2021 Bay-Delta Science Conference: Oral Abstracts

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Tuesday Scheduled Sessions

Smelt Science for Management

Responses of Wild Delta Smelt to Climate Variation

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Climate models, laboratory experiments, and distribution data all indicate that Delta Smelt are likely to be negatively impacted by future changes in California's climate. In order to prevent the extinction of this critically endangered species, our society needs to quickly and significantly invest in novel and effective conservation approaches. The severity of future impacts on the wild population, however, remains uncertain, possibly limiting the political will for expediency in addressing this ecological crisis. Using otolith-based approaches, we examined how the growth, phenology, and life history of Wild Delta Smelt respond to variation in environmental conditions. Our results examining wild fish confirm previous findings and indicate that population dynamics of wild Delta Smelt could be even more sensitive to climate change than previously thought. Results of this work can be used to forecast how different climate scenarios are likely to impact the remnant Delta Smelt population and, perhaps, to also help identify and justify effective interventions.

Quantifying the Evolutionary Potential for Delta Smelt Persistence in a Warming Habitat

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Long-term persistence of the endangered Delta Smelt (*Hypomesus transpacificus*) will depend, in part, on whether the species harbors the genetic variation necessary to adapt to changing environmental conditions such as warm temperatures. Temperatures

in the San Francisco Bay-Delta are increasing and extreme temperature spikes are becoming more common. The availability of additive genetic variation for traits that affect fitness directly determines the ability to evolve; however, nothing is currently known about the presence of genetic variation for resistance to elevated temperature in Delta Smelt. We performed a quantitative genetics experiment to test whether Delta Smelt harbor the necessary genetic variation for adaptation to elevated temperatures. We established crosses between wild and hatchery-reared (domesticated) fish and raised siblings from each family in both an optimal temperature (15) and an elevated temperature (18). We estimated thermal tolerance and genotyped 1,000 fish raised in these two thermal environments. Genetic variation for thermal tolerance will indicate whether the species has the capacity to evolve adaptations to warming temperatures in the Delta. Our experiments will also reveal whether domesticated and wild fish differ in their thermal tolerance abilities. Together, this information can be used to manage the refuge population and inform supplementation by maintaining genetic variation that may be crucial for resilience in a changing Delta.

An Individual-Based Model of Delta Smelt Population Dynamics: A Versatile Tool for Life-Cycle Analyses of Management Actions

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Tools to evaluate the effects of stressors and natural variation on Delta smelt at the population level are needed for the design of effective conservation and recovery actions. Individual-based life-cycle models are well suited to incorporating spatial information and for simulating the complex interactions between the transport and movement of individuals and dynamic environmental conditions. We describe a Delta Smelt individual-based model (DSIBM) that follows the daily reproduction, growth, survival, and movement of individuals from eggs through adults within the same spatial grid as that used by the DSM2 hydrodynamic model. An earlier version of the DSIBM was developed by Rose, Kimmerer, and others more than eight years ago. We recently updated the model by incorporating new Delta Smelt biology and adding new features for exploratory analyses. These advanced features include: tightly coupling the IBM to environmental conditions generated from DSM2, expanding the historical years simulated to 1990-2012, adding capability to use CALSIM output to drive 82-year simulations under synthetic hydrology, and adding an option to examine effects of supplementation. We have also demonstrated two analyses often not included in complex IBMs and are of particular use to management: an optimization algorithm to help examine trade-offs between alternative restoration actions, and a computationally efficient Monte Carlo uncertainty analysis leading to a statistical meta-model of the IBM dynamics that is solved very fast. We briefly describe these advances with selected example analyses. The updated version of the DSIBM is undergoing calibration and validation to establish model skill and the results will inform how to appropriately interpret model results for alternative scenarios. The updated and expanded model provides a quantitative tool for providing mechanistic explanations for Delta Smelt population responses to variation in environmental conditions and multiple stressors, and for comparative analysis of the effectiveness of alternative management actions.

How Can Isotopes Inform Understanding of Life History Diversity in Wild Longfin Smelt

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The Longfin Smelt (*Spirinchus thaleichthys*) is an estuarine species that is distributed up and down the western coast of North America. The population in the San Francisco Estuary, which represents the southernmost extent of the species, has seen precipitous declines due to water diversions, climate change, and other human impacts. To better protect and manage this population, it is important to have an improved understanding of its life history and ontogeny. However, Longfin Smelt are too small for traditional tracking technologies such as acoustic tags. One potential solution is the use of otolith geochemical analysis. Stable isotopes of elements in the water are incorporated into the hard parts of the fish as they grow, and potentially represent a history of the environment the fish experienced throughout its life. Here we demonstrate the use of strontium and oxygen isotopes to estimate the changes in salinity that individual fish have experienced during their lives, as a proxy for movement throughout the estuary. Additionally, we discuss the differences between the use of each isotope, and how they can complement each other with greater specificity at high and low salinities. We find that stable isotopes reveal a diversity of life history strategies and that different groups of individuals are utilizing different areas of the estuary throughout their lives. Longfin Smelt appeared to hatch and rear in fresh to brackish water, exhibiting the use of several natal habitats. Timing of movement into more brackish water was relatively consistent among groups. This life history diversity represents a potential source of resiliency but also complicates management actions.

Estimation of Longfin Smelt Hatching Distribution, Abundance and Entrainment using Three-Dimensional Hydrodynamic and Particle-Tracking Models

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The distribution of larval fishes in estuaries is influenced by where they hatch and their movements after hatching. In the San Francisco Estuary, the threatened longfin smelt (*Spirinchus thaleichthys*) spawn adhesive eggs in shallow, fresh to brackish water. Attached eggs hatch and the larvae disperse seaward toward higher-salinity water. Actual locations of spawning are unknown, and cannot be inferred from distributions of larvae because intense tidal mixing erases the history of movement. Human interventions such as manipulations and diversions of freshwater flow may contribute to the ongoing decline of this species, and these effects depend on where the fish hatch. We combined connectivity estimates from hydrodynamic and particle-tracking modeling with trawl data in a Bayesian model to estimate the location and timing of hatching, as well as natural mortality of larvae and losses to freshwater diversions. Longfin smelt were estimated to have hatched further seaward than previously believed; estimated diversion losses were small compared to natural mortality, and therefore pose only a minor risk to the population. Similar methods could be applied in other estuarine and coastal systems where strong mixing reduces the ability of simpler models to predict spawning location and larval movement.

Physical Processes: Shaping the Bay-Delta

A Systematic Evaluation of Empirical X2 Models Published Over the Past 25 Years

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Problem Statement: This work surveys the performance of several empirical models that were developed over the past 25 years to relate freshwater flow and salinity in the San Francisco Estuary. The estuary's salinity regime, broadly regulated to meet urban, agricultural and ecosystem beneficial uses, is managed in spring and certain fall months to meet ecosystem objectives by controlling the 2 parts per thousand bottom salinity isohaline position (referred to as X2). Multiple empirical models have been published for X2 since 1995, using different data and assumptions. Our goal was to compare their performance in a systematic manner using the same data for calibration and testing.
Approach: Five previously developed models, all configured to relate freshwater flow to X2 position in the estuary, were recalibrated to a common data set and tested for accuracy, mean and transient behavior using standard statistical approaches.
Results: Model performance was observed to vary with hydrology, year and season, and in some cases exhibited unique limitations due to mathematical

formulation. However, no single model was found to be consistently superior across a wide range of tests and applications. One test revealed that the models performed similarly when recalibrated to a uniformly perturbed input time series. Thus, while the models may be used to identify anomalies or seasonal biases, their use as inverse models to infer freshwater outflow through the estuary from salinity observations is not expected to improve upon the accuracy of existing outflow estimates.
Conclusions/Relevance: This is the first simultaneous evaluation of the different empirical X2 models published for the San Francisco Estuary over the past 25 years. No model was found to be uniformly superior, and this work suggests that, for analyses spanning a long hydrologic record, an ensemble approach may be preferable for exploiting individual model strengths.

Hydrodynamic Metrics to Evaluate Tidal Marsh Dynamics in the Sacramento-San Joaquin Delta

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The most ubiquitous landscape feature in the historic Delta were dendritic marsh systems that periodically, from daily to spring-neap timescales, inundated the marsh plain. Projects to restore landscapes to tidal marsh systems will provide support for multiple food web constituents, including detrital and pelagic productivity. We hypothesize that, with the hydrodynamic metrics developed, phytoplankton production can be maximized and exported out of tidal marsh systems. Using a combination of field data and numerical modeling we demonstrate the utility of length-scale and volume-ratio metrics to describe where phytoplankton production occurs within tidal marsh systems and how phytoplankton biomass is exported out of these systems.

On neap tides, phytoplankton production occurs in the regions upstream of the tidal excursion, because these regions are isolated from exchange at the mouth of the system, which creates longer residence time. The regions where higher production is likely can be predicted by a length-scale ratio, the ratio of the tidal excursion to the channel length. However, during spring tides, the marsh plain becomes inundated at high water, significantly increasing the volume of water that exchanges with the system. Optimal resource exchange from the tidal marsh system to surrounding channels occurs as phytoplankton from the upper channels is flushed out of the system, and nutrients are imported to the regions of longer residence time to allow for continued production on the subsequent neap tide. Accordingly, we show that phytoplankton flux out of the system can be reasonably predicted using two metrics: the ratio of tidal prism at tidal timescales: flood to ebb, and fortnightly timescales: spring tide to neap.

Finally, through the use of numerical modeling, we demonstrate, using these hydrodynamic metrics, how the flux of phytoplankton out of these systems can be maximized through changes in marsh elevation and berm height at the channel-marsh plain interface.

Accurate, High Resolution, Measurements of River Surface Velocity and Turbulence Metrics Over Large Areas in the Sacramento River and Its Implications for Water Resource Management

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Measurements of instantaneous water flow velocity, from which turbulence metrics are calculated, are important for advancing the understanding of river hydrodynamics beyond fundamentals such as discharge and mean velocity.

However, most velocity measurement methods that can be used in the field are capable of measuring only at a point, or along a transect of the river, but not over a two-dimensional area. In addition, commonly used tools such as ADCPs (acoustic Doppler current profilers) generally require temporal and spatial averaging, and therefore can not resolve the instantaneous velocity.

We present instantaneous velocity and turbulence metrics measured in the side boundary layer at two sites on the Sacramento River. The measurements were made using IR-QIV (Infrared Quantitative Imaging Velocimetry), a method developed by the authors in a partnership between Cornell University, DWR Bay-Delta office, and USGS, that uses images of the river surface collected using a sensitive thermal infrared camera, and tracks thermal patterns at the surface of the river to calculate the time-resolved instantaneous two-dimensional surface velocity field. IR-QIV is capable of calculating the instantaneous velocity at high accuracy and high resolution, in both space and time (centimeter scale, at rates of several Hz), and over a large area—up to hundreds of square meters of the river surface.

This type of velocity measurement is uniquely suited to a wide range of applications, including verification of computational flow models (CFD), and studying fish behavior, e.g., interaction between migrating fish and guidance structures/barriers or flow diversions.

Monitoring Elevations of Tidal Marshes in San Pablo Bay-Delta: Update on Surface Elevation Table (SET) Monitoring

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Accelerating sea-level rise, changes in storm frequency and intensity, shifting patterns in freshwater flow and precipitation will impact marsh habitats and local wildlife communities. Marsh elevations are a balance among local suspended sediment delivery to the surface, subsidence, organic matter production, and tidal flooding for vertical accretion. Monitoring marsh elevation in the San Francisco Bay-Delta, many managers have questions – Are marshes keeping pace with sea-level rise? And is there enough sediment for marsh accretion? To better assess stability and elevation building of tidal marsh elevations over the near and long-term, we have been monitoring a network of deep rod Surface Elevation Tables-Marker Horizon (SETs-MH) since 2013 in San Pablo Bay-Delta, CA. At each marsh site we have water level loggers deployed to assess trends in water level and inundation relative to elevation change, as well as salinity. Sites are located across a tidal and salinity gradient from Miner Slough, Browns Island, Rush Ranch, San Pablo NWR, and Petaluma Marsh. The rate of elevation change has varied between sites and between the high and low marsh elevations within each site. The average elevation change since installation is 26.61 mm/yr at Miner Slough, 6.78 mm/yr at Browns Island, 1.85 mm/yr at Browns Island, 4.90 mm/yr at San Pablo NWR, and 2.61 mm/yr at Petaluma. The current rate of sea-level rise at the San Francisco Bay Golden Gate tide gauge is ~2 mm/yr, with most of our SET locations keeping pace with sea-level rise. Updated results from water logger will be provided with further insight into tidal inundation and accretion patterns.

Sediment Transport Modeling Using Artificial Neural Network

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The Sacramento-San Joaquin Delta is characterized by an interconnected system of sloughs, waterways, and a tidal outlet. Such complexity often makes it challenging to model the suspended sediment transport within the Delta using process-based approaches (e.g., numerical models), because the mechanisms governing sediment transport are not yet fully understood. As a complementary tool, a machine learning model was developed. Employing the Long Short-Term Memory (LSTM) Networks, which are a type of Artificial Neural Networks (ANN), the model can predict the suspended sediment concentration (SSC) by treating the unknown as a missing piece in a recognized pattern, rather than relying on the governing equations behind the physics. To train the model, historical records of flow and SSC at various locations within the Delta were used. The study period was water years 2011 through 2016, but the training period (i.e., range of observed data used to train the model) was varied to assess the model's sensitivity to the inputs and to determine the optimum model setup. Comparison between the model-predicted SSC and the observation at fourteen key locations within the Delta showed that the performance of the LSTM model is comparable or superior to that of DSM2-GTM, a process-based transport model. The study findings suggest that machine learning models can be an effective tool for sediment transport applications, especially when necessary inputs to numerical models (e.g., observation data) are not available or difficult to attain. In fact, the LSTM model has a potential to become a valuable management tool in the future, as the fast-changing climate and intensifying weather events will make calibration of process-based approaches increasingly difficult.

Food Web Foundations

Nutrient Status of San Francisco Bay

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Managers in San Francisco Bay (SFB) are faced with the great challenge of protecting the estuary from nutrient enrichment. Meeting this challenge requires scientifically grounded information to determine when and how to implement policies of nutrient control. Our five decade USGS sampling program in SFB was designed to capture seasonal and spatial variability of water quality parameters including dissolved inorganic nitrogen and phosphorus concentrations. In recent years, sampling for organic and particulate N and P forms was added. We synthesize these data to assess the nutrient status of SFB from lower South Bay to Suisun Bay. Our assessment is based in five categories that characterize nutrient pollution in estuaries: (1) the estuarine setting and indicators of current water quality, (2) external nutrient sources and input rates, (3) concentrations and forms of SFB nutrients, (4) nutrient-based indicators of the potential for algal biomass production and the degree to which that potential is realized, (5) budgets to estimate the fates of externally derived nitrogen and phosphorus. We found that despite the high nutrient inputs and concentrations, SFB is not impaired by hypoxia, recurrent HABs, or excessive algal production. Causes for concern include nutrient concentrations higher than other impaired estuaries, chronic presence of multiple algal toxins, recent increases in primary production, and projected hydroclimatic conditions that could increase the magnitude and frequency of algal blooms. In this presentation we discuss our assessment of SFB's nutrient status to inform nutrient management.

Loss, and Potential Recovery of Primary Production from the Sacramento-San Joaquin Delta

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Humans are changing the Earth's surface at an accelerating pace, with significant consequences for impacted ecosystems and their biodiversity. Landscape transformation has far-reaching implications including reduced net primary production (NPP) available to support ecosystems, reduced energy supplies to consumer organisms, and disruption of ecosystem services. Anthropogenic activities have reduced global NPP available to terrestrial ecosystems by nearly 25%, but the loss of NPP from wetland ecosystems is unknown. We used a simple approach to estimate aquatic NPP from measured habitat areas and habitat-specific areal productivity in the Sacramento-San Joaquin Delta, comparing historical and modern landscapes and a scenario of wetland restoration. Results show that a 77% loss of wetland habitats (primarily marshes) has reduced ecosystem NPP by 94%, carbon (energy) flow to herbivores by 89%, and detritus production by 94%. To our knowledge, this is the first estimate of lost NPP across multiple producer groups in a large wetland ecosystem. Our results also show that attainment of the Delta Plan's habitat restoration goals could recover 12% of lost NPP and measurably increase carbon flow to consumers, including at-risk species and their food resources. This study illustrates how a simple approach for estimating the loss of ecosystem functions from measured habitat losses can guide conservation plans by establishing historical baselines, projecting functional outcomes of different restoration scenarios, and establishing performance metrics to gauge success.

