Ecosystem-Scale Rates of Primary Production Within Wetland Habitats of the Northern San Francisco Estuary

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Large-scale tidal wetland restoration is planned for the northern San Francisco Estuary (SFE) and is thought to provide a variety of ecosystem services including shoreline stabilization, fish habitat, and organic carbon subsidies for estuarine food webs. Organic carbon comes from diverse primary producers that differ in carbon fixation rates and areal extent within wetland systems. This study was designed to obtain some of the first estimates of relative contribution of different primary producers to total organic carbon production within open water and tidally flooded wetlands of the SFE. Carbon fixation rates of phytoplankton, microphytobenthos, and low marsh vegetation were measured in two natural and four restoring wetlands in 2004. Areal (m^2) rates of carbon fixation were greatest for low marsh vegetation, while phytoplankton and microphytobenthos rates were one and two orders of magnitude lower, respectively. However, when areal production rates were scaled to the amount of habitat available for each primary producer group, the relative importance of each group varied by location. Given that each primary producer group supports a different subset of estuarine consumers, the type of food subsidy desired should influence the amount open water channel, mudflat and low marsh area restored. Large-scale wetland restoration activities should consider the types of primary producers likely to occupy restored habitats when estimating future food web impacts.

Keywords: Tidal wetlands, primary production, phytoplankton, microphytobenthos
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 3:00PM – 4:40PM Room 311-313

Nutrient and Organic Carbon Cycling Processes in Tidal Marshes and Shallow Water Habitats

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Tidal wetlands and shallow water habitats can be sites of high aquatic productivity, and they have the potential of exchanging this newly produced organic carbon with adjacent deeper habitats. Indeed, export of organic carbon from wetlands and shallow water habitats to pelagic food webs is one of the primary ecosystem functions contemplated in the Bay Delta Conservation Plan (BDCP). Alternatively, wetlands and shallow water habitats can function as retention areas for nutrients due to the nutrient demand of emergent macrophytes and denitrification in anoxic zones. They can also remove phytoplankton and non-algal particles from the aquatic food webs because the shallower waters can result in higher rates of benthic grazing and higher settling due to lower water velocities.

We conducted studies on Brown's Island, on Liberty Island, in the upper Cache Slough complex, and in the Deep Water Ship Channel to investigate the dynamics of nutrients and phytoplankton production at a variety of temporal scales. We collected continuous time series of nutrients, oxygen, chlorophyll and pH in conjunction with continuous acoustic measurement of water velocity and discharge to provide mass controls and used simple biogeochemical models to assess rates.

We found a high degree of temporal variability in individual systems, corresponding to, for example, changes in nutrient supply, water level, light level, wind, wind direction, and other physical factors. There was also large variability among the different systems, probably due to differences in flows and geomorphic features. We will compare the aquatic productivity of these environments and speculate as to their formative elements. Our findings demonstrate the complex interaction between physical, chemical, and biological factors that determine the type of production and degree of export from tidal wetlands and shallow water habitats, suggesting that a clearer picture of these processes is important for guiding future large scale restoration efforts.

Keywords: Wetlands, nutrients, Cache Slough, aquatic productivity, organic carbon, phytoplankton **Session Title:** Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes **Session Time:** Thursday 3:00PM – 4:40PM Room 311-313

The Utilization of Tidal Marshes by Fishes of the Upper San Francisco Estuary

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There are only about thirty published papers that are explicitly about fishes in tidal marshes and 'shallow water habitats' of the upper San Francisco Estuary. This paucity of publications from a system that generates a lot of scientific literature undoubtedly reflects how few tidal marshes remain or are recently restoring. However, when the estuary was in its pre-1850 configuration, it probably would have been difficult to discern among 'tidal marsh fish' and 'not tidal marsh fish'. Estuarine fish habitat emerges from combinations of relatively stationary landscape features and more dynamic water quality attributes. Different fish species and life stages live and die according to vital rates that emerge from these drivers, but studies that explicitly quantify vital rates inside and outside of nominal habitat types or along habitat gradients are lacking. The primary role of tidal marsh restoration in the estuary is to increase bathymetric variability including emergent marsh plains. This restoration goal is 'co-equal' with re-establishing appropriate dynamic habitat attributes to diversify fish habitat opportunities. To re-establish some of the historical interplay between stationary and dynamic fish habitat features, tidal marsh restoration must be combined with other actions such as an appropriate freshwater flow regime to support native species.

