Science-Based Strategies to Restore Key Ecosystem Processes in the Delta

Julie Beagle, San Francisco Estuary Institute, julieb@sfei.org
Scott Dusterhoff, San Francisco Estuary Institute, scottd@sfei.org
Erica Spotswood, San Francisco Estuary Institute, ericas@sfei.org
Amy Richey, San Francisco Estuary Institute, amyr@sfei.org

The Sacramento-San Joaquin Delta—an area the size of Rhode Island that drains more than 40% of California—has been dramatically transformed by human activity over the last two centuries. While regional planning efforts identify the need to restore large tracts of interconnected habitats, very little information is available to help design the complex landscapes that are likely to achieve this goal. To help fill this gap, we drew on an understanding of the Delta's historical ecology (circa 1800) and a detailed study of landscape change since the pre-development period to identify a series of strategies to help develop functional and resilient landscapes in the present and future Delta. These strategies emphasize the reestablishment of the physical processes that sustain interconnected habitats (as opposed to emphasizing the restoration of habitats themselves). Examples of strategies include 'Reestablish tidal marsh processes in areas at intertidal elevations,' 'Reestablish connection between streams and tidal floodplains,' and 'Reestablish fluvial processes along actively migrating streams.' For each strategy, we layered relevant environment data sets to identify "opportunity areas" in the Delta where the strategy might be implemented and considered how individual strategies should be arranged and combined to achieve desired ecological functions at the landscape-scale. This information can be referenced during regional and local planning processes to ensure individual, site-scale projects add up to a whole that ultimately helps to sustain healthy populations of native wildlife.

Keywords: ecosystem restoration, natural processes, landscape-scale
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Landscape-Scale Integration of Process-Based Restoration Strategies to Support Desired Ecological Functions in the Sacramento San Joaquin Delta

April Robinson, San Francisco Estuary Institute, april@sfei.org
Sam Safran, San Francisco Estuary Institute, sams@sfei.org
Julie Beagle, San Francisco Estuary Institute, julieb@sfei.org
Letitia Grenier, San Francisco Estuary Institute, letitia@sfei.org
Robin Grossinger, San Francisco Estuary Institute, robin@sfei.org
Ruth Askevold, San Francisco Estuary Institute, ruth@sfei.org
Erica Spotswood, San Francisco Estuary Institute, ericas@sfei.org
Amy Richey, San Francisco Estuary Institute, amyr@sfei.org
Scott Dusterhoff, San Francisco Estuary Institute, scottd@sfei.org

The Sacramento San Joaquin Delta has been dramatically altered over the past two centuries, severely reducing the ability of the Delta to support native wildlife. Recovering robust wildlife populations and ecological communities, and supporting their long-term resilience, will require yet another transformation in the Delta. We used our understanding of historical ecology (circa 1800) and landscape change since the pre-development period to make recommendations for how process-based restoration strategies might be implemented and combined to best support different wildlife groups at a landscape scale. We make recommendations for anadromous and non-anadromous fish, marsh wildlife, riparian wildlife, waterbirds, and wildlife associated with habitats historically on the periphery of the Delta (including vernal pools, alkali wetlands and oak savannas). We highlight the importance of appropriate levels of habitat connectivity, diversity, and redundancy, and how these levels might be achieved in the future Delta.

Keywords: Sacramento San Joaquin Delta, Ecological Function, Landscape-scale, Resilience, Historical Ecology
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Primary Production in the Delta, Then and Now

James Cloern, US Geological Survey, jecloern@usgs.gov
April Robinson, San Francisco Estuary Institute – Aquatic Science Center, april@sfei.org
Amy Richey, San Francisco Estuary Institute – Aquatic Science Center, amyr@sfei.org
Letitia Grenier, San Francisco Estuary Institute – Aquatic Science Center, Richmond, letitia@sfei.org
Robin Grossinger, San Francisco Estuary Institute – Aquatic Science Center, robin@sfei.org
Katharyn Boyer, Romberg Tiburon Center – San Francisco State University, katboyer@sfsu.edu
Jon Burau, U.S. Geological Survey, jrburau@usgs.gov
Elizabeth Canuel, Virginia Institute for Marine Science, ecanuel@vims.edu
John DeGeorge, Resource Management Associates, jfdegeorge@rmanet.com
Judith Drexler, U.S. Geological Survey, jdrexler@usgs.gov
Chris Enright, Delta Science Program (retired), Chris.Enright@deltacouncil.ca.gov
Emily Howe, Aquatic and Fishery Sciences, University of Washington, ehowe2@uw.edu