Floodplain Trophic Subsidies Support Juvenile Salmon in a Highly Altered River Network

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Trophic subsidies transport nutrients and energy from areas of surplus to areas of deficit, driving food web structure and growth opportunities for fishes and other taxa. In the Sacramento-San Joaquin River Delta, large reductions in productivity, fueled by habitat loss and invasive species, have impacted its ability to support resident and migratory fishes. Despite this habitat loss, remnant patches of floodplain and other off-channel habitats continue to produce high densities of high-energy prey items (e.g. large-bodied cladoceran zooplankton), increasing growth rates of juvenile Chinook salmon able to access these habitats. However, the extent to which advection of these prey items into downstream habitats also supports the diet of native fishes in the Delta is less well understood. Here, juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and zooplankton were sampled from locations above and below the outlets of the two major floodplains draining into the Delta (Yolo Bypass and Cosumnes River floodplain). We analyzed spatiotemporal patterns in juvenile salmon stomach fullness and diet composition annually from 2014 to 2018, incorporating a range of hydroclimatic conditions. The results suggest significant advection of invertebrates from the two floodplains into the Delta, particularly in wetter years 2016 and 2017. Cladocera – in particular, *Daphnia pulex* - dominated the diet of salmon caught immediately below the floodplains and decreased with increasing distance downstream. Stomach fullness index and cladocera abundances (both in stomach samples and the ambient water column) were also higher in years characterized by higher flows and longer inundation periods. Overall, these data suggest that flow-assisted 'food delivery' from floodplains and other off-channel habitats could play a key role in supporting the growth of juvenile salmonids in the Delta, and emphasize the importance of maintaining a diverse habitat mosaic and foodscape to support resilient fish populations.

A Synthesis of Productivity Estimates for the Abundant Copepod *Pseudodiaptomus Forbesi*

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Phytoplankton productivity in the San Francisco Estuary is available to fish only after it has been consumed by one or two trophic levels of zooplankton. Although phytoplankton primary production is reasonably well known, we know less about the efficiency by which grazing and growth convert phytoplankton to zooplankton biomass. To fill this gap in knowledge, we synthesized data from >100 measurements of growth rate and >200 measurements of reproductive rates of *Pseudodiaptomus forbesi* from several field-based projects starting in 2006. Data were separated into four habitat types: brackish and fresh open-water estuarine channels, the Cache Slough Complex (CSC), and the Yolo Bypass toe drain. Neither growth nor reproduction was related to salinity, reinforcing previous work showing that the seaward limit of this euryhaline population is not determined by salinity tolerance. Rates of growth and reproduction were chronically food limited. Growth rate was related to chlorophyll concentration by a saturating function that explained about 24% of the variance. This function did not differ among habitat types, so higher growth rates in the CSC and especially the Yolo Bypass were mainly due to higher phytoplankton biomass. Chlorophyll was a weaker predictor of reproductive rate but the estimated maximum rate was about twice as high in the CSC as in the other habitats. Estimated secondary production by copepods was ~5% of estimated primary production, consistent with the important role of microzooplankton as a partial intermediate trophic level that reduces foodweb efficiency. These results highlight how variability in foodweb processes is key to variability in energy available to higher trophic levels. Results for shallow, off-channel habitats are encouraging, but our

ability to scale these habitats up may limit their quantitative contribution to the pelagic food web.

Zooplankton Community Response to Extreme Environmental Events in the Cache-Lindsey Slough Complex

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In the past decade, the north Delta has been subject to drought, high flows, and record temperatures. Climate change will continue to exacerbate these events. To help understand how the food source of native Delta fishes may be impacted, we are analyzing monthly zooplankton samples collected since 2012 from the north Delta. The areas of focus are within the Cache-Lindsey Slough Complex (CLC), specifically upper slough sites. The CLC is influenced by agriculture, water export, artificial lakes, restoration sites, wetlands, and natural upland inputs. Cache and Lindsey Slough vary significantly in water input, flow, and nutrient load, and have very different plankton dynamics.

Our initial results build on previous studies that show higher densities of zooplankton near terminal ends of slough complexes, and abundance shifts in response to local flows from precipitation, irrigation and flood control districts, and agriculture. Our study compares the hydrodynamically different Cache and Lindsey Sloughs, as well as upstream and downstream slough sites within each. We compare samples taken during drought years with very wet years to understand how flow effects nutrient dynamics and food web response. Our spatial, temporal, and hydrodynamic study will support management of adjacent landscapes to help offset impacts of climate change, and create optimal nutrient and flow dynamics for food webs.

New Habitat, New Science: Advances in Wetland Restoration

After the Breach - First Year Monitoring of the Tule Red Tidal Restoration Project

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The Tule Red Tidal Restoration Project (led by Westervelt and SFCWA, with DWR) restored and enhanced 420 acres of tidal wetlands in Suisun Marsh, with the goal of increasing primary and secondary productivity to enhance food supplies for listed fishes (delta smelt, juvenile salmonids, and longfin smelt). In October 2019, the outer natural berm of a former duck club was breached to restore tidal flows to constructed channels, ponds and pannes. During the first year after breaching (June-December 2021), ESA measured physical, water quality, and biological conditions to test hypotheses of tidal marsh function and restoration.

A bathymetric survey documented the outboard breach channel deepening and interior channels re-sizing and widening. Water level gauges documented increasing tidal conveyance at the outboard channel. The back marsh was fully connected, with flows limited by channel conveyance at ebb and flood tides. Large ponds flooded on spring tides and were disconnected during neap cycles, as designed. Small pannes on the high marsh stayed inundated. Chlorophyll-a concentrations were higher in the ponds than the channel. Dissolved oxygen levels were variable August-September, sometimes below 5 mg/L in a dead-end channel, which was likely due to algal blooms. Methyl mercury (unfiltered water) averaged 0.05-0.21 ng/L, similar to other restored tidal wetlands. Vegetation mapping documented pickleweed establishment on the constructed habitat berm, poor plant establishment near the levee crown, and rapid revegetation in the tidal marsh. Phragmites is colonizing new areas from pre-existing stands. Invasive plant mapping in May guided weed management.

The ponds are functioning as designed: high hydrologic residence time to enhance productivity, with periodic tidal exchange to export resources through channel to Grizzly Bay. Monitoring by other partners of foodweb, fish (larval longfin smelt were documented in the channel), birds and Phragmites complement these findings and broaden lessons learned from this newly restoring site.

Dutch Slough Tidal Marsh Restoration Monitoring: Launching a Program to Track Ecosystem Development

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Tidal wetland restoration is increasingly used to meet habitat goals in the San Francisco Bay-Delta. Thousands of acres of additional restoration is planned in the near-term, using the green infrastructure of tidal wetlands to protect against rising tides, provide habitat for key plant and animal species, and ensure continued ecosystem processes like nitrogen removal and carbon storage. However, the effectiveness of tidal wetland restoration and the trajectory of restoration sites is still unclear, especially at the freshwater-saltwater interface (~2 ppt salinity). The Dutch Slough Tidal Marsh Restoration Project was designed to be a living laboratory for scientific studies and will be breached within the next two years, creating an opportunity to study the benefits of restoration when compared to other land uses and to inform adaptive management of tidal wetland restoration trajectories. We will quantify conditions pre- and post-breach at Dutch Slough, in nearby reference Delta islets, and in former tidal wetlands under agricultural production to compare land uses. We will track development of vegetation composition and abundance, elevation capital, water quality in channel and groundwater (nutrient concentrations, salinity, turbidity), soil carbon and nitrogen stocks, and greenhouse gas emissions. This project will quantify key long-term tidal wetland processes including elevation change, carbon sequestration, methane emission, and nutrient removal, providing baseline information that will inform response of tidal freshwater wetlands to sea-level rise, drought, and other climate/anthropogenic changes. The integrated monitoring program at Dutch Slough will include UC Davis Bohart Entomology Museum, Cramer Fish Sciences, River Partners, and others. Ultimately, initial responses and long-term evolution of this site will provide crucial information to inform adaptive management of restoration projects, future restoration design in the Bay-Delta and beyond, and tidal wetland baselines as climate change alters conditions across the Estuary.

Montezuma Wetlands Project: Early Results and Lessons Learned from a Newly Breached Marsh

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The Montezuma Wetlands Project is a multi-phase restoration project that uses dredged sediment to raise elevations in diked, subsided baylands to restore ~2,000 acres of a tidal wetland ecosystem. This project is unique, as it receives most of its revenue from the acceptance of dredged sediments. These include sediments not suitable for unconfined aquatic disposal, then buried and isolated in an anoxic environment under at least 3 feet of cleaner sediments. The project owns the highest rate sediment offloading system west of the Mississippi, and has operated successfully since 2003 by placing almost 9 million cubic yards. The project is on target to accomplish its restoration goals in support of the Long-Term Management Strategy (LTMS), established by a joint effort of the Corps and other federal, state and regional agencies to maximize the safe beneficial reuse of sediment dredged from SF Estuary.

Montezuma breached its first phase of over 500 acres in October 2020, and has been monitoring development of the new marsh system. Early post-breach monitoring data includes fish use, vegetation development, water quality, and tidal channel formation. Early monitoring indicates the breach was successful, with encouraging physical (tidal flows matching with target site elevations), chemical (water quality), and biological (early wildlife use) results. Ongoing monitoring over the coming years will provide important data on early marsh development. Pre-breach data includes detailed elevation and habitat surveys and over 15 years of biological and chemistry sampling results, which documented safe handling of the sediments. The extensive data collected has allowed Montezuma to adaptively manage and improve its restoration methods to increase resiliency for sea-level rise and changing needs and conditions. By working in

collaboration with regulatory agencies, project partners, and the Technical Review Team, Montezuma has pioneered many new scientific and engineering approaches and methods for large-scale tidal marsh restoration.

Reconnecting Delta Food Webs: Evaluating the Influence of Tidal Marsh Restoration on Energy Flow and Prey Availability for Native Fishes

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In the upper San Francisco Estuary species introductions, tidal wetland loss, and watershed modifications have led to long-term declines in primary productivity and native fish populations. While expansive tidal wetland restoration is planned for the region, our knowledge on how pelagic, benthic, and terrestrial components of Delta food webs interact is cursory. This data gap precludes systematic understanding of restoration benefits for native fishes such as delta smelt (*Hypomesus transpacificus),* longfin smelt (*Spirinchus thaleichthys*), and salmonids. The goal of our research is to elucidate the effects of tidal marsh restoration on food web structure and prey quality for native fishes. To accomplish this, we are comparing pelagic, benthic, and terrestrial prey resources, fish catch, trophic structure, and multiple physical variables among six relict and recently breached wetlands. Preliminary findings from our first year of sampling indicate that early season (Feb) prey availability and food web complexity were limited at all wetlands compared with late season (May), suggesting less opportunity, capacity and realized function for early season fish. Additionally, we found differences in native fish catch and size among sites during spring sampling, including the presence of 70 longfin smelt (mean fork length + SE = 31.0+0.35 mm) at the mouth of the Tule Red restoration that were statistically larger than 48 longfin smelt (28.9+0.41 mm) captured within Chipps Island ($F_{1,116}$ = 15.51; $P < 0.001$). We are currently completing invertebrate prey identification and calorimetry, fish diet, stable isotope and ecosystem metabolism analyses on our first year samples as well as preparing for a second year of sampling. Results from this on-going project will address key Bay-Delta management questions centered on how restoration of tidal wetland structure translates into the recovery of food web processes and improved fish habitat.

How Do Food Webs Change Following Tidal Restoration? a Preliminary Assessment of Restoration Success in Two Fish Restoration Project (FRP) Wetlands

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Much of the tidal wetland restoration in the Sacramento-San Joaquin Delta and Suisun Marsh (the Upper SF Estuary) is being constructed under the premise that wetland restoration will increase the resilience of Delta Smelt, Longfin Smelt, and rearing Chinook salmon. We examined changes in water quality and food webs following restoration of tidal wetlands at two sites: Decker Island and Yolo Flyway Farms.

The Fish Restoration Program (FRP) Monitoring Team is tasked with developing monitoring plans for tidal wetland sites. We approach restoration for fish using a whole-ecosystem approach, collecting data on the physical habitat and multiple levels of the food web. We sample water quality, nutrients, primary producers (phytoplankton and vegetation), invertebrates (mesozooplankton, macrozooplankton, surface, epiphytic, and benthic), and fish at and adjacent to each of our restoration sites. Data are collected and analyzed using a BACI (Before-after-control-impact) design; each restoration site is paired with a reference wetland site and is sampled before and after restoration.

We analyzed patterns in phytoplankton, invertebrate, and fish abundance and diversity (richness and evenness) using GLMM with restoration status, season, year, and region as factors. We examined differences in species composition of phytoplankton, invertebrates, and fish using PerMANOVA. Overall, abundance of all food web levels was highly variable, with differences between wetlands, years, and seasons. Species composition differed between seasons and wetlands.

This study provides a much-needed look at how food webs change following restoration of tidal wetlands. Through monitoring we can empirically understand the potential of tidal restoration to provide food and habitat for at-risk fish as the sites evolve. Findings will be shared with scientists and managers across the SF Bay Delta community to inform future tidal restoration projects.

IEP Special Session: The Value of Long-term Biological Monitoring in the San Francisco Estuary

(*IEP) The Value of Long-Term Monitoring of the San Francisco Estuary for Delta Smelt and Longfin Smelt

Trishelle Tempel[1], Timothy Malinich[1], Jillian Burns[1], Arthur Barros[1], Christina Burdi[1], James Hobbs[1]

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Long-term monitoring programs are an important tool for understanding ecosystem change but are rare due to the challenges of supporting these types of studies over time. The California Department of Fish and Wildlife has been conducting long term monitoring surveys in the upper San Francisco Estuary for over 60 years, and this longevity has been made possible by adapting to suit management needs, expanding our knowledge about the Estuary, and legal mandates requiring their continuation. The surveys produce annual abundance indices for multiple life stages of Delta Smelt (*Hypomesus transpacificus*) and Longfin Smelt (*Spirinchus thaleichthys*), and are used in protective measures to minimize entrainment into the large water diversions in the south Delta and facilitate our understanding of the drivers of population declines. The long-term decline of native smelt species occurred as a part of four major regime shifts in the ecosystem; Pre-Clam, the time before the invasion of the overbite clam (*Potamocorbula amurensis*; past-1986), Post-Clam, the time leading up to the Pelagic Organism Decline (POD; 1987-2001), the POD (2002-2012), and a new regime we identify as the Climate Shift (2013-present day). While some regimes are linked to single causes (i.e., the invasion of *P. amurensis*), others are correlated with multiple environmental stressors including decreased freshwater flow (drought, freshwater diversion), invasive species, changes in food availability and composition, and contaminants. Our changing climate is exacerbating the impact of existing stressors and accelerating population decline which while require new, innovative strategies to ameliorate impacts to Delta and Longfin Smelt.

(*IEP) The Influence of Environmental Conditions in Long Term Fish Abundance Data

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The California Department of Fish and Wildlife has been conducting long-term monitoring studies in the upper San Francisco Estuary to document the distribution and relative abundance of fish and zooplankton to inform management of freshwater flows since 1959. The value of this long-term monitoring relies on the consistency of the survey design and execution, sampling gear and catchability over time. However, catchability is known to be affected by environmental conditions such as water clarity, which has greatly increased over time. Here we attempt to explain long term patterns in fish catch for the Fall Midwater Trawl and Summer Townet surveys within the San Francisco Estuary relative to environmental conditions such water clarity and water outflow as influencing factors. For many fish species, we have found a long-term decrease in catch which has been compounded during periods of low flow, high water temperature, and high water clarity. These factors potentially increase the ability of fish to avoid or escape capture by trawl nets, reduce their presence in the water column via lack of feeding or predator avoidance, or some combination thereof. Reduced use of pelagic habitat means reduced carrying capacity for fishes. These results highlight the importance of understanding the role of environmental conditions in the context of catchability and the value of long-term datasets to give insights into these relationships.

(*IEP) Invasion of the Water Body Snatchers: Invasive Goby Trends from the San Francisco Bay Study and Summer Townet Survey.

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The California Department of Fish and Wildlife (CDFW), part of the Interagency Ecological Program, has been informing resource managers, the scientific community, and the public on the San Francisco Estuary (Estuary) fish and invertebrate community abundance and diversity through long-term monitoring studies such as the Summer Townet Survey (STN) and the San Francisco Bay Study (SFBS). These surveys have produced invaluable datasets that are used to identify subtle and significant changes occurring within the Estuary, such as the Pelagic Organism Decline (POD). A more recent change in the Estuary, observed by STN and SFBS, has been the rapid population growth of invasive goby *Tridentiger* species (i.e. *trigonocephalus*, *bifasciatus*, and *barbatus*) even following the sharp decline of common pelagic species. Abundance patterns measured by STN, which catches fish species in the water column during their larval and early-juvenile stages, show that yearly production of *Tridentiger* species is increasing. Similar patterns in abundances of juvenile and adult *Tridentigers* have been observed by the SFBS otter trawl, a demersal sampling survey, which provides a spatial context to *Tridentiger* populations across the Estuary. Factors that contributed to the POD may be impacting the presence of *Tridentigers* in the Estuary. However, environmental factors such as increasing water clarity, which negatively affected pelagic fishes, may be benefiting benthic communities by increasing benthic production. We compare our observations to other demersal species, such as native gobies and sculpins, to determine if there is a growing benthic trophic community or only the rising success of invasive gobies. Monitoring by STN and SFBS on *Tridentiger* abundances will help inform how rising goby populations impact the health and structure of aquatic communities, and the response of fish to management actions for species of concern (i.e. salmon, smelt, sturgeon) in the Estuary.

