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). Restoration of large areas of tidal marsh is ongoing 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 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), one important function ascribed to restoration of freshwater tidal marsh is that they make large contributions to the food web of fish in open waters (BDCP 2013). The Ecosystem Restoration Program (CDFW

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

2010) ascribed a suite of ecological functions to tidal marsh restoration, including habitat and food web benefits to native fish. 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 conclusions drawn by the authors from the symposium.

Consensus conclusions

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

1. Restoration of tidal marshes benefits many fish, mammals, and birds. These benefits can be extremely important for growth and survival of individuals of desirable species on site. Site location of restored marshes will determine which species will use them. Site-specific design is therefore required to support targeted species and to reduce impacts of invasive species. Important design considerations include area, elevations, residence time, extent of edge and channels, the nature of adjacent habitats, and connectivity with adjacent habitats.

2. Movement of plankton from a tidal marsh (beyond the immediate area of tidal exchange) is likely to be limited and to decrease strongly with distance. Even under ideal circumstances, plankton in water discharged from tidal marsh cannot greatly affect the standing crop of plankton in large, deep channels. Feeding by clams and other introduced species can further reduce contributions of marsh plankton to open-water foodwebs.

3. Large areas with diverse physical structure will enhance habitat diversity and help meet various needs of targeted species. No quantitative guidelines exist to relate restoration

extent to functional contributions at the population scale, but areas large enough to support tidal channels of diverse size and density similar to natural Delta tidal marshes is 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 perspective at a decadal, or greater, scale. 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 also 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 about functions and processes in Delta tidal marshes are large but can be filled by designing restoration projects as experiments. In particular, larger restoration areas may produce changes in system response that are large enough to be detected. 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 comparatively little tidal marsh (< 5 % of the historical extent) and so its role is little understood. Experience from previous restoration efforts throughout the Estuary, both intentional and accidental, can guide future work. The consensus of the group was that restoration of tidal marsh should proceed both boldly and carefully. Restoration should be accompanied by studies that fill crucial information gaps to help navigate the environmental changes expected in the coming decades.

Selected Findings

Tidal marsh was the dominant component of the primeval Delta (over 90% of its area) and was probably key to historical fish productivity, now largely lost. Other elements of the landscape, including the natural hydrograph, floodplains, sediment supply, and slough networks are also greatly altered. These alterations and abundant alien species preclude a return to the original Delta. Climate change, earthquakes, and future species invasions will further alter the Delta. Creation and management of tidal marshes can help protect species and ecosystem services 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 join 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 years, providing a diverse portfolio of aquatic habitats. Overall, wetland area exceeded open-water area by about 14:1; today wetland area is less than open water area by a ratio of 1:6, an 80-fold switch in dominant habitat types (Whipple et al. 2012).

Shallow areas like those of ancient San Francisco Estuary are nurseries for fish in 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 small 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 increases with marsh area, presumably because shrimp are not restricted to the edge (Turner 1977). Thus, the processes that benefit wetland species differ strongly from species to species. 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 crucial to understand marsh characteristics important to each species when determining 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 40 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 gained since 2003 and a revised summary of the current knowledge and knowledge gaps is expected in 2014 (Brown pers. comm.). Most knowledge has been garnered incidental to restoration activity, rather than as an integrated part. For example, isotope studies have been conducted in several tidal marshes with different restoration histories along the Napa River. These studies showed that fish draw much of their nutrition from upstream sources during wet periods, but that nutrition comes largely from tidal marsh and marine sources when river flow declines and tidal influence 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; new marshes provide habitat and food web support comparable to reference sites (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 will have little impact on export of food available to fish 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). Consumption of on-site productivity by small fishes, including valued species such as delta smelt, is presumably facilitated by low populations of invasive clams, aquatic plants, and predators in Liberty Island (Sommer and Mejia 2013) and similar areas in Suisun Marsh (P. Moyle, unpublished data). Seasonal floods bring riverine materials into Liberty Island, but daily tidal action seems not to move much material off-site; data are lacking on export of material that may occur during occasional large-scale flood events.

Tidal wetland channels can facilitate phytoplankton growth and accumulation if they are shallow and clear enough that light penetrates most of the water column. Long residence time allows buildup of high biomass, which can fuel further phytoplankton 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 shallow depth and 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 would be inconsequential to pelagic 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 to fish consumption on site.

Tidal wetland restoration without analysis of processes in the developing ecosystem and in the landscape overall, wastes opportunities to learn from ongoing projects and to improve design of future projects. For example, breaching of dikes at Blacklock in Suisun Marsh was accompanied by little effort to study evolution of the site, so insights to guide future restoration are limited. If levee work does not keep pace with sea level rise, more of Suisun Marsh may become tidal than the amount considered in the Suisun Marsh Plan (USBR 2011). Inundation of large parts of Suisun Marsh would reduce tidal energy entering the Delta and change inundation patterns (and salinity) at other tidal wetland sites. Similarly, inundation of lands in the Delta will alter tidal dynamics throughout the Delta. Thus, studies are needed on restored sites, in areas adjacent to restored sites, and in areas that are affected by changes in hydrodynamics due to the restored sites. In short, landscape-level analyses of restoration effects are essential.

Tidal marsh restoration outcomes are site-specific, in that different sites will support different species and functions based on location, elevation, adjacent habitats, and degree of hydrodynamic connectivity. Tidal marsh restoration can benefit a wide variety of birds, mammals, and plants but to support target fish populations, tidal wetland restoration must target sites that can be accessed by desired fish species and that are minimally affected by invasive species. In the western Delta, the reach from Suisun Marsh to Liberty Island may provide an opportunity for landscape-scale restoration and increase the habitat suitability for a variety of native fish (Moyle et al. 2012, Hanak et al. 2013). Integrated, multi-purpose designs have been developed for some specific sites, including McCormack-Williamson Tract, Dutch Slough, and Prospect Island.

Achieving successful restoration outcomes is severely constrained by many external factors including: alien species, Delta water management, sea level rise, climate change, sediment supply, and contaminants. Alien species and altered habitats dominate most of the Delta and have profound impacts on the aquatic ecosystem. The value of tidal wetland restoration to native species will be greatest where aliens are less abundant or where conditions can be altered to reduce their impacts. Climate change, sea level rise, and invasive species will require knowledge and flexibility to restore desirable traits to estuarine ecosystems. Early restoration efforts must be approached as experiments in management that will guide later efforts, and be integrated over the entire Estuary. We must increase our knowledge of the trajectories of restoration if we are to achieve our goals and adequately respond to future challenges.

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