Low primary production is a constraint on meeting California's goal of protecting, restoring and enhancing the Delta ecosystem. But is low primary production an inherent attribute of the Delta, or is it largely a result of landscape changes? Recent analyses from the Historical Ecology Team and Delta Landscapes Project provide quantitative comparisons of the areal extent of 14 habitat types in the modern and historical Delta. We describe an approach for using these metrics of landscape change to: (1) produce the first quantitative estimates of how overall Delta primary production and contributions from five different producer groups have been altered by landscape transformations; (2) convert these production estimates into a common currency so the contributions of each producer group reflects its food quality and efficiency of transfer to consumers; and (3) use simple models to discover how tidal exchange between marshes and open water influences primary production and its consumption. Application of this approach would inform Delta management in two ways. First, it would measure historical losses in the Delta's capacity to produce food for native biota, providing a basis for understanding landscape change as one of multiple stressors on the Delta ecosystem. Second, it would provide restoration practitioners a new approach for establishing targets and performance measures based on the ecosystem processes that could be amplified by different restoration actions.

Keywords: ecosystem restoration, primary production, historical ecology, food quality, habitat connectivity
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Reinvesting in the Delta's Food Web Portfolio

Emily Howe, School of Aquatic & Fishery Sci., ehowe2@u.washington.edu
Charles Simenstad, School of Aquatic & Fishery Sci., Univ. of Washington, simenstd@u.washington.edu

Due to a century of human alterations to the Sacramento-San Joaquin Delta (Delta), the sources and magnitudes of living and detrital organic matter (OM) imported into the Delta from the watershed has changed. In concert with this change, the potential contributions of primary producers contributing to food web processes within the Delta has shifted from enormous production by marsh vascular plants to substantially less production by phytoplankton and submersed and floating aquatic vegetation. This change underlies considerable scientific debate about (1) the relative importance of production sources to consumers in the existing, relict Delta, and (2), the potential food web benefits of future tidal wetland and floodplain restoration.

Interpreting the relative significance of living (algal) and detrital sources to important consumers is complex because of differences in their quality and availability in food web pathways and processes. We utilize stable isotope analyses from the 2008-2012 BREACH III investigations of the restoring Liberty Island tidal freshwater wetlands and the on-going SFCWA Cache Slough Complex studies to provide insights into the present OM sources to food webs in a reach of the Delta with minimal tidal wetland production. Our findings indicate that larval fishes, and ecologically-important planktonic and epibenthic macroinvertebrates, are supported by a diverse mix of phytoplankton, filamentous green algae, and detrital particulate OM from macrophytic plants within the Liberty Island/Cache Slough Complex. Despite differences in the spatial and temporal variability in controls on production and the nutritional quality of these living and detrital sources, contributions of OM from tidal wetlands are non-trivial, and likely significant during periods of low algal production. Reinvesting in recovery of the Delta's historic tidal wetlands should contribute to a more diverse portfolio of widely variable quantities, qualities and timing of both living and detrital OM sources, and ultimately a more productive and resilient food web.

Keywords: food web, Delta, restoration, organic matter
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A Tale of Two Deltas: A Comparison of Transport Processes in the Historical and Contemporary Delta

Jon Burau, USGS, jrburau@usgs.gov
John DeGeorge, Resource Management Associates, jfdegeorge@rmanet.com

Modification of the Delta's landscape has fundamentally changed hydrodynamic and transport processes in the Delta. Here, we compare transport processes in the historical and contemporary Delta based on a scaling-up of insights gained from a handful of targeted small-scale site-specific field experiments and numerical model results. Principal among the changes are:

(1) The fortnightly (e.g. spring/neap cycle) decoupling/coupling of pelagic and marsh plain habitats that occurred on a massive scale in the historical Delta, now occurs in only a couple small-scale select locations.

(2) The historical delta was a dendritic marsh system comprised mostly of a hierarchy of independent dead-end channel systems that supported pelagic habitat diversity, unlike the homogeneous habitats created by the interconnected web of canals that exists today.

(3) Except for high flow periods, transport of the river flows through the historical Delta was mainly accomplished through a relatively few, large channels. In contrast, the contemporary Delta is fundamentally a "flow through (conveyance) system", where virtually every single channel is engaged in moving the river flows (and exports) through the system.

(4) The geomorphology of natural channels in the historical Delta created within-channel velocity gradients; these velocity gradients are largely absent in the narrow, deep, rocked, steep-sided and prismatic channels that make up the contemporary delta, possibly reducing the suitability of contemporary pelagic habitats.

The consequences of these changes, particularly the periodic fortnightly decoupling/coupling of pelagic and marsh plain habitats at the scale of the Delta on the biogeochemistry, on primary producers and on both the pelagic and marsh plain ecosystems is unknown. However, the magnitude of the differences in transport processes between these systems suggests the possibility that the historical Delta supported a radically different ecosystem at the primary producer level than the ecosystem that exists today.