(*IEP) Fish Food, Outflow, and Management Implications: The Values of Long-Term Zooplankton Monitoring in the SFE

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Long-term Interagency Ecological Program surveys conducted since the 1970s have described the overall historical trends in zooplankton resource within the San Francisco Estuary (SFE). Zooplankton communities in the estuary have changed dramatically since surveys began as a result of changes in outflow and phytoplankton communities, as well as other habitat modifications[TL1] . Zooplankton are a vital trophic link between aquatic primary producers and higher-level consumers of the SFE, as primary consumers of phytoplankton they facilitate the flow of carbon into a large and complex food web. Zooplankton in the SFE are also a key food source for several endangered and threatened species, notably the Delta Smelt (*Hypomesus transpacificus*) and Longfin Smelt (*Spirinchus thaleichthys*). IEP surveys have shown that substantial changes in zooplankton communities have been linked to major declines in the pelagic fishes of the upper estuary. One goal of the Flow Alteration Management and Synthesis Team (FLOAT-MAST) is to determine how freshwater outflow through the estuary impacts the distribution and abundance of key zooplankton species to better manage for smelt food resources in the estuary. The FLOAT-MAST has synthesized research overviewing the mechanisms in which outflow affects resource availability. These mechanisms include: increasing stratification in the water column, dictating the horizontal positioning of the low-salinity zone, and through the spatial subsidy of zooplankton to the low salinity zone from upstream populations. Preliminary analysis utilizing an integrated dataset of long-term zooplankton sampling in the SFE shows varying relationships between outflow and the abundance and distribution for key prey species. Determining if and how outflow may be used to improve the availability of prey species will allow for more informed management decisions to increase food access for imperiled fish populations.

(*IEP) The Value of Long-Term Zooplankton Monitoring for Detecting Impacts of the Suisun Marsh Salinity Control Gate Managed Flow Action

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Zooplankton communities in the San Francisco Estuary (SFE) have been altered by freshwater flow regulation, water diversions, and species introductions. Zooplankton are an important component of the food web and prey for many SFE fish species, including Delta Smelt (*Hypomesus transpacificus*) and Longfin Smelt (*Spirinchus thaleichthys*). The California Department of Fish and Wildlife’s (CDFW) Summer Townet (STN) and Fall Midwater Trawl (FMWT) are two long-term monitoring projects that target pelagic fishes in the upper SFE. Beginning in 2005, these surveys added zooplankton sampling to detect trends in food availability for fish. The Suisun Marsh Salinity Control Gates (SMSCG) managed flow action is one of the Delta Smelt Resiliency Strategies to increase accessible habitat for Delta Smelt by maintaining fresh water in Montezuma Slough. In 2018 the gates were operated in August to facilitate movement of Delta Smelt into Suisun Marsh. In support of monitoring for the SMSCG action, STN and

FMWT increased sampling frequency and added three additional stations to detect impacts to the zooplankton community. There was no action in 2019 and 2020, however additional sampling was still conducted to determine seasonal trends in non-action years. Meso-zooplankton samples that target copepods and cladocerans were collected bi-weekly from July to October. Zooplankton biomass in Suisun Marsh was compared to surrounding areas such as the lower Sacramento River and Suisun Bay. The copepods *Acartiella sinensis* and *Pseudodiaptomus* spp. were the dominant species during this time and are important prey for fish. 2019 showed higher meso-zooplankton biomass than 2018, and a decrease in biomass occurred in August in all years, which consistent with historic trends. Long-term monitoring allows for the detection of historic trends to determine the impact of adaptive management actions such as the SMSCG on the zooplankton community and therefore to zooplanktivorous fish in the SFE.

Special Featured Session: Raising Awareness and Shifting the Paradigm: Fostering Diversity, Inclusion and Equity in the Bay-Delta System (Featured Special Session)

Employee-Led Efforts to Foster Equity and Inclusion at the U.S. Geological Survey

Alexandra Etheridge[1], Tina Roberts-Ashby[2], Kristen Bennett[3]

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A lack of diversity in geosciences limits science reach and relevance, particularly in an age of climate non-stationarity with impacts amplified in marginalized sectors of society. Recognizing structural and cultural barriers to diversity internal and external to the U.S. Geological Survey (USGS), a growing population of USGS employees lead multiple efforts aimed at cultivating an inclusive peer culture while engaging the workforce in discussion about the impacts of harm and exclusion in the workplace. Three examples will be discussed.

1. USGS StepUp! Employee Empowerment Strategies (USGS SEES) is a 4-hour peer-led, open-source bystander intervention workshop created in late 2017. The authors have since offered USGS SEES workshops to hundreds of co-workers and funding partners while expanding the pool of facilitators to include employees representing USGS, several academic institutions, and several federal science agencies.

2. The USGS Peer Support Worker (PSW) program provides peer-to-peer support for USGS employees within science centers across the nation. PSWs facilitate awareness of issues specific to the peer culture in their workplace, such as overcoming harmful biases, challenging crude language during field campaigns, or finding work/life balance

during extended telework. PSWs are also trained internally to provide resources to mitigate misconduct while providing support to co-workers who have specific concerns.

3. In June 2020, USGS hosted a workshop titled *Preventing Harassment in Science: Building a Community of Practice for Meaningful Change*. The workshop brought leaders of anti-harassment efforts together to share best practices to reduce harassment in the scientific workplace.

Results from each of these efforts show that a sense of belonging can be curated culturally through open dialogue that promotes awareness and empowered prevention of harm. Sustaining these and other employee-led initiatives pushes scientific workplaces toward enhanced science relevance when all members of society can safely participate in offering solutions to society's most pressing problems.

Making Waves: Piloting Community Engagement in Adapting to Rising Tides

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In 2017, the Bay Area Regional Collaborative (BARC), the San Francisco Bay Conservation and Development Commission (BCDC), and the Metropolitan Transportation Commission (MTC) launched the Adapting to Rising Tides (ART) Bay Area project.
The ART project was the first regional-scale effort to plan for sea-level rise and other climate impacts for the Bay Area's communities, natural systems, and critical infrastructure. In 2018-2019, the Bay Area Regional Health inequities Initiative (BARHII) worked with BARC to create a unique strategy for public health and communities to pilot deep community engagement processes in two under-resourced locations.
This work had three goals: understand how local vulnerability and resilience factors impact our region, strengthen the ability of community organizations to positively shape resilience planning, and increase the capacity of public agencies to meaningfully partner with community-based organizations to understand local conditions and improve climate resilience and health equity.

Youth Advocates: Increasing the Voices of the Most Impacted

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The history and preservation of South Stockton and marginalized communities is Little Manila Rising's foundation. Our focus on environmental justice is an opening to take that same lens of using history as a tool for building equity. Little Manila Rising has been focusing on South Stockton for nearly twenty years. The people who built the organization are South Stocktonians and their families are also South Stocktonians. They have educated and guided youth from South Stockton who now have created their own families and call South Stockton home. Moreover, South Stockton consists of census tracts that rank in the 95-100 percentile of pollution, high PM 2.5 rates, disproportionate asthma rates, and population burdened areas in the state. These are communities that have been negatively impacted by environmental, educational, economic, and health issues due to systemic policies and systems.

Youth Advocates for Environmental Justice

Little Manila Rising is currently focusing on educating youth on environmental justice and civic systems to the neighborhoods/residents in South Stockton. Through the work of AB 617, a legislation bill that allows for a community-led process with participation from California's communities experiencing high environmental burdens from poor air quality to engage in the AB 617 process, our youth advocates have been able to engage in citizen science and become community experts in environmental justice. They have testified at the California Air Resource Board for systems change and facilitated workshops on environmental justice issues affecting South Stockton. The goal is to share the experiences and voices of the youth who are directly impacted by the inequities and injustices that impact Stockton. We will also talk about community involvement, community leadership, and regulatory reform through the work of AB 617.

White-Led Leadership in Complex Ecological Systems

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What is an appropriate role for white ecologists, environmental scientists, and land-use planners? How can whiteness be directly dissected and addressed in order to be used as a tool for deconstructing systemic inequity and structural violence? In this talk, the framework and lane of white-led leadership, within institutions, research labs, and academic settings, will be focused upon, with the goal of harnessing the deconstruction of whiteness to actively engage in institutional anti-racism, harm-reduction, and power redistribution.

Wednesday Scheduled Sessions

Salmon Science for Management

Mechanisms, Impacts, and Mitigation for Thiamine Deficiency and Early Life Stage Mortality in Central Valley Salmon

Rachel Johnson[1], Nate Mantua[2], Jacques Rinchard[3], Heather Bell[4], Taylor Lipscomb[5], Anne Todgham[4], John Field[2], Nann Fangue[4], Dennis Cocherell[4], Donald Tillitt[6], Kevin Kwak[7], Brett Kormos[7], Bruce Finney[8], Steven Litvin[9], Illiana Ruiz-Cooley[10], Carson Jeffres[4], Scott Foott[5], Mark Adkinson[7], Steve Lindley[2], Dale Honeyfield[6], William Ardren[5], Thomas William[2]

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Thiamine Deficiency Complex (TDC) is a nutritional deficiency of thiamine (vitamin B1) recently linked with high mortalities of early life stages of Chinook salmon in Central Valley (CV) hatcheries. Clinical signs of TDC are anorexia and sporadic spinning prior to death. Offspring of female salmon with reduced levels of thiamine are prone to TDC. The current hypothesis: a narrowing of the diversity of CV Chinook salmon marine diet and/or a more southerly ocean distribution where prey are either deficient in thiamine levels or high in thiaminase (Northern anchovies). Thiaminase is an enzyme that destroys or inactivates thiamine, and was identified as the primary explanation for low levels of thiamine and subsequent onset of TDC in Great Lakes and Baltic Sea salmonids. While the cause may be due to a reorganization of marine food webs, there are significant consequences to salmon populations in freshwater. TDC was first observed in CV hatcheries in broodyear (BY) 2019 spring, fall and late-fall Chinook salmon, and then in BY2020 winter run and spring run. TDC continues to afflict CV salmon stocks and we will continue our surveillance of BY2020 eggs and progeny from other populations. Our work to-date has revealed prophylactically treating female winter run with thiamine resulted in significant improvements to egg thiamine concentration (35.0 ± 7.2 nmol/g) and survival of progeny of this endangered species. Baseline levels of egg thiamine in un-treated winter run were low (5.2 ± 4.4 nmol/g), resulting in 50% of their fry expressing TDC symptoms. Our work has generated significant insights and necessary data needed to quantify impacts to naturally spawning populations, which remains the greatest data gap relevant for conservation, water project operations, and harvest management. Our rapid scientific inquiry into this new stressor has resulted in actionable science to support salmon hatchery management and assess population-level impacts.

Insights into the Life History and Habitat Use of Historical Salmon in the Bay-Delta Watershed

<u>Malte Willmes[1|2]</u>, Flora Cordoleani[1|2], Anna Sturrock[3], Jeff Rosenthal[4], Jelmer Eerkens[5], Levi S. Lewis[6], James A. Hobbs[6], Rachel Johnson[1|2|3]

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Climate change is resulting in increasingly frequent and extreme weather events in California, transforming the Central Valley watershed and the San Francisco Estuary. Chinook Salmon (*Oncorhynchus tshawytscha*) have long thrived in California's variable climate, including prolonged drought periods, by utilizing a vast habitat mosaic and highly adaptable life history phenology. However, habitat loss and simplification, modified flow regimes, and management practices that have promoted synchrony among populations, are threatening the long-term survival of Central Valley Chinook Salmon. Surveys and geochemical tools have provided crucial insights for salmon populations in California. However, these data were collected after significant population declines and extirpation from a large fraction of historic habitat had occurred and thus may miss key aspects of potential salmon life history.

We applied a suite of morphological and geochemical tools to Chinook Salmon otoliths (ear stones) collected from an archaeological site (1835-1870 CE) from the lower Feather River to reconstruct age, size, and migratory behavior. We then contrasted our findings with modern Chinook Salmon from the same watershed and with populations throughout the Central Valley. Our analyses showed that these historic salmon exhibited a broader age distribution with age-3 and age-4 dominating, while their modern counterparts were shifted to younger ages and had a truncated age structure. The natal origins and rearing behaviors of the historic population suggest that most originated from the local watershed and used a diverse range of rearing habitats. In contrast to their modern counterparts, these historic salmon did not migrate fully to the ocean but appear to have stayed in the Estuary at low salinities. This represents a life history strategy that has been lost for California Chinook Salmon and showcases the potential for archaeological fish remains to provide unique insights into past salmon populations to guide future conservation, management, and recovery.

Using Multiple Years of Data to Link Environmental Covariates to Juvenile Steelhead Population Dynamics in the South Delta

<u>Adam C. Pope[1]</u>, Russell W. Perry[1], Rebecca A. Buchanan[2]

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Estimation of demographic parameters for threatened and endangered fish populations in the Sacramento-San Joaquin Delta is key to understanding their viability. To manage for these populations' success, demographic parameters such as travel times and survival must be linked to environmental covariates to provide insight into how management actions affect population dynamics. For steelhead (*Oncorhynchus mykiss*) in the San Joaquin River, until recently efforts to quantify population dynamics have largely focused on a single year at a time. More recent work aimed at using multiple years of data to better understand linkages between steelhead population dynamics and environmental variables such as river flow or freshwater exports has focused on these relationships at near Delta-wide spatial scales. Additionally, low steelhead survival through the Delta has made parameter estimation difficult since fewer survivors lead to sparse data and greater parameter uncertainty, particularly in tidal regions farthest downstream from release.

We used a Bayesian complete data likelihood structure to analyze acoustic telemetry data for steelhead released into the San Joaquin River near Vernalis each spring from 2011 through 2016. By modeling survival and travel time on multiple years of data, we were able to quantify the relationship between these demographic parameters and key environmental and operational variables including San Joaquin river flows at Vernalis, inflow to export ratios, Old and Middle River flow index, and whether a temporary barrier to fish passage at the head of Old River was installed. Our model framework allowed simultaneous modeling of multiple, smaller-scale spatial regions within the Delta in order to pinpoint where the effects of changing variables might be observed. We will present these associations within the context of travel time and survival estimates from previous analyses. Our results should prove useful to managers seeking to mitigate effects of operations on the native steelhead population.

The Drought and the Deluge: Daily and Reach-Specific Estimates of Survival, Travel-Time and Routing Probabilities Through the Sacramento River Delta and Yolo Bypass for Winter-Run Chinook Salmon from 2014-2018

<u>Dalton Hance</u>[1], Russell Perry[1], Adam Pope[1], Arnold Ammann[2], Jason Hassrick[3], Gabe Hansen[1]

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Problem Statement: The endangered Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*) is a major species of concern for management of water resources in the Sacramento-San Joaquin River Delta. In particular, understanding daily and reach-specific survival in relation to environmental conditions and the probability of entering and surviving through Yolo Bypass or the interior Delta are critical management needs. However, most existing estimates are based on late-fall run Chinook salmon and the relationships may differ for winter-run Chinook.

Approach: We analyzed multiple years of acoustic telemetry data for juvenile winter-run Chinook Salmon to generate reach-specific estimates of survival, travel time and routing probabilities in relation to daily flows and temperatures in the Sacramento-San Joaquin River Delta and Yolo Bypass. Our study spans the years from 2014 through 2018 and temporally contrasts the intense drought conditions during the winters of 2013-2014 and 2014-2015 as well as the extremely wet winter of 2016-2017. We developed a novel statistical mark-recapture model to efficiently estimate daily survival and travel times while accounting for imperfect detection and tag battery failure.

Results: We found that daily discharge tended to have a positive effect and maximum water temperature a negative effect on survival in most reaches. Winter-run Chinook salmon were increasingly likely to enter the Yolo Bypass with increasing stage height above the Fremont Weir. Additionally, survival through Yolo Bypass was equivalent to survival in the mainstem Sacramento despite much longer travel times. Survival through the interior Delta was consistently low.

Relevance: Our results establish relationships between flow, water temperature, and survival for winter-run Chinook salmon. These relationships can be used to inform management actions affecting this endangered population.

Counting the Needles in the Haystack: Estimating Juvenile Production of Endangered Winter Run Chinook Salmon Leaving the Delta

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Problem Statement: Juvenile production estimates of salmon populations exiting the Delta have been identified as a key management parameter. Although trawl catch data provide a relative index of abundance and outmigration timing of juvenile Chinook salmon, estimating absolute abundance for federally endangered winter run Chinook salmon has proven elusive due to 1) difficulty in estimating trawl sampling efficiency, 2) inaccuracy of race assignment based on length-at-date criteria, and 3) inability to distinguish unmarked hatchery-origin fish from wild fish.

