The Role of Tidal Marsh Restoration in Fish Management in the San Francisco Estuary

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Tidal marsh restoration[1] is an important management issue in the San Francisco Estuary (Estuary). Large areas of tidal marsh restoration is on-going or planned in the lower Estuary (up to 6,000 hectares, Callaway et al. 2011). Large areas are proposed for restoration in the upper Estuary under the ESA Biological Opinions (3,237 ha) and under the Bay Delta Conservation Plan (26,305 ha). In the lower Estuary, tidal marsh has proven its value to a wide array of species that live within it (Palaima 2012). In the Sacramento-San Joaquin Delta (Delta), much of the value ascribed to freshwater tidal marsh restoration involves potential contributions to the

[1] Restoration as used here implies a reversal of impaired ecological features and processes that support desired species of wildlife, not a return to historic conditions.

food web of fish in open waters. This background was the basis for a symposium, *Tidal Marshes and Native Fishes in the Delta: Will Restoration Make a Difference?"* held at the University of California, Davis, on June 10, 2013. This paper summarizes the symposium with conclusions drawn by the authors.

From the scientific work done in the San Francisco Estuary and elsewhere we conclude:

1. Local productivity in tidal marshes benefits local consumers, including fish, mammals, and birds. These benefits are often extremely important for growth and survival of individuals on site but site-specific design is required to support targeted species and to reduce impacts of invasive species. Important design considerations include area, depth, residence time, extent of edge and small channels, location within the Delta, the nature of adjacent habitats, and connectivity of the restored site with adjacent habitats.

2. Movement of potential food items from a tidal marsh beyond the immediate area of tidal exchange is likely to be small. Even under ideal circumstances, plankton in small volumes of water from tidal marsh cannot greatly affect standing crop of plankton in large deep channels. Impacts of clams and other introduced species, either on site or downstream, can further reduce downstream contributions.

3. Large areas with diverse physical structure will enhance physical diversity and help meet various needs of native species. No quantitative guidelines exist but areas big enough to support both small and large internal tidal channels would be a good starting point. Diverse habitat types provide benefits to an array of desirable species at multiple life stages.

4. Effective tidal marsh planning requires a landscape-level and decadal perspective. Large-scale construction of tidal marsh will change tidal dynamics and alter the tidal inundation regime over a broad area. Sea level rise and inundation of Delta islands will change tidal dynamics, as will changes in timing or quantity of freshwater flow resulting from management or climate change. Tidal wetland design must plan for future tidal and flow regimes.

5. Information gaps for functions and processes in Delta tidal marshes are large but can be filled by designing restoration projects as experiments. Planning for new tidal marsh should use site-specific modeling to develop realistic expectations and testable hypotheses, incorporate experimental design to test hypotheses, actively investigate ecological mechanisms that develop in new environments, and contribute toward landscape-level ecological models.

Tidal wetlands elsewhere make broad, multifaceted contributions to fish habitat, productivity and resilience. However, the present Delta has little tidal marsh (< 5 % of the historical extent) and so its role is little understood. Experience from previous restoration efforts in the Delta, both intentional and accidental, can guide future work. Restoration of tidal marsh is well worth doing and should proceed boldly, carefully, and in a way that will fill crucial information gaps as we navigate massive environmental changes in the coming decades.

Tidal marsh was the dominant component of the primeval Delta (over 90% of its area) and was probably key to historical fish productivity that has been largely lost. Other elements of the landscape, including the natural hydrograph, floodplains and slough network are also greatly altered. Human alterations and abundant alien species preclude a return to the original

Delta. Climate change, earthquakes, and future species invasions will not allow us to sustain the present Delta. Creation and management of tidal marshes (and other elements of the historical landscape) can help protect species that humans value.

Historical records and maps reveal an intricate mosaic of diverse habitats dispersed across three main Delta regions - a floodplain region off the Sacramento River, a meandering channel region from the San Joaquin River and a tidal region where the rivers came together before flowing into Suisun Bay (Whipple et al. 2012). Lakes and marshes, riparian forests and seasonal wetlands, and other landscape forms were inundated to different depths and durations during different seasons and water years, providing a diverse portfolio of aquatic habitats. Overall, wetland area exceeded open water area by about 14:1; today it is 1:6, an 80-fold switch in dominant habitat types (Whipple et al. 2012). Open-water channels historically were considerably narrower and shallower than in the current Delta so volumetric change is even greater than areal change.

Shallow areas like those of ancient San Francisco Estuary are nurseries for fish in other estuaries along the Gulf Coast, the Pacific Northwest, and Chesapeake Bay. Small fish use edges of wetlands to feed and to avoid predation by larger fish (Baltz et al. 1993, 1998). Fish-eating wading birds enhance nursery function by preying on larger fish, thus reducing the risk of predation for smaller fish. The nursery value of a wetland for a particular species is affected by both accessibility and areal extent. In Louisiana, marsh value is affected by both edge and area. In early stages of degradation, shrinking wetlands retain their value for young fish because the amount of edge increases as wetlands are initially fragmented, which increases fish access (Chesney et al. 2000). On the other hand, harvest-per-hectare of commercial shrimp decreases strongly with declining marsh area (Turner 1977). Black rails and clapper rails in the lower Estuary have a minimum marsh size of about 50 ha and clapper rails have an optimum patch shape with minimum edge to area ratio. (Spautz and Nur 2002; Liu et al. 2012). Thus, it is important to understand marsh characteristics important to each species as we determine size, location, and configuration of new tidal marshes.