Keywords: Native fish, tidal marsh, fish habitat
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 3:00PM – 4:40PM Room 311-313

Linking Tidal Marshes, Open Water, and Novel Ecosystems for Fish Recovery in the Upper San Francisco Estuary

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Problem: Native fishes of the upper San Francisco Estuary are a subset of the endemic and rapidly declining native fishes of California. Seven species are listed and at least 10 more could be soon. Tidal marsh restoration has been pushed as a key recovery strategy, along with floodplain restoration, improved flow regimes, and reducing effects of other stressors. However, the efficacy of tidal marsh restoration has been questioned, both in terms of its potential for improving conditions for pelagic fishes and in terms of the overall benefits large-scale tidal marsh restoration. *Approach:* I review data and literature from past and ongoing studies for fit with new insights from the conservation literature. These data and literature span the range from very local field studies of focused questions to comparing changes at the landscape and multiyear scale. *Results:* Three major areas, the south-central Delta, the north Delta, and Suisun Marsh differ in their fishes, with natives most abundant in Suisun Marsh and least abundant the south-central Delta. The entire estuary is a novel ecosystem, one irreversibly altered by humans in myriad ways and supporting a mixture of native and alien species. Such systems can be fairly stable and resilient, if environmental change is not too rapid or severe. They presumably can also manipulated to some degree to generate favorable outcomes. *Conclusions:* Actions such as tidal marsh restoration can benefit native species in Suisun Marsh and the Delta, but only if combined with regional actions such as floodplain restoration, improved flow regimes, and resolution of the most critical other stressors. The novel ecosystem context, however, means that surprises can be expected. Reconciliation ecology is recommended as a basic approach to conservation.

Keywords: tidal marsh, novel ecosystems, Suisun Marsh, Delta, reconciliation ecology, fishes
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 3:00PM – 4:40PM Room 311-313

Delta ISB Review of BDCP Documents, Particularly Regarding Reliance on Habitat Restoration

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The Delta Independent Science Board (DISB) completed its review of the draft Environmental Impact Report/Environmental Impact Statement (DEIR/DEIS) for the Bay Delta Conservation Plan (BDCP) in May, 2014. This review was required under the Delta Reform Act of 2009, and it presented a rare opportunity to provide science guidance to a very large, very complex, and (mostly) socially desired capital project. The co-equal goals of water reliability and ecosystem health, together with the "tri-equal goal" of Delta as place, all relying on "best available science", presents the regional science community with a challenge as well as opportunity.

The DISB recognized the many strengths embedded within the BDCP and its associated DEIR/DEIS, but also identified several substantive shortcomings in the technical underpinning of the analyses of project impacts and mitigation or remediation. These are summarized in our review document, but pertinent to this session is the heavy reliance on habitat restoration as an offsetting measure of project impacts. The DISB specifically stated "Many of the impact assessments hinge on overly optimistic expectations about the feasibility, effectiveness, or timing of the proposed conservation actions, especially habitat restoration". The interplay between habitat restoration and resulting ecosystem outcomes, as a mitigation for project impacts, particularly with looming alterations to the biophysical system resulting from climate change, requires more explicit attention.

Keywords: BDCP; habitat restoration; mitigation; Delta Independent Science Board; climate change
Session Title: Exploring Emergent Tidal Marsh Restoration in Suisun and the Delta for Fishes
Session Time: Thursday 3:00PM – 4:40PM Room 311-313