Approach: Here, we analyze data from a novel study design that pairs acoustic tagged (AT) fish with releases of coded wire tagged (CWT) hatchery Chinook salmon. In this hybrid design, a multistate mark-recapture model applied to AT fish is used to estimate survival to the Chipps Island trawl site. In turn, survival estimates allowed us to estimate the abundance of CWT fish available to be captured by trawls and trawl gear efficiency. Given estimates of trawl efficiency, we then estimated total abundance and run timing of winter run Chinook salmon from genetic monitoring data that identified true winter run in subsamples of the daily trawl catch.

Results: We found the hybrid study design allowed for daily and tow-level covariates to be incorporated into the model to quantify factors affecting gear efficiency. Simulations revealed that bias in abundance and run timing estimates was low even at small population sizes and trawl efficiency as low as 0.5%. We will present preliminary juvenile production estimates of true winter run Chinook salmon for 2018 – 2020 and contrast these estimates against length-at-date classified winter run and hatchery origin winter run.

Relevance: Devising methods to estimate abundance of juvenile salmon entering and exiting the Delta is critical for developing long-term monitoring data for assessing population status, informing life cycle models, and guiding management actions affecting endangered populations.

Global Climate Change at the Estuary Scale

Integrated Modeling of Climate and Land Change Impacts on Future Dynamic Wetland Habitat in California's Central Valley

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California's Central Valley is a highly productive agricultural region, but also a key stopover along the Pacific migratory flyway, providing critical habitat for wintering waterbirds in North America. Understanding and forecasting the distribution, abundance, and connectivity of surface water and wetland habitats, as well as the response of wildlife that depend on these habitats, is essential for maximizing the value of management decisions for wildlife, ecosystems, and ecosystem services in this region. To identify potential future wetland habitat under a broad range of climate and land use scenarios, we integrated a climate-driven hydrologic water use model with a spatially explicit land change model. First, we adapted the non-spatial Water Evaluation and Planning model for Central Valley's waterbird habitat (WEAP-CV_{wh}) to model five future land use and climate scenarios from 2011 to 2101. Scenarios were developed with multiple stakeholder engagement activities and represent a divergent range of future climates, perennial expansion rates, water allocation priorities (i.e. for wetlands and winter flooded agriculture), and habitat restoration goals. Next, we used the WEAP-

CV_{wh} scenarios as input to the spatially-explicit Land Use and Carbon Scenario Simulator (LUCAS) model to produce 270-m mapped scenario projections of land use and flooded habitat out to 2101 based on varying climate futures, water availability, management decisions, and competitive land-use related water demand. Our results show significant declines (25 and 33%) in future flooded cropland habitat availability by 2101, even under favorable climate conditions, exposing habitat vulnerability to both climate, water prioritization and availability, and human land use. Even if the waterbird and shorebird habitat restoration targets set forth in the Central Valley Joint Venture (CVJV) Implementation Plan are realized, such efforts may prove ineffective if not coupled with both land use and water resource co-management.

Mapping Social Vulnerability to Climate Change in the Delta and Suisun Marsh

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As part of the Delta Adapts climate change vulnerability assessment (VA), the Delta Stewardship Council created a custom social vulnerability index (SVI) to identify the most socially vulnerable communities to climate change in the Delta and Suisun Marsh. Delta Adapts defines vulnerability as the intersection of exposure to climate hazards, sensitivity to those hazards, and adaptive capacity, or the ability to respond to and recover from climate hazards. The SVI captures sensitivity and adaptive capacity to flooding, extreme heat, and wildfire smoke, by using 14 socioeconomic and health indicators at the census block group and tract scale. Indicators were selected based on a literature review that identified factors that increase vulnerability to the three climate hazards of interest. Results indicate that the most socially vulnerable communities are in West Sacramento, Antioch, Pittsburg, Stockton, and much of the southern Delta. In the Delta Adapts VA, climate hazard exposure data was overlaid on the SVI results to identify communities most vulnerable to current and future climate hazards.

The SVI has many potential uses relevant to Delta management. Understanding the sources of climate vulnerability in the Delta and how they interact to increase vulnerability can help decisionmakers prioritize projects, research, and funding to address those sources and increase the resilience of Delta communities. The SVI is already being applied in this way: applicants for 2021 Delta Science Awards are directed to use the SVI to evaluate whether their research project will benefit specific vulnerable communities in the Delta. Local governments could use the SVI as part of local climate vulnerability assessments to comply with SB 379. Ultimately, the SVI will inform climate adaptation planning in the Delta region and help ensure that adaptation actions are equitable.

Results of Integrated Modeling of the Physical Systems of the San Francisco Bay-Delta Estuary and Watershed for Future Scenarios

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An improved understanding of how changes in climate may affect the San Francisco Bay-Delta is needed to provide a context for long-term planning. The U.S. Geological Survey has led a project (CASCaDE 2) designed to link models of the Bay-Delta estuary and its watershed to help better understand the possible impacts of climate change on the combined system. Meteorological quantities projected by an ensemble of global climate models (GCMs) have been translated by models of watershed hydrology, operations, and sediment into managed daily inflows, temperatures, and sediment loads at the estuarine boundaries. The associated trends at the Delta boundaries include increased wet-season Delta inflows, increased magnitude and frequency of extreme high inflows, reduced dry-season inflows, increased water temperatures, and an increased sediment supply. Linked hydrodynamical and water-quality modeling tools are being used to evaluate the impacts of these projected changes on the estuary. Results describing changes over the 21st century for a scenario from a moderately warmer and wetter GCM include increased mean water levels and tidal ranges throughout the Delta driven by sea level rise; increased water temperatures throughout the Delta that roughly parallel the surface air temperature increase; increased salinity intrusion, particularly in the dry season; additional reservoir releases required to comply with environmental standards; and minor changes in salinity stratification, primarily in deeper channels. Results for suspended sediment concentrations will also be discussed.

Re-Calibrating Sacramento and San Joaquin Water Year Types in a Changing Climate

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The Sacramento and San Joaquin water-year type indices are fundamental to the operations of the State Water Project and Central Valley Project. Changes in the seasonal and total availability of water as a result of climate change may alter the frequency distribution of the Sacramento and San Joaquin water year types. A recalibration of water year types to shifting seasonal runoff patterns driven by atmospheric warming is tested for the California Water System. The analysis uses a decision scaling approach previously developed and applied by both the California

Department of Water Resources and Delta Stewardship Council for climate change vulnerability assessments. A paleo-informed 1,100-year climate trace of daily precipitation and temperature is systematically perturbed to explore the climate vulnerability domain of the California Water System to the full range of changes projected by global climate models at a mid-century time horizon. Streamflows, developed using the Sacramento Soil Moisture Accounting distributed hydrologic model (SAC-SMA-DS), are input to the water system model, CalLite 3.0 to simulate the coordinated operations of the California Water System. Because CalLite 3.0 simulates the current regulatory framework built around water year types, the modeling platform is capable of exploring how modifying water-year type calculations may affect Delta water management objectives. With recalibration of water year types to maintain the historical, paleo-informed estimated frequency of occurrence, the analysis suggests a tradeoff of 10,000 acre-feet between average annual Delta exports and Net Delta outflows per degree Celcius of temperature rise, which is shown to mitigate some portion of increases in average annual salinity at key locations in the Delta. The results underline the importance of anticipating more certain large-scale hydrologic changes driven by atmospheric warming and provide insight into potential policy levers for mitigating impacts.

Spatial, Seasonal, and Climate Change Signals in Water Temperatures in the Upper San Francisco Estuary from 11 Discrete Monitoring Programs

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Temperature has profound impacts on ecosystem functions and biodiversity, from subcellular to community scales. Climate change is expected to increase water temperatures in the upper San Francisco Estuary (SFE), which could impact native species by inducing physiological stress, increasing predation pressure, interfering with reproduction, increasing food demands, and synergistically interacting with the effects of other stressors. The continued persistence of many species may depend on localized regions of temperature refuge, which could be co-located with restoration efforts to achieve maximum benefits. Before we can identify areas of refuge or adapt to expected water temperature increases, we must study the past to understand spatiotemporal water temperature patterns and quantify the rate of temperature increase across the upper SFE. To accomplish these objectives, we compiled an integrated discrete temperature dataset of 11 boat-based surveys in the upper SFE, comprising over 100,000 temperature records from 1969-present. Using this dataset, we fit a spatiotemporally explicit generalized additive model to quantify the spatial landscape of water temperature for each year and month in the dataset. This model can generate temperature estimates for each month and year in any location covered by the discrete monitoring dataset. Then, to estimate the rate and spatial variability of temperature

increases, we fit a generalized additive mixed model to the subset of this dataset with fixed sampling locations. This latter model estimated the linear rate of temperature increase over all years in the dataset and allowed that rate to vary seasonally and spatially. Temperature increased significantly over time (average of 0.02 °C/year), and this rate varied seasonally and spatially. These findings can be used to estimate expected impacts of climate warming on native species and to prioritize restoration sites based on past and expected future temperature trends.

Getting into the Weeds: Aquatic Vegetation

Using Sentinel-2 to Provide Open-Access Tools for Plant and Water Mapping in the Sacramento Bay-Delta

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Building resilient Bay-Delta ecosystems is underpinned by monitoring, and satellite remote sensing provides many robust and diverse monitoring methods. Satellite remote sensing offers systematic, repeat measurements that create time series of different performance metrics, for example, aquatic vegetation community composition, plant traits, and their change over time, wetland biomass turnover, or dynamics of floodplain inundation. The Sentinel-2 mission, recently launched by the European Space Agency, provides free, open access data and an excellent opportunity to develop ecosystem performance metrics from satellite remote sensing. The mission provides a 5-day revisit time, 10-meter spatial resolution on the ground for 4 bands in the visible and near-infrared region, and 20-meter spatial resolution for another 9 bands ranging from the visible to the shortwave-infrared region. The Sentinel-2 sensors, and their replacements, are fully funded for the next two decades, offering the opportunity for high resolution, high-frequency continuous mapping in the entire Delta regularly. Using imagery downloaded from 2017 to 2020, we created open-source software workflows for 20-meter resolution aquatic vegetation functional type maps, phenology time series and derived metrics, and inundation metrics of a variety of restoration sites and the Yolo Bypass. Regular meetings with different stakeholders and working groups, such as the Interagency Ecological Program, provided feedback to strengthen these tools' utility for a broad range of managers, agencies, and other interested parties. The long term objective of this work is to ensure that all methods developed for this project, including algorithms with rigorous uncertainty quantification and well-documented open-source software workflows for monitoring aquatic and marsh plant communities, can be used broadly to meet Delta science and management needs.

Invasive Aquatic Vegetation Detection using Hyperspectral Remote Sensing from UAV

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Invasive plants are non-native species that can spread rapidly, leading to detrimental economic, ecological, or environmental impact. In aquatic systems such as the Sacramento-San Joaquin River Delta in California, USA, management agencies use manned airborne hyperspectral remote sensing missions to map and track annual changes in invasive aquatic plants. Advances in unmanned aircraft and sensor miniaturization are enabling higher spatial resolution species mapping, which is promising for early detection of invasions before they spread over larger areas. This study compared maps made from unmanned aircraft-based hyperspectral remote sensing with the manned airborne hyperspectral remote sensing-derived maps that currently produced for monitoring invasive aquatic plants in the Sacramento-San Joaquin Delta. Concurrent imagery was collected using the HyMap sensor and the Nano-Hyperspec at a wetland study site and classification maps generated using random forest models were compared. Classification accuracies were comparable between the Nano- and HyMap-derived maps, with the Nano-derived map having a slightly higher overall accuracy. Additionally, the higher resolution of the Nano imagery allowed detection of patches of water hyacinth present in the study site that the HyMap could not. This study establishes the techniques and workflows for vegetation community assessments in support of the Proposition 1 CDFW-funded research project "Ecosystem Engineering Impacts of Water Primrose in the Delta." However, it would not be feasible to operate the Nano as a replacement to HyMap at scale despite its improved detection capabilities to due to the high costs associated with overcoming area coverage limitations. Overall, unmanned aircraft-based hyperspectral remote sensing provides comparable or improved capability, and we suggest it could be used to supplement existing monitoring programs by focusing on target areas of high ecologic or economic priority, or to support scientific investigations, such as floating aquatic vegetation invasion dynamics.

The Potential of Satellite Remote Sensing Time Series to Uncover Wetland Phenology under Unique Challenges of Tidal Setting

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The San Francisco Bay Delta (Bay Delta) is one of the largest continuous estuarine systems in the United States. It is well known that wetland vegetation sequesters carbon in their below and above ground biomass, however through plant and microbial respiration greenhouse gases such as carbon dioxide and methane are released back into the atmosphere. This makes understanding of seasonal plant growth within wetlands a vital input into greenhouse gas modeling; however, across the large study region with limited site access frequent field surveys of biomass become impractical. Here our goal is to extrapolate the seasonal vegetation growth curve and assess its regional variation within the Bay Delta using vegetation indicators from the time series of publicly available images of Landsat 8, a multispectral satellite. In this effort, we also aim to address the major challenges for landscape-scale assessments of wetland plant phenology due to spatial and temporal variability in tidal flooding and plant biomass, impacting the satellite signal of vegetation.

Using Google Earth Engine (GEE), we acquired and processed Landsat, climate, and elevation data within the Bay Delta region focusing on the years 2013–2020. Using a subset of the data from GEE we trained a series of models estimating Landsat-based indicators of plant greenness over a given time period. We compared models using Akaike Information Criterion analysis and determined the highest-support model including temperature, elevation, Palmer drought severity index, day of the year, and the historical mean greenness observed at the given pixel.

Results indicate that our modeling approach can estimate plant greenness within the Bay Delta's tidal marshes reasonably well. Higher model errors were observed largely in managed marshes, salt ponds, and disturbed marshlands. Our approach circumvents mentioned challenges and provides a useful tool for estimating wetland phenology to support ecosystem modeling over large spatial scales.

Ecosystem Engineering Impacts of Invasive Submerged Aquatic Vegetation in the Delta

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Invasive submerged aquatic vegetation (SAV) acts as an ecosystem engineer by altering water chemistry, plant community composition, and phytoplankton productivity. Less is known about how invasive SAV affects long-term ecosystem processes such as carbon storage and sediment dynamics. In this study, we determined whether *Egeria densa* (Brazilian waterweed), a globally invasive species of SAV, is storing "blue carbon" and trapping sediment required by adjacent marshes to maintain their elevation in the tidal frame. We studied three sites in the Sacramento-San Joaquin Delta with differing energy dynamics. At each site, we collected (1) five surficial push cores in sediments within and outside of *E. densa* patches, (2) two sediment cores on the marsh plain, and 3) two gravity cores under *E. densa* patches. Bulk density, % organic carbon, and loss on ignition were determined for all cores and ^{210}Pb, and ^{137}Cs were measured in marsh and gravity cores. Our results show that *E. densa* patches function as sinks for carbon and inorganic sediment under all three energy regimes studied. Compared to marshes, *E. densa* patches have greater inorganic sedimentation rates (*E. densa*: 1103 – 5989 g m^{-2} yr^{-1}, marsh: 393 – 1001 g m^{-2} yr^{-1}, $p < 0.01$) and vertical accretion rates (*E. densa*: 0.4 – 1.3 cm yr^{-1}, marsh: 0.3 – 0.5 cm yr^{-1}, $p < 0.05$), but similar carbon accumulation rates (*E. densa*: 59 – 242 g C m^{-2} yr^{-1}, marsh: 109 – 169 g C m^{-2} yr^{-1}, $p > 0.05$). Due to its harmful traits, planting *E. densa* to achieve carbon storage benefits would likely result in a disproportionate amount of negative impacts vs. positive gains. Our results suggest that invasive estuarine SAV such as *E. densa* reduces the resilience of adjacent marshes to sea-level rise by trapping sediment that would otherwise have been available for marsh accretion.

Floating Wetlands for Food-Web, Greenhouse Gas Benefit and Potential Subsidence Reversal

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The Delta pelagic food web no longer adequately supports native species. Development of management strategies for food-web support and habitat for fish species of concern is a key goal and substantial challenge. It is expected that restoration of tidal-wetland food webs will produce resources that will benefit species of concern on-site, and through export, will support pelagic habitat in adjacent waters and regionally. However, Delta-island subsidence substantially inhibits timely and large-scale tidal restoration in most of the central and western Delta. While the food-web and habitat benefits of fresh-water tidal wetlands that dominated the pre-reclamation Delta are not well documented, recent research provided a reasonable case for experimental implementation. Considering the difficulty of creating tidal habitat on subsided Delta islands, floating peat mats that could provide marsh habitat, which is hydraulically connected to Delta waterways, are being investigated on Bouldin Island. Peat blocks were excavated from the Twitchell Island wetland which was permanently flooded in 1997 and placed in eight mesocosms (18-foot diameter Doughboy pools) on Bouldin Island in 2019. The peat blocks have continued to float and produce emergent vegetation (primarily *Schoenoplectus* sp).