Keywords: hydrodynamics, transport, historical
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A New Dimension to Historical Ecology: Insights from a 3D Hydrodynamic Model of the Pre-Development Estuary

Samuel Safran, SFEI, sams@sfei.org
Stephen Andrews, RMA, steve@rmanet.com
Letitia Grenier, SFEI, letitia@sfei.org
Robin Grossinger, SFEI, robin@sfei.org

A 3D hydrodynamic model of the pre-development (ca. 1800) upper San Francisco Estuary has been developed to help understand how changes in the geometry and hydrology of the system have altered key physical and ecological processes. This hydrodynamic model was constructed using a new digital elevation model of the pre-development upper estuary and new estimates of "natural" Delta inflows, and then calibrated using historical information on tidal characteristics. Once completed, the pre-development model was paired with a similar model of the contemporary system in order to analyze hydrodynamic changes in the upper estuary, including changes in tidal prism, isohaline position, low-salinity zone habitat, channel velocity, and source water distribution. This paper presents the results of these analyses and considers the ecological implications of the modeled differences in estuarine hydrodynamics. The models suggest that there has been a decrease in temporal variability of water salinity (with implications site-scale heterogeneity in tidal marsh plant communities), a landward movement of X2 due to changes in estuarine geometry and sea level rise (with implications for aquatic organisms and human water supply), a loss of low-velocity refugia in blind tidal sloughs (with implications for juvenile fish), and dramatic changes in the distribution of freshwater from the Delta's many tributaries (with implications for migrating adult anadromous fish). Understanding changes in these and other hydrodynamic variables can help to improve our understanding of the desirable ecosystem functions provided by the historical system and, as a result, improve our ability to recover these functions now and into the future.

Keywords: historical ecology, pre-development, Delta, Suisun, hydrodynamic modeling, X2, processes
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Time Travel in the Sacramento-San Joaquin Delta: Developing Photorealistic Images of the Historical Landscape to Inspire Restoration

Erica Spotswood, San Francisco Estuary Institute, ericas@sfei.org
David Osti, 34 North, david@34north.com
April Robinson, San Francisco Estuary Institute, april@sfei.org
Sam Safran, San Francisco Estuary Institute, sams@sfei.org
Robin Grossinger, San Francisco Estuary Institute, robin@sfei.org

The Sacramento-San Joaquin Delta has been fundamentally altered by human modification. Once an extensive tidal and freshwater emergent marsh, the Delta has been transformed by agriculture, water diversion and development. So little remains of the former Delta that it is difficult to envision what the Delta looked like historically, and few modern analogs exist. Yet, visual representations of the historical Delta can serve as a valuable tool for guiding and inspiring future restoration efforts. To fill this gap, we drew upon historical and contemporary ecology to reconstruct the Delta's many historical habitat types, including tidal and freshwater emergent wetland, riparian forests, and the transitional and upland habitats that once occurred along the margins of the Delta. By combining historical information with modern analogous habitat types from around the state, we determined the most likely dominant species composition for each habitat, as well as the likely structure and configuration of the Delta's former plant communities. Species assemblages for each habitat type and a historical digital elevation model were used as inputs into a 3D modeling and visualization tool that builds renderings of landscapes from the ground up. These renderings can be used to create seamless flyovers of the Delta at broad spatial scales, as well as detailed still imagery showing close up views of habitats and locations of interest. Visual representation of lost landscapes can help inspire future restoration, can help to create a sense of place, and can be used as a tool for public engagement and education.

Keywords: Sacramento-San Joaquin Delta, restoration, historical ecology, historical habitats, visualization
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How an Understanding of Past and Present Condition is Linked to Management and Implementation of Restoration in the Delta

Carl Wilcox, California Department of Fish and Wildlife, carl.wilcox@wildlife.ca.gov

The objectives of ongoing restoration efforts in the Delta are focused on re-establishing habitat and associated processes which have been lost or degraded during the 150 years. The Delta is a shadow of its historic past and can never be restored to its previous condition. Our challenge is to understand the physical and biological attributes of that historic condition and identify opportunities to restore and enhance those functions and processes in the context of the co-equal goals of the 2009 Delta Reform Act, providing a more reliable water supply for California and protecting, restoring and enhancing the Delta, in a manner that protects and enhances the Delta as place. As discussed in the previous presentations we have a new understanding which is critical to guiding efforts to restore important ecological attributes that are critical to supporting sensitive aquatic and terrestrial species that depend on the Delta for all or part of their life-cycle. Without this knowledge we are taking action without objective criteria against which to gauge success. Restoration efforts in the Delta will be reconciling the historic past with what is possible to achieve given the physical and social realities of today's Delta and that of the future.

Keywords: restoration, Delta, habitat, functions, processes, sensitive species, co-equal goals, historic, ecological
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