Reclaiming tidal wetlands from salt harvest, military use, and agriculture has been a major effort in the Estuary for the last 15 years and has improved our understanding of tidal marsh processes. A 2003 summary of the value of tidal wetlands to native fishes found large gaps in knowledge and many unfounded assumptions about tidal marsh function with respect to fishes (Brown 2003). Much knowledge has been gathered since then, usually as an aside rather than as an integrated part of restoration. For example, Napa River restoration sites illustrate alternating effects of riverine flow vs tidal flow; carbon isotope studies showed that fish draw much of their nutrition from upstream sources during wet periods and from marine sources when the river flow declines and tidal influence from the bay increases (Howe and Simenstad 2007, 2011). Three broad themes have emerged about fish use of restored tidal marsh:

1. Food web pathways for fish within a marsh are largely detritus-based, rather than phytoplankton-based (Howe and Simenstad 2007, 2011).
2. The vegetated edge is important for small fish foraging and predator avoidance (Gewant and Bollens 2012).
3. Newly constructed marshes are rapidly occupied by fish and their prey and are similar in value to reference tidal marshes (Cohen and Bollens 2008; Howe and Simenstad 2007, 2011).

In the modern San Francisco Estuary, tidal wetlands can be important habitats for many fishes, but likely have little impact on ecosystems at any significant distance. Measured flux of organic material into and out of Liberty Island (flooded in 1997, now tidal marsh and open water) suggests that little of the productivity that supports pelagic food webs on site is exported (Lehman et al 2010). Low populations of invasive clams, aquatic plants, and predators in Liberty Island presumably facilitate consumption of on-site productivity by small fishes, including valued species such as delta smelt (Sommer and Mejia 2013). Seasonal floods bring riverine materials into Liberty Island, but daily tidal action generally does not move much material away.

Tidal wetland channels can facilitate phytoplankton growth and accumulation if light penetrates most of the water column, due to shallowness or low turbidity. Long residence time allows build-up of high biomass, which can fuel further phytoplankton growth and zooplankton development. Benthic algae can be important parts of primary productivity in shallow or low-turbidity areas. Conversely, grazing impacts of clams are heightened in shallow water with long residence time (Lucas and Thompson 2012). Therefore, optimizing tidal wetland benefits to fish requires a balance between water depth and residence time to promote planktonic and benthic algal growth while minimizing clam impacts. Such balancing requires site-specific design considerations and improved understanding of factors affecting clam abundance.

Restored tidal wetlands are unlikely to have much impact on food webs in the upper Estuary's open waters. The small volume of water on tidal wetlands compared to the vast volume of open water in Delta channels and Suisun Bay means that flux of wetland phytoplankton and zooplankton cannot fuel downstream food webs. We are unaware of reports from the worldwide literature in which substantial quantities of zooplankton are exported from marshes to open waters, whereas several studies show net import of zooplankton .

Tidal wetland restoration without analysis of the processes in the developing ecosystem on site and in the landscape overall, wastes our limited opportunities to fill knowledge gaps. For example, breaching dikes at the Blacklock site in Suisun Marsh was not accompanied by studies of the evolving site, so much valuable insight was lost that would likely have been useful in guiding future restoration. Because of sea-level rise, Suisun Marsh is likely to change substantially as more diked ponds and wetlands become tidal. Inundation of large parts of Suisun Marsh will reduce tidal energy entering the Delta and change inundation patterns (and salinity) at other tidal wetland sites. Thus, studies are needed on restored sites, in areas adjacent to restored sites, and in areas that are affected by change in hydrodynamics due to the restored sites. In short, landscape-level analyses of restoration effects are essential.

Site-specific tidal-marsh restoration means that location is of primary consideration and that different sites will support different species and functions. Tidal wetland restoration should target specific sites that can be accessed by desired fish species and are minimally affected by invasive species. In the western Delta, the reach from Suisun Marsh to Liberty Island may provide an opportunity for landscape design and increase the habitat suitability for a variety of native fish (Moyle et al. 2012, Hanak et al. 2013,). Integrated, multi-purpose designs such as those for McCormack-Williamson Tract, Dutch Slough, and Prospect Island are good models for future design work.

Estuarine fish productivity will increase in and near carefully designed sites and may significantly affect fish populations overall. However, tidal marsh restoration will not result in broad increases in pelagic phytoplankton and zooplankton. Successful design is severely constrained by the limited knowledge of our few current tidal wetlands and by likely future changes. Exotic species and altered habitats dominate most of the Delta and have profound impacts on the aquatic ecosystem. Thus, the value of tidal wetland restoration to native species will be greatest where exotics are less abundant or where conditions can be altered to reduce exotic species' impacts. Climate change, sea level rise, and invasive species will require knowledge and flexibility to achieve ecosystems with desirable traits. Early restoration efforts must be approached as experiments in management that will guide later efforts, and be integrated over the entire Estuary. Increasing our knowledge of the trajectories of restoration is required to achieve our current goals and respond to future challenges.

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