Floating peats supported zooplankton communities in the pelagic space between the benthos and the peat mat. Zooplankton function as a trophic link between basal carbon sources (detrital/primary production) and higher trophic levels. As such, zooplankton abundance and species composition are good indicators of productive potential. Zooplankton abundances remained relatively stable throughout the year after the peats were placed in the mesocosms. There was an apparent lag in colonization by macroinvertebrates but as the sites became colonized over time, taxa observed were typical of wetland habitats. Water quality data, gas flux measurements and quantification of wetland biomass provide evidence for the GHG benefit of floating peats on subsiding peat soils and long-term continued flotation.

Social Science and Human Dimensions

Hunters as Stakeholders in the Bay-Delta Watershed

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Hunters are major recreational users of the Bay-Delta watershed, hunting waterfowl in its freshwater and tidal marsh areas as well as deer and upland gamebirds in the riparian forests and grasslands along its source rivers. As part of a larger project aimed at assessing the economic value to hunters of riparian and tidal marsh restoration, we surveyed more than 1100 hunters about their experiences during hunting season 2019-20. Preliminary data show that waterfowl hunters were more satisfied with the quality of the habitat in Central Valley managed ponds and in Suisun Marsh than in sites recently reclaimed from industrial uses in the North Bay and South Bay. Deer and gamebird hunters generally preferred restored sites to unrestored sites, but responses on habitat quality were more mixed. Loss of the spring turkey season to COVID-19 shutdowns complicated this analysis and decreased sample sizes. We also report results from a smaller survey on the demographics of hunters, their preferences for water and vegetation management at hunt areas, and their opinions about the effects of drought, fire, climate change, and invasive species on the sustainability of the sport. Our findings can help inform managers of wildlife refuges and wildlife areas about the needs and preferences of this important stakeholder group.

From California’s Water Wars to America’s Culture Wars: A Media Analysis of the Delta Smelt Controversy

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In recent decades Americans’ attitudes about environmental issues have become polarized along partisan lines. While significant research demonstrates this broad trend, we know less about the meso-level processes that produce and sustain such divisions. Drawing on over 3,000 news articles, nearly 14,000 Tweets, and Google search data, I analyze the public sphere controversy surrounding the delta smelt, an endangered species of fish caught in the center of California water politics. Legal protections of the species have impacted water conveyance to farms and cities. Most observers view the controversy as a simple reflection of pre-existing interests. This explanation cannot capture the cultural appeal of the delta smelt to right-wing observers disproportionate to its modest impact on water policy. Offering an alternative explanation, I show that how the delta smelt became a means by which California's "water wars" became enrolled into America's "culture wars." I show that the delta smelt is more meaningful for opponents to environmental protection than proponents, and for those outside California than inside of it. Next, I trace the controversy over time to show how skillful partisan elites articulated continuity between a narrow set of material interests and broader partisan identities which stand in symbolic opposition to liberal environmentalism by drawing on extant cultural, political, and geographic resentments. Finally, I show how the delta smelt's unique symbolic power owes in part to its physical characteristics as an "uncharismatic microfauna." By showing how the delta smelt became a symbol of partisan animosity, this study offers a processual and case-analytic complement to the burgeoning body of quantitative work on environmental partisan polarization.

Wings Landing Tidal Habitat Restoration Project Environmental Education Program

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The 267-acre Wings Landing Tidal Habitat Restoration Project is located in the Upper Suisun Marsh and was completed in fall of 2020. Permit conditions required public access; however post-restoration site constraints left no publicly accessible land. Most marsh or wetland restoration projects are located far from public access points with limited, difficult, or distant access. The close proximity of Wings Landing to the public Suisun City boat launch provided the unique opportunity for safe water access to the restoration site. The Wings Landing Project Team developed the Wings Landing Tidal Habitat Restoration and Suisun Marsh Natural History and Cultural Kayak Tour Program (Program). The Program supports environmental education for low income and minority students through a partnership with a local Title I middle school. The Program also partners with a local Native American Tribe and will provide opportunities for Native American youth to experience their cultural heritage within the Suisun Marsh. Research shows that children who spend time outdoors in natural environments experience improved health and cognitive functions, strong motor coordination, reduced stress, enhanced social skills, increased enthusiasm toward school, and have fewer attendance problems. The Program provides direct community outreach to local youth, many of whom have not had opportunities to learn about the cultural, recreational, and ecological importance of the Suisun Marsh, despite it being located in their "back yard". Under the Program, groups of students will paddle kayaks to the Wings Landing Tidal

Habitat Restoration Site where instruction will be provided on natural history, birding, wetland ecology, tidal marsh restoration, and Native American history by trained docents. This Program will expand the environmental benefits of the Wings Landing Tidal Habitat Restoration Project beyond its biological attributes, to include the social sciences and address environmental justice issues in underserved communities.

Surfacing Areas of Consensus and Disagreement Across Diverse Practitioner Groups to Inform Science & Restoration Priorities for Salmonids in the Bay Delta

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The many organizations and programs working to support salmonid recovery in the Bay Delta have given rise to numerous initiatives, each with their own specific objectives, approaches, and recommended priority activities. However, a lack of alignment and coordination of mandates across these initiatives have made it challenging to understand science, management, and monitoring priorities of greatest benefit to salmonids in a way that also considers stakeholder perspectives, a key aspect of the Delta Stewardship Council's Science Action Agenda.

To shed light on cross-cutting priorities, previously proposed salmonid science, management, and monitoring activities were first collated from a wide range of existing plans, strategies, and studies. This set of over 300 prospective activities formed the basis of a rigorous online Q-survey that solicited perspectives on the relative benefits of activities from 50 experienced salmonid science and management practitioners across a diverse range of organizations. Analysis of results revealed practitioner perspectives on the relative benefits and implementability of activities as well as the level of agreement in responses across organizations. Results were used to shortlist a set of 41 activities across three themes that emphasize key dimensions to consider in decision-making: (1) beneficial activities with high across-group consensus regarding benefits; (2) beneficial activities also considered easiest to implement; and (3) beneficial activities with the least across-group consensus about benefits.

By comparing activities within each theme, practitioners can identify potential projects representing low-hanging fruit, opportunities for collaboration, or areas where more information and discussion is needed to increase alignment. This study will also assist planners to more effectively consider the human dimensions of natural resource management decisions in their deliberations on potential projects intended to benefit salmonids in the Delta and, in doing so, also help to support the objectives of the Science Action Agenda.

Governing Multiple Forms of Connectivity in the Bay-Delta

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Governance of cross-scale dependent systems such as estuaries requires integrating knowledge about biophysical and ecological connectivity in its multiple forms and scales. While scientists, managers, and policy-makers are increasingly recognizing the importance of connectivity, ecosystems with strong cross-boundary dependencies challenge current environmental governance structures. Managing connectivity, in each of its forms, requires building social connectivity to increase the flow of information and social and financial capital among both formal and informal governance bodies. We describe the diverse forms of connectivity in the San Francisco Estuary in their natural and human-impacted states, and demonstrate the human dimensions of restoring ecosystem processes. Connectivity occurs along four spatial dimensions: cross-scale to adjacent and distant ecoscapes, longitudinally, laterally, and vertically. It involves marine, brackish and freshwater aquatic, and terrestrial systems. Work in the Bay-Delta shows that for restoring connectivity to distant ecoscapes collaboration between international jurisdictions, finding multi-benefit solutions, and devising funding mechanisms for large-scale restoration are vital. Restoring longitudinal connectivity is difficult to balance with flood control and water supply for human communities and agriculture, and intense management actions sometimes need to replace natural processes. Reestablishing lateral and vertical connectivity in estuaries, for example through reconnecting floodplains to the rivers and curbing groundwater overdraft, can be a trade-off between water use for humans and ecosystems. Economic disparities need to be considered in the planning process when leveraging ecosystem services of floodplains such as flood control. To increase ecosystem resilience in the Bay-Delta we recommend (1) identifying a set of metrics to represent estuarine connectivity and monitor changes in connectivity over time, (2) assessing tradeoffs among the different forms of connectivity, (3) creating or enhancing social networks for conservation, management, and restoration of natural processes, and (4) governing, managing, and providing funding at a system level to regain natural connectivity.

IEP Session: Success at Different Trophic Levels: Gaining Insight from Nutrients to Otoliths

(*IEP) A View from the Landscape Scale: Using Spatial Variation of Nutrients and Phytoplankton Across the Delta to Identify Underlying Biogeochemical Processes

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Identifying management actions that may help protect pelagic food webs in the Sacramento-San Joaquin Delta (Delta) is difficult because of the complex interactions between phytoplankton, nutrients, hydrodynamics, and landscape features. Gaining a better understanding of these interactions is important to help evaluate effects of the upgrade to the Sacramento Regional Wastewater Treatment Plant (SRWTP) as well as the potential effects of future changes, such as additional nutrient-management actions, large-scale wetland restoration, drought, flood, levee failure or changes to water management.

We investigated these interactions by characterizing the abundance and distribution of nutrients and phytoplankton across much of the Delta during different hydrologic conditions using high-speed moving-boat surveys. The concentration and spatial distribution of all major nutrient forms were collected simultaneously with information about the major classes of phytoplankton and associated water quality conditions. These data comprised spatial surveys that used continuous underway high frequency sampling and measurements onboard a high-speed boat, allowing for the characterization of spatial variation across the breadth and width of the Delta.

The results reveal astonishing variation across both space and time, with nutrient concentrations varying from near zero to eutrophic, most often related to hydrologic mixing and water residence time. Phytoplankton productivity appeared to be a strong sink for nutrients in the Delta, suggesting that phytoplankton uptake is a larger control on nutrient concentrations than previously appreciated. Phytoplankton abundance ranged from near detection to bloom concentrations, with large variation in community composition, but little direct relationship to nutrient concentration or form. Contrary to expectations, we did not observe significant nutrient depletion near landscape-scale features such as open water habitats, submerged aquatic vegetation beds, extensive wetlands or exposed sediments, suggesting these habitat types do not act as major sinks for nutrients in the Delta.

(*IEP) Nine Years of Flow Pulses: A Synthesis of Water Quality, Plankton Subsidies and Fish Communities in the North Delta

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Resource management in the San Francisco Estuary (SFE) is largely focused on maintaining freshwater inflow to improve habitat conditions for endangered fishes such as Delta Smelt (*Hypomesus transpacificus*). In addition to habitat, food-limitation in the SFE is hypothesized to be a driver of fish declines. Studies in the North Delta region of the SFE have shown that phytoplankton blooms and increases in zooplankton abundance have followed hydrological changes (i.e. flow pulses or above-average flows) in the Yolo Bypass during summer or fall. These observations led to an ongoing adaptive management strategy known as the North Delta Flow Action, using a managed flow action to alter summer-fall net outflow in the Yolo Bypass to increase the availability of plankton in important downstream fish habitat in the Cache Slough Complex. Through coordinated water operations, three augmented flow pulses have now been conducted with the overall goal to redistribute food through the North Delta and potentially trigger a downstream plankton bloom. However, the effects of flow actions on downstream food availability have varied across years. Here, we present a synthesis study of all summer-fall flow events in the Yolo Bypass monitored since 2011 to 2019 to evaluate the efficacy of the management action to improve habitat and food conditions downstream for Delta Smelt. We compiled, integrated and analyzed physical, chemical, and biological monitoring data (e.g., phytoplankton, zooplankton, fish) from Interagency Ecology Program surveys throughout the North Delta to quantify meaningful changes in water quality and biota in response to non-managed and managed-flow pulses. Additionally, we assessed how pulse water source (agriculture drainage or Sacramento River), hydrologic year, and antecedent conditions may influence food web responses to flow pulses. This synthesis provides critical information for adaptive management of flow actions and ecological resources in the North Delta.

(*IEP) I'm not that Shallow – Surprising Similarity in Zooplankton Communities Collected at Different Depths Near Wetland Restoration Sites.

Rosemary Hartman[1], Michelle Avila[2], Arthur Barros[2], Christy Bowles[2], Daniel Ellis[2], April Hennessy[2], Trishelle Tempel[2], Stacy Sherman[2]

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Wetland restoration has been identified as a key management tool for increasing food availability for at-risk fishes in the San Francisco Bay-Delta Estuary. To characterize the benefits of restoration sites, it is critical to quantify the abundance and composition of food resources in and near the wetlands. Characterization of zooplankton communities is considered particularly important, but accurate analysis of zooplankton samples is time-consuming and expensive. The recently established Fish Restoration Program Monitoring Team assessed whether data from existing IEP surveys could be used to characterize shallow-water zooplankton communities prior to restoration. During the spring of 2017-2019, FRP collected zooplankton samples near the mouth of tidal wetland sites, or immediately outside future restoration sites, and compared them to samples collected roughly concurrently in adjacent channels by IEP long-term monitoring surveys. We found many seasonal and landscape-scale differences in species composition, but very few differences in community composition between

shallow and deep samples collected concurrently. We found higher overall CPUE in the deeper samples collected by IEP, but this may be due to inconsistencies in towing speed and gear type, rather than habitat differences.

(*IEP) Every Cog and Wheel: Understanding the Importance of Genomic Diversity in Central Valley Chinook Salmon

Mariah Meek[1], Shannon O'Leary[1 | 2], Tasha Thompson[1], Melinda Baerwald[3]

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The field of genomics is rapidly increasing our understanding of biodiversity and its distribution across species and populations. This includes recent advances in the identification and quantification of genomic diversity in Central Valley Chinook salmon. These advances have strong implications for the conservation and management of the different run types. In this talk, we will both provide a synthesis of the recent developments in our understanding of genomic diversity in Central Valley Chinook salmon, as well as present the results of our new analyses of genomic diversity. Together with previous work, this new assessment demonstrates the unique contribution of each Chinook tributary population to the genetic portfolio of the entire Central Valley population complex, and emphasizes the need to protect each run and tributary to ensure the health and sustainability of Central Valley Chinook salmon. Additionally, we will highlight how we are using these new insights to develop better tools to allow rapid genetic identification of the different Chinook runs. This tool development will revolutionize the way we can identify the ESA listed runs in the field in real time and drastically improve our ability to sustainably manage Central Valley Chinook salmon.

(*IEP) Years in their Ears: What can Fish Earbones Tell Us About Spring-Run Chinook Salmon Success in an Increasingly Volatile Climate?

Flora Cordoleani[1 | 2], Corey Phillis[3], Anna Sturrock[4], George Whitman[5], Rachel Johnson[2 | 5]

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To track changing climate regimes, many species have shifted their phenology, distribution, and abundances. For salmon populations, life history diversity is one way to buffer themselves against natural or anthropogenic perturbations. Plasticity in migration timing may be particularly important, as their ability to respond spatially to adverse

ambient conditions is constrained by the configuration of the stream network. In the Central Valley, land-use changes have fragmented river corridors and restricted access to high-elevation habitats that would have otherwise provided thermal refugia for Chinook salmon populations. Therefore, restoring local landscapes that support climate-adapted behaviors is critical to increase salmon resilience to future climate changes.

To investigate how life history diversity may allow threatened Central Valley spring run Chinook (CVSC) salmon populations to persist in a warming climate we used otolith strontium isotopes to reconstruct the juvenile migratory strategies of adults sampled in Mill, Deer and Butte Creeks (the last three self-sustaining CVSC populations) between 2003 and 2018. For Mill and Deer Creek populations we found that yearling migrants, an increasingly rare phenotype, were critical to cohort success during drought years. Cool summer temperatures, critical for supporting the yearling strategy, were only found in a few accessible Central Valley tributaries. Providing access into high elevation habitats might be vital to allow these populations to persist in a rapidly changing climate. For Butte Creek returns, we found that most had emigrated as subyearlings, and strongly benefited from access to the Sutter Bypass floodplain for increased growth opportunities. Our findings are an important step towards identifying the management strategies that will protect and promote expression of life-history diversity that contributes to CVSC recovery and stability in California's warming climate.

Thursday Scheduled Sessions

Advances in Understanding Thermal Effects on Salmon and Temperature Management for Salmon in the Central Valley

Physiological Variation in Thermal Traits among Eight Populations of Chinook Salmon from the West Coast

Kenneth Zillig[1], Robert Lusardi[1|2], Dennis Cocherell[1], Nann Fangue[1]

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Fish populations, and salmonids specifically, are known to match their physiology to the local thermal environment. This physiological plasticity can be a result of acclimatization and local adaptation. Chinook salmon exist across a large latitudinal range, with individual populations experiencing a variety of temperature regimes. Within California Chinook salmon, those living at the southern range boundary appear to be quite thermally tolerant; however, without direct comparisons with other populations and iterated across acclimation regimes, our understanding of the thermal capacity of Chinook salmon remains limited. Our work compares the thermal biology among 8 populations of Chinook salmon: five California hatchery populations, including Central Valley Spring and Winter-run, and three populations form Oregon and Washington hatcheries. Each population was reared at three acclimation temperatures (11, 16 and

20°C) to explore interpopulation variation in acclimation capacity and thermal physiology. Physiological thermal performance metrics included growth, critical thermal maxima swimming capacity and energetics (i.e., aerobic scope). Results indicate that populations do differ in their thermal capacity and acclimation response, with variation occurring over a latitudinal range and among life-history strategies (run-timing). Our work is relevant to the management of salmonid populations undergoing rapid environmental change. Understanding the differences between populations, and their capacity to acclimate or adapt to future climate conditions is essential to effectively managing these vulnerable stocks.

Survival Thresholds for Chinook Salmon Smolts in the Sacramento River

<u>Cyril Michel</u>[1], Jeremy Notch[1], Flora Cordoleani[1], Arnold Ammann[2], Eric Danner[2]

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In California's Central Valley, studies have found that increased streamflow can improve survival of imperiled juvenile salmon populations during their oceanward migration. These studies have not explored the potential nonlinearities between flow and survival, giving resource managers the difficult task of designing flows intended to help salmon without clear guidance on flow targets. We used an information theoretic approach to analyze migration survival data from 2,436 acoustic-tagged juvenile Chinook salmon from studies spanning differing water years (2013-2019) to extract actionable information on the flow-survival relationship in the Sacramento River. This relationship was best described by a step function, with three flow thresholds that we defined as minimum (4,259 cfs), historic mean (10,712 cfs), and high (22,872 cfs). Survival varied by flow threshold: 3.0% below minimum, 18.9% between minimum and historic mean, 50.8% between historic mean and high, and 35.3% above high. We also found evidence that these flow-survival thresholds were likely driven by water temperatures, fish travel times, and floodplain connectivity.

We used these thresholds to design alternative hydrographs over the same years that implemented managed spring pulse flows so as to leverage these survival thresholds. We compared predicted cohort migration survival between actual and alternative hydrographs. Managed hydrographs with pulse flows that targeted high survival thresholds were predicted to increase annual cohort migration survival by 55% to 132% without any additions to the water budget, and by 79% to 330% with a modest addition to the water budget. These quantitative estimates of the biological consequences of different flow thresholds provide resource managers with critical information for designing flow regimes that benefit salmon in California's highly constrained water management arena.

Exploring the Drivers of River Temperature Below a Large Dam, an Example from the Sacramento River

Miles Daniels[1], Eric Danner[2]

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Water flow and temperature play a critical role in salmon health, especially during early life stages where exposure to high water temperature in spawning grounds can drive high mortality rates. Large reservoirs can fundamentally alter downstream water temperatures, and dams are often operated to protect thermal regimes of downstream ecosystems. In this study we modeled water temperature dynamics in a large regulated river (Sacramento River, CA) to better understand how thermal flux, and ultimately river temperature, responded to different physical drivers. Specifically, we used global sensitivity analysis to identify the dominant physical drivers of temperature in the Sacramento River and explored how these drivers varied over space and time. We also sought to better understand the relationship between upstream boundary conditions (dam discharge temperature and volume) and under what conditions downstream water temperature responded more to perturbations of either of these two inputs. Understanding spatial and temporal extents of drivers of water temperature and the relative importance of these factors is critical when managing for river water temperature. This presentation will focus on understanding the drivers of river water temperature in the Sacramento and relate findings to the management of anadromous fish species.

The Biophysical Basis of Thermal Tolerance in Salmon Eggs and the Implications for Sacramento River Winter-Run Chinook Salmon

Eric Danner[1], Ben Martin[1 | 2 | 3], Miles Daniels[1 | 2], Peter Dudley[1 | 2], Neosha Kashef[1 | 2], David Stafford[1 | 2], William Reeder[4], Daniele Tonina[4], Annelise Del Rio[3], Scott Foott[5]

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Construction of Shasta Dam created Lake Shasta, the largest reservoir in California and largest provider of water, via the Sacramento River, to the Delta. The dam blocks the upstream migration of anadromous fish, including endangered Sacramento River

Winter-run Chinook salmon (SRWRCS), which are now forced to spawn in the mainstem Sacramento River below the dam. Salmon eggs require cold water to develop, and operations of Shasta Dam now control the thermal quality of the remaining SRWRCS spawning habitat. There is not enough cold water in the thermally stratified reservoir to meet temperature targets in all years, resulting in significantly lower observed egg to juvenile survival when temperature targets are exceeded. However, this decrease in observed survival is significantly lower than what can be explained using temperature criteria derived from laboratory experiments.

We have attempted to address this discrepancy through a series of models and refined laboratory experiments. Our work has resulted in two main conclusions. First, egg thermal tolerance is not fixed, but depends on the complex interactions between developmental stage, ambient O_2 concentration, interstitial flow velocity, and the proximity to neighboring eggs. Second, as a result of this complex interaction, thermal tolerance is significantly lower under field conditions than had been predicted from laboratory experiments. There are important management implications of this work because the amount and timing of water release from Shasta Dam has significant impacts on egg survival, and also on the amount of water reaching the Delta. To place these findings within a management context, we developed a biophysical model of O_2 limitation that provides a mechanistic explanation for the elevated thermal sensitivity of fish embryos. This model can be used to quantify the temperature dependent egg mortality associated with any range of water operations scenarios, including near and long-term climate impacts.

Quantification of Thermal Impacts Across Freshwater Life Stages to Improve Temperature Management of Anadromous Salmonids

Alyssa FitzGerald[1 | 2], Sara John[1 | 2], Travis Apgar[3], Benjamin Martin[4]

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Temperature is the major controlling factor that influences ectotherms via their daily and long-term survival. Here we examine temperature effects on the survival of Chinook salmon (*Oncorhynchus tshawytscha*), a species of high economic and conservation importance. We implement a framework that provides a quantitative approach for assessing incremental changes in temperature on survival across runs and life stages using the best thermal performance models currently available for Chinook. These temperature-dependent models were combined with local spatial distribution and phenology data to translate spatial-temporal stream temperature data into maps of life stage-specific physiological performance in space and time. Specifically, we converted temperature-dependent performance (i.e. energy used by adults during pre-spawn holding, mortality of eggs during incubation, and juvenile growth rate) into a common currency that measures survival in order to compare thermal effects across life stages. Based on two years of temperature data for three managed rivers in the Central Valley, California, temperature-dependent mortality during pre-spawning holding was more limiting than embryonic mortality or juvenile mortality prior to smolting. We also found that threatened Central Valley spring-run Chinook were more thermally vulnerable than fall-run, and high temperatures may inhibit successful reintroduction to two rivers where spring-run have been extirpated. To increase Chinook population sizes, especially for the threatened and declining spring-run, our results indicate that adults may need more cold-water holding habitat than currently available in order to reduce pre-spawning mortality stemming from high temperatures. To conclude, our framework is an effective way to calculate thermal impacts on multiple salmonid runs and life stages within a river over time, providing local managers the information to minimize negative thermal impacts on salmonid populations, particularly important during years when cold-water resources are scarce.

Flood and Other Hazards

Delta Flood Risk under Climate Change: Key Findings from the Delta Adapts Flood Risk Analysis

Andrew Schwarz[1], Cory Copeland[1], Kaylee Griffith[1], Erin Mullin[1], Justin Vandever[2], Ricky Torres-Cooban[2], Phillip Mineart[2], Jamie Anderson[3], Prabhjot (Nicky) Sandhu[3], Brad Tom[3]

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The Delta Stewardship Council, with the assistance of partner agencies and consultant AECOM, developed a climate change vulnerability assessment for the Sacramento-San Joaquin Delta (Delta) also known as Delta Adapts. One critical vulnerability is increased flood risk due to higher riverine inflows and sea level rise. Unfortunately, it is difficult to model the influence of climate change on the Delta's flood risk because of its unique geometry, and tidal and riverine influences. The combined influence of projected fluvial inflows and sea level rise on planning scenarios in the Delta requires making choices across multiple dimensions of uncertainty. In order to address this difficulty, we used a novel approach employing Bayesian methods with a decision-scaling framework. This allowed the team to simulate millions of potential future conditions to stress test the existing system of levees and channels. The resulting analysis was used to develop flood maps that show existing and future projected flood risk throughout the Delta in terms of likelihood of flooding. Flood maps will be used in a wide array of public outreach and education settings as well as policy and investment decision making. Ultimately, the results will be used to inform future climate change adaptation decisions, investments, and policies.

The presentation will provide a high-level overview of the data and methods used to develop the model, a demonstration of the flood mapping produced, and a discussion of how the maps are being used for communication of flood risk and adaptation decision making.

Delta Adapts: Assessing Ecosystem Vulnerability to Climate Change

Dylan Chapple[1], Annika Keeley[1], Kirstin Tremain Davis[2], Tayler Tharaldson[2], Kerstin Kalchmayr[2]

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The loss of the majority of ecosystems in the Bay-Delta has heavily compromised the functioning of the remnant ecosystems, which are anticipated to be further impacted by climate change. It is critical to establish a solid understanding of current Bay-Delta ecosystem vulnerabilities to climate change and identify opportunities for adaptation. To understand specific regional climate vulnerabilities, the Delta Stewardship Council conducted a climate changevulnerability assessment, estimating exposure, sensitivity, and adaptive capacity ofdominantecosystemtypes to sea level rise, increasing air temperature, and changes in local precipitation within the Delta and Suisun Marsh. Results indicate that by 2085, rising sea levels will put remaining tidal wetlands at risk of transitioning to low marsh or drowning. Of the ecosystems currently protected by levees, 73% are at risk of flooding due to levee overtopping by 2085 resulting from a combination of sea level rise and storm events. This risk is especially high in the Central Delta and Suisun Marsh. Projected reductions in spring and fall precipitation and increased inter-annual precipitation variability will stress Delta species, favor less diverse species assemblages, and lead to increased presence of non-native species. Increases in both average air temperature and extreme heat days, especially when occurring sequentially, will stress Delta plant and wildlife species and alter ecosystem dynamics. The vulnerability assessment highlights the importance of resilience-focused ecosystem restoration in the Bay Delta. Actions should include (1) substantially increasing natural ecosystems acreage through restoration and management, (2) increasing shade by expanding the extent of riparian vegetation throughout the Delta, (3) restoring tidal wetlandswith upland connection, and (4) implementing subsidence reversal wetlands to reduce the likelihood of levee failure. The vulnerability assessment provides the foundation for developing and communicating climate resilient restoration strategies as a mechanism for adaptation throughout the Bay-Delta.

Earthquake Event Selection for Regional Seismic Hazard Analysis of Levee Systems

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Probabilistic seismic hazard analysis is generally performed at a single site, where ground motion hazard from all of the faults that might shake the site is integrated to express the annual probability of exceedance as a function of ground motion intensity. This site-based calculation is then often repeated at many different sites to develop uniform hazard maps, expressing the ground motion intensity measure values associated with a specific annual probability of exceedance. While such maps are useful for selecting a ground motion intensity measure for structures or other infrastructure systems with geographic footprints that may be approximated as a point, they are not appropriate for application to spatially distributed infrastructure systems such as levees. The problem is that many different earthquake events contribute to the hazard at each site, and none of those events on their own will produce uniform hazard shaking levels over a spatially distributed infrastructure system. Rather, spatially distributed infrastructure systems must be analyzed using an adequate number of scenario events to reasonably represent the hazard. We present a method for selecting an event subset from a probabilistic seismic hazard disaggregation, and adjusting the rates of occurrence of the events in the subset to recover the target hazard curve. We select the event subset based on the percent contribution to the seismic hazard at a set of locations, and then utilize a weighted least squares regression approach to identify the rates for the event subset. We illustrate the procedure for Bacon Island in the Sacramento / San Joaquin Delta.

Integrating Climate Driven Hydrologic and Subsidence Models and Geophysical Data to Predict Delta Levee Failure Risks

Sandra Bachand[1], Scott Brandenberg[2], Paolo Zimmaro[2]

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The Delta is integral in managing California Water as a critical surface water conduit to meet domestic, agricultural and wildlife water needs. Water supply and quality management relies on a vast levee system, much on peat soils and all at risks from subsidence, climate change and earthquakes. Effective management of this levee system will increasingly rely upon more efficient and accurate assessments leveraging technological and data advances. This project is part of a Next Generation Multi-Hazard Levee Assessment for Delta levees to assess subsidence, climate change, and earthquake impacts on levee integrity using Bacon Island levees as an example. For

this project, RMA's 3D SF Estuary Model predicts future water levels in response to climate change and Hydrofocus' SUBCALC and SEDCALC models estimate future subsidence. Geophysical data collected by Lawrence Berkeley Lab will be groundtruthed against soil boring and cone penetrometer data records and used to map heterogeneous underlying soil conditions impacting levee strength and permeability estimates. Here, we provide an overview of our approach to integrate these data to better model levee failure mechanisms from seepage and overtopping risks. In greater detail, we focus on overtopping to follow initial erosion from wave overtopping toward likely overtopping failure. Future river stages are predicted higher from sea-level rise and tidal amplitude increases. We analyze potential overtopping in 2050 and 2100 due to 10, 20, 50, and 100-yr storms. We estimate erosion based upon Briaud (2017) who accurately predicted overtopping-induced failure in the New Orleans 2008 flood event. We calculate erosion caused by over-topping induced shear stresses by summing erosion for each time step during a storm event with significant erosion indicating potential failure. We will discuss the increasing likelihood of overtopping failure (2050, 2100) and the implications for future levee height requirements.

Modeling High Water Events to Inform a Multi-Hazard Levee Risk Assessment

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With approximately 1100 miles of levees within the Delta and future increases in sea level rise and land subsidence, identifying levees with the highest risk of failure is critical to preserving life and infrastructure within the Delta. This modeling effort is part of a larger group effort to evaluate levee risk due to long-term stressors (sea level rise, subsidence) and short-term events (flooding, earthquakes) in an integrated way, and using the best available data and modeling approaches. To assess high water risk, hydrodynamic model simulations were performed using the RMA 2D Bay-Delta Model. The model grid and boundaries were recently calibrated for high water events in the Delta as part of work for the Central Valley Flood Protection Plan 2016 Update. A series of high flow simulations were run to represent storm events with recurrence intervals of 10, 20, 50 and 100 years. These simulations were run using both a high and low estimate of future sea level rise as specified by the State of California Sea Level Rise Guidance document. For each sea level rise and flood event scenario, there were two sets of simulations: one assuming a 'hard shoreline', where present-day Delta shorelines are maintained (levee heights keep pace with sea level rise), and another where low-lying levees are allowed to overtop based on present-day elevations. Spatial maps of calculated maximum water levels were developed for comparison against existing levee elevations and to inform the seepage and overtopping levee risk analyses. Additional simulations performed with long-term planned restoration projects in place reduced peak Delta water levels.

Multiple Perspectives on Sediment in the Bay and Delta: Supply, Transport, and Sink in a Complex Environment

Is There Enough? the Future of Bayland Sediment Supply and Demand under a Changing Climate

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Sediment is a critical resource that is essential for sustaining San Francisco Bay tidal marshes and mudflats (i.e., baylands) under a changing climate. Currently, there are approximately 80,000 acres of baylands that will need an increased sediment supply to keep pace with sea-level rise (SLR). In addition, tens of thousands of acres of restored tidal marsh planned throughout the Bay will need sediment to fill subsided areas and maintain tidal marsh elevation into the future. With an increasing bayland sediment demand and recent studies showing a declining Bay sediment supply, there is a critical need to determine if there will be enough sediment delivered to the Bay to support baylands over the long-term.

This talk presents the findings from an EPA-funded effort focused on comparing bayland sediment demand and sediment supply to the end of the 21st century for scenarios that consider bayland extent and climate change impacts. Sediment demand was assessed for existing baylands and for existing baylands plus 24,000 acres of planned tidal marsh restoration assuming 1.5 ft of SLR by 2050 and an additional 5.0 ft of SLR by 2100. Bay sediment supply from the Delta and local Bay tributaries was assessed for a wetter future and drier future by using precipitation from downscaled global circulation models to calculate runoff and sediment loading to the Bay. The results show that there will likely not be enough sediment coming into the Bay under a wetter or drier future to sustain all existing baylands, with the deficit being far greater in South Bay-Lower South Bay than Suisun Bay-San Pablo Bay. The findings are used to determine future bayland resilience with respect to vertical accretion around the Bay. Outside sediment sources that should be called upon to support long-term bayland resilience are also discussed.

How Do Physical and Biological Properties of Bed Sediments Influence Erodibility?

Jessca Lacy[1], Maureen Downing-Kunz[2], Francis Parchaso[3], Samantha McGill[1], David Hart[2], Jan Thompson[3], Emily Zierdt Smith[3], Rachel Allen[1], Lukas WinklerPrins[4], Andrew Stevens[1]

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Sediment and sediment transport are important components of the physical habitat and ecology of the San Francisco estuary. Numerical sediment transport models, used to predict sediment movement, erosion, and deposition, require specification of properties including critical shear stress, erodibility, and particle settling velocity. There are few field measurements of these properties in muddy systems like San Francisco Bay. This project investigates the role of hydrodynamic forcing, physical properties of sediment, and benthic infauna on erosion parameters in the shallows of San Pablo and Grizzly Bays, where wind waves frequently mobilize fine sediments. During summer 2019 and winter 2020 study periods, we measured time series of waves, currents, depth, salinity, suspended-sediment concentration (SSC), and particle size in suspension at the two sites. We collected bed sediment 5 or 6 times per study period to analyze for bulk density and grain size distribution. Simultaneously, we measured erodibility in an erosion microcosm designed for this purpose. We also measured the abundance of benthic infauna in replicate 0.052 m^2 area samples collected every two weeks. Despite the similarities in the settings of the two sites, results show clear differences between them and between the study periods. Bed shear stress due to waves was greater in San Pablo Bay than Grizzly Bay. Bulk density of surficial sediment was lower in winter than summer in Grizzly Bay, whereas in San Pablo Bay there was no significant seasonal difference. The abundance and community composition of benthic infauna varied between the two embayments and the two periods. We are investigating how these variations influence sediment erodibility as measured by two methods: in the erosion microcosm, and from time-series measurements of near-bed velocity and SSC. In future work, we will evaluate the sensitivity of model predictions of SSC and sediment transport to the observed range of erodibility parameters.

Variations in Microcosm Measured Bed Erodibility in Grizzly Bay and San Pablo Bay, Summer 2019 and Winter 2020

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Quantifying variability in the erodibility of bed sediments is critical for developing robust sediment transport models. As part of a larger U.S. Geological Survey study seeking to quantify the roles of hydrodynamics and biology on erodibility and hydrodynamic roughness, a series of sediment cores were eroded using a Gust microcosm and the results analyzed to assess temporal variations in bed erodibility in two subembayments of San Francisco Estuary—Grizzly Bay and San Pablo Bay—during summer 2019 and winter 2020. Eleven erosion experiments were completed at each site over the course of the study, six in summer and five in winter, totaling 22 experiments. The Gust microcosm takes a collected sediment core and uses a rotating disc and radially pumped water at the sample water surface to generate a nearly uniform and known shear stress across the sample sediment bed. For each experiment two sediment cores were collected and simultaneously eroded in individual microcosms though a

fixed range of shear stresses (range: 0.01 - 0.60 Pa). The effluent turbidity from each core was monitored and sampled for suspended sediment concentration to determine individual erosion rates. Early results show that the critical shear stress necessary to initiate erosion is consistently low and invariable (range: 0.03 - 0.075 Pa) while total eroded mass (kg/m^2) at applied shear stress of 0.45 Pa varies by an order of magnitude (range: 0.023 – 0.29 kg/m^2). Further analyses of the results are currently underway.

Evaluating the Effect of Realignment of Coyote Creek on Sediment Supply to Bothin Marsh, Marin County, California

Michael MacWilliams[1], Aaron Bever[1], Roger Leventhal[2]

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Bothin Marsh is a narrow urban-fronting marsh in Marin County which provides habitat for threatened and endangered species. Bothin Marsh and adjacent infrastructure, including the Mill Valley-Sausalito Multi-Use Path, are subject to significant flooding during high tides. The marsh is experiencing erosion and loss of habitat, which are expected to worsen with sea level rise. A 2-D hydraulic model, HEC-RAS, was used to screen alternatives that minimize upstream flood impacts by realigning Lower Coyote Creek, currently an adjacent straightened flood control channel, through Bothin Marsh. A 3-D hydrodynamic, wave, and sediment transport model was then applied to evaluate how the realignment would affect sediment supply to Bothin Marsh. The simulations indicated that, even under existing conditions, sediment originating from Coyote Creek provides a significant portion of the sediment supply to Bothin Marsh. Realignment increases the predicted deposition of sediment from upstream tributaries in Bothin Marsh. However, the model also predicted that the increased connectivity between Bothin Marsh and Richardson Bay because of the realignment resulted in less net sediment accumulation in Bothin Marsh during periods with lower creek flows and low to moderate tidal ranges. The net sediment deposition in Bothin Marsh during the analysis period was predicted to be 37% higher under the realignment alternative than under existing conditions. These results highlight the complex interactions which can affect sediment supply from both upstream and downstream sources, and that must be considered in effective restoration design. The results indicated that the benefit of increasing the connectivity between Coyote Creek and Bothin Marsh on sediment supply from the creek outweigh the potential reduction in net sediment supply because of increased tidal exchange under the realignment alternative evaluated. This study demonstrates the potential benefits of reconnecting flood control channels into sediment-starved marshes for resiliency as sea levels rise.

Sediment Deposition and Marsh Accretion Properties in San Pablo Bay-Delta

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Sediment deposition is an important component of accretion processes that builds tidal marsh elevations relative to local sea levels. Interactions among suspended sediment concentration, tidal hydrodynamics, wind and waves, and distance to sediment source influence deposition rates within marshes and locations throughout the San Pablo Bay-Delta, CA. Spatial and seasonal variation of storm flooding and sediment transport processes can also affect short-term deposition rates within a tidal marsh. Determining spatio-temporal patterns of sediment deposition across tidal marsh landscapes is key to understanding accretion rates and helps inform sea-level rise vulnerability. Here, we sought to answer the questions - what determines the amount of sediment deposition on a marsh surface? and does this vary across San Pablo Bay-Delta? We deployed feldspar marker horizons and sediment traps in tidal marshes to determine sediment deposition amounts over months and years. We found variation in marsh surface sediment deposition rates across geographic locations and within marshes. Also similar to previous studies, we found sediment deposition was highest closer to channels and at lower elevations. Mineral deposition rates were greater at brackish marsh sites in Suisun Bay-Delta (Rush Rach, Browns Island, and Miners Slough) when compared with marsh sites in San Pablo Bay (Petaluma marsh, China Camp SP, and San Pablo Bay NWR). Organic matter deposition was greater at brackish marsh sites, presumably reflecting the different plant communities due to the salinity gradients. Our study suggests sediment deposition varies across the San Pablo Bay-Delta estuary and is driven by site specific characteristics such as marsh elevation and channel complexity. An introduction to a new study starting in 2021 located in south SFB measuring marsh deposition will also be presented. A greater understanding of the seasonality and spatial heterogeneity in marsh mineral deposition and elevations is needed.

Linkages Among Physics, Chemistry, and Biology in the Sacramento Deep Water Ship Channel

Sacramento Deepwater Ship Channel Science and Delta Ecosystem Rehabilitation

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Since 2012, Reclamation has sponsored monitoring and research in the Sacramento Deepwater Ship Channel (SDWSC) because, though manmade, it is one of the most scientifically interesting features of the Sacramento-San Joaquin Delta and, more importantly, because of the positive contribution it could make to a broader effort to enhance the Delta's primary (plant) food supply. This broader effort includes the California Department of Water Resources North Delta Food Subsidy Action and

creation of 8,000 acres of restored tidal wetlands over the next decade.
Boosting primary productivity is necessary to increase the abundance of plant-eating crustaceans and insects that constitute the bulk of Delta Smelt, Longfin Smelt, juvenile Chinook salmon and most other fish diets. The underlying assumption is that, in most circumstances, a well-fed fish is likely to fair better (survive and reproduce) than a poorly-fed one. This assumption is supported by the generally positive correlation observed between annual fish production and primary production among lakes and estuaries worldwide. The upper section of the SDWSC supports moderate levels of primary production regulated by thermal stratification, light intensity and nitrogen concentration. Because the SDWSC has no net flow, however, little of this production reaches the middle section, where Delta Smelt tend to congregate, and even less is transported to the relatively nitrogen-rich lower Sacramento River, where it could potentially provide a seed source for blooms. Reclamation's 2019 Biological Assessment for the long-term operation of the Central Valley Project includes a provision (programmatic-scale proposed action) to determine the feasibility of boosting SDWSC primary production and export by adaptively managing inflow and nutrient supply at its upstream end. Continued research will be needed to develop and calibrate models and other quantitative tools required to assess the feasibility of this proposed action and to predict and document outcomes of subsequent management decisions.

Phytoplankton and Zooplankton Dynamics in the Sacramento Deep Water Shipping Channel

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The Sacramento-San Joaquin Delta supports relatively low phytoplankton biomass compared to other aquatic ecosystems despite generally high nutrient concentrations. Variation in rates of primary production has important implications for zooplankton community dynamics, energy flow between trophic levels, food web structure, and many species of native fishes. Here, we describe spatial and temporal patterns in phytoplankton and zooplankton biomass and community structure throughout the Sacramento Deep Water Ship Channel (DWSC) in relation to potential physical, chemical, and biological drivers. Sampling was conducted over an eight year period (2012 – 2020) at 12 stations spanning a 40 km reach from Rio Vista to West Sacramento. Spatially, algal biomass was highest in the upper portion of the DWSC, where primary production transitioned from being light limited due to high turbidity to nutrient limited due to longer water retention times and increased water clarity. Although characterized by higher variability, zooplankton biomass generally mirrored spatial patterns in phytoplankton biomass, becoming elevated in the uppermost part of the DWSC. Communities of phytoplankton and zooplankton co-varied along the DWSC's longitudinal axis; while diatoms, c*opepods, and* smaller bodied species typical in lotic environments were abundant throughout the DWSC, the community of the upper channel regularly included chlorophytes, *cryptophytes*, *cladocerans, and other larger bodied species typical in lentic environments. We illustrate the extent to which spatial and temporal patterns in community structure at the base of the DWSC food web are responding to phenological patterns in water temperature, light, turbidity, nutrient availability, and hydrodynamic characteristics. Our analysis suggests that* management strategies to boost the pelagic food web and promote secondary production of zooplankton and/or fisheries should consider the spatial and temporal heterogeneity of multiple physical and chemical properties that regulate ecosystem functions in the northern Sacramento-San Joaquin Delta.

Hydrodynamics Drive Pelagic Communities and Food Web Structure in a Tidal Environment

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Hydrodynamic processes can lead to accumulation and/or dispersal of water column constituents, including sediment, phytoplankton, and particulate detritus. Using a combination of field observations and stable isotope tracing tools, we identified how hydrodynamic processes influenced physical habitat, pelagic communities, and food web structure in a freshwater tidal system. The pelagic habitat of a terminal channel differed spatially, likely aligning with differences in hydrodynamics. Three zones that we classified by exchange with downstream habitat had distinct water quality characteristics, supported different densities of zooplankton and nekton, and exhibited disparate support from benthic and pelagic trophic pathways to pelagic consumers. Hydrodynamically driven zones and their emergent characteristics appeared sensitive to hydrology, as elevated runoff was correlated with a shift in hydrodynamic habitat and organismal distributions. The results of our study highlight the relationship between hydrodynamic processes, biological responses, and climate, and suggest that understanding the physical processes can improve understanding of pelagic habitats and communities.

Dispersion and Stratification Dynamics in the Upper Sacramento Deep Water Ship Channel

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Hydrodynamics control the movement of water and material within and among habitats, where timescales of mixing can exert bottom up regulatory effects on aquatic ecosystems through their influence on primary production. Habitat restoration efforts in the San Francisco estuary are focused on increasing productivity to support fisheries and ecosystem services. The Sacramento Deep Water Ship Channel (DWSC) is a terminal channel that, although entirely human-made and engineered, exhibits physical and biological characteristics like the dead-end sloughs that were common in the historic Delta and supports endemic, endangered Delta smelt. We investigated the physical mechanisms that control mixing and thermal stratification in the upper DWSC. Our study was conducted in conjunction with a whole-ecosystem experiment investigating whether phytoplankton production and biomass would respond to nitrate additions, which could potentially be exported to food-limited regions in the Delta.

Analysis of the mixing mechanisms and timescales revealed that tidal currents and wind controlled mixing and stratification that developed due to heat fluxes at the surface. On average, longitudinal mixing over the average tidal excursion length (2.6 km) occurred every 14 hours, while vertical mixing over the total depth (8 m) occurred on average every 1.5 hours. Longitudinal and vertical dispersion increased during periods of high wind, and wind speed had a greater influence on dispersion rates than tidal currents. Thermal stratification developed on most days, temporarily inhibiting vertical mixing but was rapidly broken down by wind-induced mixing. Days with stronger stratification had greater concentrations of chlorophyll. However, stratification rarely (5 out of 78 days) persisted overnight, which may be an important limitation on algal bloom formation. The observations of the physical mechanisms in the DWSC that affect stratification and interconnectivity among habitats that enhance primary production may be useful in informing habitat restoration elsewhere in the Delta.

Whole Ecosystems Experiments Unravel Effects of Nutrients, Light, and Hydrodynamics on Productivity in the Upper Sacramento-San Joaquin Delta

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The Sacramento-San Joaquin Delta has experienced long-term declines in multiple measures of aquatic ecosystem health, including decreases in pelagic phytoplankton and native fishes. Nutrient subsidies may be a bottom-up strategy to increase productivity in the delta to the ultimate betterment of the pelagic food web. Although primary production through much of the delta does not appear nutrient limited, waterways where flushing rates are low, such as the upper portion of Sacramento Deep Water Ship Channel (DWSC), can become nitrogen limited under certain circumstances. We conducted a whole ecosystem field experiment in the upper portion of the DWSC to test whether adding nitrogen, when and where it appeared limiting, would stimulate primary productivity. Following periods of nitrogen addition (as nitrate), gross primary production and chlorophyll biomass increased. However, the ecosystem responses were brief (<2 days) as primary production also responded to variation in hydrodynamics and light availability. The influence of wind, tides, and stratification were equally important as nutrients and light in regulating productivity. Our experiment captured dynamics at a transition point along a spatial continuum within the DWSC. In landward ecosystems, hydrologic isolation and higher water clarity indicate that primary productivity is regulated by nutrient availability. Moving seaward, production appears to be regulated by light limitation and the continual resuspension of sediment, reflecting faster water velocities and connections with the greater Delta waterway. Thus, productivity along the DWSC reflects gradients in hydrodynamics, and generalizing controls of other biogeochemical processes and community dynamics require a spatial framework that accounts for connectivity among ecosystems. All told, our experiment illustrates the high degree of heterogeneity among factors controlling primary production in a relatively simple channel, emphasizing the importance of hydrodynamics and the need for high frequency sampling in space and time to evaluate ecosystem energetics and food web dynamics in estuaries.

IEP Session: Fish Habitat Spatial Arrangements: Experience from Across the Estuary and Beyond

Four Decades of Juvenile Fish Responses to Hydroclimate: Advancing a State-Space Modeling Approach in the San Francisco Estuary

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In the San Francisco Estuary, the relative magnitude of marine vs. freshwater influences varies with hydroclimate patterns. Over the last decade, abundant research has shown how such fluctuations drive primary and secondary production; however, variation in target species and sampling methodology across monitoring programs often hindered synthesis, limiting generalizability. Here we used Multivariate Autoregressive State-Space (MARSS) models on CDFW Bay Study otter and midwater trawl long-term data to examine juvenile fish dynamics and the influence of environmental fluctuations and trends. Specifically, we built a set of species- and spatially-structured MARSS models to answer the following questions: How does juvenile fish abundance vary along the estuarine gradient over time? How do watershed hydrology and ocean conditions explain inter-annual variation in abundance across the different species, and along the estuarine gradient? We focused on 15 common young-of-the-year fishes sampled at 35 core stations from 1980 to 2018. Overall, mean annual Delta outflow best explained community-wide abundance fluctuations. Notably, anadromous species such as longfin smelt (*Spirinchus thaleichthys*), striped bass (*Morone saxatilis*), and American shad (*Alosa sapidissima*) responded similarly, with significant positive responses to flow

('freshening') in the lower estuary (e.g., San Pablo Bay, Central Bay). In contrast, marine-dependent species such as Pacific herring (*Clupea pallasii*), Northern anchovy (*Engraulis mordax*), and English sole (*Parophrys vetulus*) displayed the opposite pattern, with significant negative responses to flow ('salinity intrusion') in the upper estuary (e.g., Suisun Bay). Building on these findings, we plan to further quantify the potential effects of historical and future hydroclimatic anomalies (flood vs. drought) and explore the life-history mechanisms that may confer response diversity--and thus temporal stability--at the community level. This work may advance the notion that directional trends, fluctuations, and extremes in the environment (due to water management and climate) will continue to reshape estuarine fish communities in the future.

(*IEP) Space Jam: A Spatially Explicit History of Estuary Fish Species

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The San Francisco Estuary (estuary) is a dynamic and highly altered system with myriad abiotic and biotic changes since its widespread colonization by European-Americans in the 1800s. As a result of these changes and others, including overfishing and pollution, many native and some introduced species have experienced drastic declines in the past 100 years. To track these species declines several state and federal agencies, as well as research groups at the University of California, Davis, have operated regular estuary fish surveys dating back to the late 1950s. While most of these fish surveys are designed to track estuary-wide fish abundance, they are logistically restricted in their total number of stations, frequency of sampling events, and differing gear types. These constraints mean that a single survey likely does not capture all of the intricacies in long-term species trends, as changes in species distribution, behavior, and/or changes to the condition of sampling sites may artificially alter capture efficiency. To combat this, we have combined eight surveys that have operated continuously between 1980 and present into a spatially explicit integrated dataset, capturing 30 years of trends in estuary fish abundance at a much higher seasonal and spatial density than could be provided by any single survey. By leveraging this data in a yearly aggregate format, we examine trends in the distribution of several important estuary species over time.

(*IEP) Suisun Marsh on the Edge of Resilience in an Era of Rapid Change

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UC Davis has been researching water quality, invertebrates, fishes and wetlands as part of the Suisun Marsh Fish Study since 1980. During that period, the Bay-Delta has been subject to droughts, floods, record temperatures, species invasions, and food web degradation. Suisun Marsh remained largely resilient to these stressors. Since a decline in the early 1980s, native fish catch in Suisun mostly remained stable, even while introduced fish have increased. Much of the marsh avoided aquatic weed and clam invasions, and pelagic food remained abundant in terminal sloughs and managed wetlands. Remnant tidal wetlands created habitat for juvenile and adult fishes and new wetlands were being restored. Even stakeholder conflicts over water management and low dissolved oxygen levels were resolved through coordinated action. Some of this resilience was likely due to its location in the low-salinity zone, its complex geomorphology, and its long, shallow, low gradient slope to uplands.

However, there are early signs that Suisun Marsh may be entering a new phase of vulnerability. In the years following the 2012-16 drought, the marsh has had elevated water temperatures and clarity. The typical post-drought recovery pattern has not been seen for many fishes, including Delta smelt, which have not been detected since 2015, and longfin smelt, which are increasingly rare. An emerging threat to wetland restoration is the invasive alligator weed, which is tolerant of brackish water. Sea level rise will soon submerge the outer marsh, while upland marsh will be compressed against the growing urban interface. Solutions will emerge by incorporating science into management practices, seeking novel collaborations among stakeholders and agencies, and using traditional practices to better integrate the working landscape with naturalistic restorations.

(*IEP) Differences Between Surface and Bottom Temperatures in the Upper San Francisco Estuary: Implications for Temperature Refugia

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Water temperature is an important water quality parameter to monitor in estuaries as it is one of the main factors underlying distribution, growth rate, and survival of key fish species. Climate change is expected to have especially profound effects on the upper San Francisco Estuary (SFE), because water temperatures are highly influenced by rising air temperatures. As the upper SFE warms, an important question is whether depth can provide temperature refugia for thermally sensitive listed fish species. Over the years, monitoring programs in the upper SFE have collected tens of thousands of discrete water temperature measurements at both the surface and near-bottom of the water column. To evaluate when and where thermal stratification occurs in the upper SFE, we compiled an integrated discrete temperature dataset from 11 different boat-based surveys and used a spatiotemporally explicit generalized additive model to identify patterns of stratification. Because most discrete data are collected during daytime, we also used data from four continuous water quality stations to better understand how thermal stratification changes through the course of a day and to validate our findings. Our results demonstrate that the upper SFE is a well-mixed system overall with little thermal stratification under most circumstances. We did observe cooler bottom water temperature relative to surface in certain regions of the Delta relatively often in the summer when surface water temperature is high (>~21 C). We also observed situations where bottom water temperature was warmer relative to the surface, which appeared to occur more often in the Suisun Bay region in the winter and spring when air temperature is low. Although these occasional thermal stratifications may offer some respite during extremely warm summer days, they are likely too unpredictable in time and space to play a major role in the health and survival of thermally sensitive fishes.

(*IEP) Investigating Longfin Smelt Utilization of Coastal Estuaries North of the San Francisco Estuary

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The San Francisco Estuary is home to the southernmost reproducing population of Longfin Smelt. At the edge of the species' range, it is considered a distinct population due to a low likelihood of southward gene flow contributing to genetic diversity. Despite rigorous studies within the estuary, a critical gap exists in our knowledge of the potential influence that marine immigration has on this anadromous population. Our study consisted of targeted surveys during 2019 and 2020 to identify coastal estuaries north of San Francisco Estuary where spawning might occur. We determined the importance of estuary size on the occurrence of larval Longfin Smelt and the environmental factors that might predict the presence of larvae. In the wet winter of 2019, we observed low occurrence and densities of larval Longfin Smelt in Humboldt Bay and the Eel River. Higher densities and occurrences of larvae were detected in the dry winter of 2020 at Humboldt Bay and the Eel River with additional detections at the Klamath and Mad rivers. No larvae were detected in the coastal estuaries sampled in Mendocino, Sonoma, and Marin counties closer to the San Francisco Estuary. In 2019, increased freshwater outflow appeared to reduce larval Longfin Smelt recruitment due to greater advective transport to sea. While a population of Longfin Smelt appears to exist north of Cape Mendocino, our results indicate that coastal estuaries in proximity to the San Francisco Estuary either do not support recruitment in years with high variation in hydrology or that immigration is extremely rare. Our study highlights the need for monitoring over the range of hydrologic conditions with detection probabilities that can improve future assessments of gene flow between populations.

Friday Scheduled Sessions

Integrating Data and Population Models: Understanding Factors that Affect Sensitive Fish Populations

Life Cycle Modeling Using State-Space Models for Data Integration to Identify Factors Affecting Delta Smelt Recruitment, Survival and Population Growth Rates

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Population models are most often described at an annual time step and fit using data from the same survey each year. But scientific understanding and management strategies are both improved when finer temporal resolution models are constructed that factor the population growth rate into a product of recruitment and life stage-specific survival rates. We use a hierarchical state-space model framework to describe the delta smelt life cycle fit to a sequence of abundance estimates from multiple surveys, each with unique abundance estimation biases and uncertainties. These models quantify the effects of biotic and abiotic factors on recruitment and seasonal survival of 25 years of delta smelt population dynamics, including management relevant ones such as various measures of net freshwater flow in the species' estuarine environment. Life cycle model results allow retrospective assessments of the good and bad years as measured by the realized growth rates and the relative contributions of manageable and unmanageable sources of mortality to survival processes, as well as predictions given observed environmental conditions. The linkage of abundances through time described by the life cycle models provides a path to quantitatively connect covariates controlling vital rates to the population growth rate to predict the outcomes of alternative management strategies. We describe which vital rates were the relatively limiting factors resulting in low population growth over the 25 years and what the corresponding observed covariates were, and how the probability of positive growth changes over a wide range of management relevant environmental scenarios.

Decision Analysis to Identify Optimal State-Dependent Restoration Policies for Chinook Salmon

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Anadromous fish are a valued resource for their economic, cultural, and ecological importance. Yet, their reliance on both freshwater and ocean environments makes them susceptible to myriad human-induced stressors throughout their life cycle, which have contributed to their decline in California's Central Valley. We will describe the Chinook salmon (*Oncorhynchus tshawytscha*) decision-support models developed by the Central Valley Project Improvement Act Science Integration Team as part of a larger structured decision-making effort aimed at maximizing natural adult production of Chinook salmon in California's Central Valley. We will then describe the decision-analytic tools the stakeholder group used to solve the models, explore model results, and develop a restoration strategy. Overall, we found that actions targeted at one run were detrimental to others, which was unexpected. Furthermore, information uncovered during this process was used to direct efforts towards targeted research/monitoring to reduce critical model uncertainties and make better restoration decisions moving forward. Collectively, the results of our study revealed a restoration strategy that can be applied at a broad scale and may be applied to systems with similar constraints.

Applying the Winter-Run Life Cycle Model to Pressing Hydromanagement Questions in the Central Valley

<u>Noble Hendrix</u>[1], Ann-Marie Osterback[2], Evan Sawyer[3], Brett Harvey[4], Corey Phillis[5], Eric Danner[6], Steve Lindley[6]

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Successful management of California's fresh water resources requires balancing consumptive and non-consumptive water use with fish species that depend critically on the same resources. Numerous water management decisions are being evaluated currently; many with the goal of providing protection for endangered species such as winter-run Chinook salmon. Scientists at UC Santa Cruz, NOAA Fisheries, USGS, and QEDA Consulting have developed a winter-run life cycle model (WRLCM) to support such decision-making in the Central Valley. The WRLCM is capable of incorporating other models that run at finer spatial and temporal scales (e.g., SALMOD and an enhanced particle tracking model to track smolt survival, ePTM) and has been statistically fitted to winter-run abundance data from multiple life stages. The WRLCM has been applied in several important decisions: 1) to evaluate long term operational scenarios that reflect modified water diversions, reservoir management, and export levels; 2) to determine whether Shasta temperature management and reintroduction of winter-run to tributaries above Shasta dam can improve juvenile survival during droughts; and 3) to define how restoration and associated survival experiments can ultimately lead to increased productivity of the winter-run population. Results of the

Shasta evaluation indicated that temperature management in critical water years and reintroduction to natal tributaries above Shasta dam can act synergistically to help buffer negative impacts of drought conditions. WRLCM results indicated that the optimal location for restoration (Delta versus Lower Sacramento River) depends on the survival benefits due to restoration. As a result, experiments to estimate the survival benefits of restoration are critical for maximizing the efficacy of restoration projects. Models such as the WRLCM provide an important component to decision-making because of their ability to evaluate alternative actions, even under parametric and structural uncertainty, and to evaluate the utility of data collection to reduce that uncertainty.

The Enhanced Particle Tracking Model: Bridging Science and Management

Vamsi Krishna Sridharan[1 | 2], Doug Jackson[3], Andrew Hein[2], Russel Perry[4], Adam Pope[4], Eric Danner[2], Steven Lindley[2]

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Science-based management of multipurpose water systems is challenged by two scale disconnects: (1) top-down: the macroscopic (on the order of tens of kilometers over several days) drivers and stressors that govern animal migration through complex environments and the levers that can be controlled by managers are often disconnected from local environmental cues that the animals respond to, and (2) bottom-up: the microscopic (on the order of a few meters over a few seconds) behavior patterns observed in laboratory studies are often not easily generalizable. The top-down disconnect results in empirical correlations between observed migration patterns and macroscopic environmental conditions that are not typically flexible enough to deal with out-of-sample situations such as alternative management scenarios. The bottom-up disconnect results in mechanistic models with ad-hoc rules that are not driven by data or constrained by biological plausibility so that, yet again, the applicability of these models to out-of-sample situations becomes problematic. Ecological models that serve as decision support tools therefore need to serve as a bridge to the macroscopic system-control levers in a manner that does not introduce gross inconsistencies in representing the environmental cues with minimal indefensible assumptions about the microscopic behaviors. The enhanced Particle Tracking Model (ePTM) is a juvenile salmon migration model that has been constructed with these two principles to translate what is known about microscopic salmon behavior dynamics to macroscopic migration patterns within the Delta that can be altered by hydrological and water operation levers. In this talk, we will describe the model and discuss how to extend mechanistic model development of this complex ecohydrodynamic system by utilizing higher quality datasets that are becoming available.

Merging Computational Fluid Dynamics and Machine Learning to Reveal Fish Migration Strategies

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Understanding how migratory animals interact with dynamic physical environments remains a major challenge in migration biology. Interactions between migrants and wind and water currents are often poorly resolved in migration models due to both the lack of a high-resolution environmental data, and a lack of understanding of how migrants respond to fine scale structure in the physical environment. Here we develop a generalizable, data-driven methodology to study the migration of animals through complex physical environments. Our approach combines validated Computational Fluid Dynamic (CFD) modeling with animal tracking data to decompose migratory movements into two components: movement caused by physical forcing, and movement due to active locomotion. We then use a flexible recurrent neural network model to relate local environmental conditions to locomotion behavior of the migrating animal, allowing us to predict a migrant's force production, velocity and trajectory over time. We apply this framework to a large dataset containing measured trajectories of migrating Chinook salmon through a section of river in California's Sacramento-San Joaquin Delta. We show that the model is capable of describing fish migratory movements as a function of local flow variables, and that it is possible to accurately forecast migratory movement behavior of individual migrants on which the model was not trained. After validating our model, we show how our framework can be used to understand how migrants respond to local flow conditions, how migratory behavior changes as overall conditions in the system change, and how the energetic cost of migratory movements depend on environmental conditions in space and time.

Contaminants and Toxins

What's HAB-Ening to Our Water and How can We Best Manage It?

Meghan Klasic[1], Rachel Lamb[2], Kelsey Leonard[3], Vanessa Vargas[4]

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Harmful algal blooms (HABs) are one of the greatest contemporary social-ecological challenges. HABs alter marine and freshwater food webs, cause mass aquatic life mortalities, and lead to human illness and death. HABs have an immense impact on the economy, costing an average of $49 million annually between 1987–92 in the United

States, with 45% of costs coming from public health impacts. These impacts, coupled with complications from climate change, underscore the urgent need to understand how to best manage our watersheds and social-ecological systems. In California, despite HABs in the Bay-Delta, current state efforts are underfunded and underdeveloped. Comparatively, Lake Erie watershed managers have addressed HABs for more than 40 years. This work involves a complex governance system from binational agreements down to watershed-level planning efforts. Lake Erie provides a unique opportunity for Bay-Delta managers to learn best management practices to proactively address Bay-Delta HABs and reduce impacts. We conducted social-ecological network analyses to better understand the Lake Erie governance system and decision-making processes over the last 10 years through document analysis and interviews. Preliminary findings show that: 1) the HABs governance system in Lake Erie is complex and polycentric (1500+ unique actors); 2) high-level plans claim multi-level collaboration yet most work is completed as local “random acts of restoration”; 3) plans show sweeping collaboration, while interviews reveal that work is largely conducted in clusters; and 4) tribes, métis, and first nations continue to be excluded from substantive collaboration. Given that climate change will increase the intensity and frequency of HABs, California water experts can glean strategies and cautionary tales from the Lake Erie case study to develop a more robust and anticipatory management approach for the Bay-Delta. This research can help managers better target strategies to address HABs while fostering collaborative efforts to ensure long-term Delta ecosystem sustainability.

Bioaccumulation Potential of Chlorpyrifos in Hyalella Azteca: Implications for the Bay-Delta Region

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Mutations in the target site acetylcholinesterase (AChE) gene within the freshwater amphipod *Hyalella azteca* has allowed these invertebrates to tolerate organophosphate (OP) insecticides up to 1000-fold higher than their wildtype counterparts. OPs, like chlorpyrifos, are commonly detected in the Bay-Delta region due to their application in agriculture practices and often exceed the 0.04 ug/L chronic US EPA benchmark for aquatic organisms. Since resistant animals can survive in highly contaminated waters, there is potential for them to accumulate higher insecticides, increasing the risk for trophic chemical transfer within the food web. Since *H. azteca* can provide a major portion of fish diets in some habitats, including species found in the Bay-Delta region, the question we ask is, “can resistant *H. azteca* bioaccumulate OPs at higher rates than non-resistant animals, and if so, what does it mean for the Bay-Delta food web?”

In this project, we conducted toxicokinetic experiments to estimate the uptake and elimination rate constants of chlorpyrifos in resistant and non-resistant *H. azteca.* We also compared chlorpyrifos bioaccumulation between resistant and non-resistant *H. azteca* by exposing them to ^{14}C-chlorpyrifos for 28 hours and measuring the body burden. Our results indicate that both populations accumulate similar body burdens when exposed to the same concentration of chlorpyrifos. We then investigated the accumulation of ^{14}C-chlorpyrifos in only resistant animals at six different concentrations, with four concentrations above the lethal threshold for non-resistant animals. We found that resistant animals exposed to higher concentrations can accumulate up to 50 times more. These results infer that bioaccumulation potential can be more significant in chlorpyrifos resistant *H. azteca* and may be an essential factor in assessing the full impacts of toxicants on critical Bay-Delta food webs in order to restore the health of the watershed

A New Model to Address Legacy Gold Rush Mercury in the Delta

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A mercury cycling model for the Sacramento-San Joaquin Delta was created to support the Delta Mercury Control Program. Mercury mined in California's Coastal Range and used in the Sierra Nevada Gold Rush in the 1800's continues to contaminate water that flows into the Sacramento-San Joaquin Delta today. The mercury bioaccumulates and biomagnifies in fish, which poses a threat to human health if contaminated fish are eaten. To support the goal of reducing methylmercury concentrations in the Delta, the hydrodynamic and water quality Delta Simulation Model 2 was expanded to add suspended sediments, a sediment bed, and three forms of mercury (methylmercury, inorganic divalent mercury (Hg(II)) and elemental mercury (Hg0)). The Delta Mercury Model (DSM2-Hg) results for October 1999 to July 2006 show that the Delta is a net sink for sediment solids, inorganic mercury and methylmercury. The magnitudes and relative importance of different mercury sources vary widely during wetter and drier years. Typically, the Sacramento River is the main source of mercury in the Delta, however in wet years when the Yolo Bypass floods, the Bypass can contribute up to half of the annual methylmercury. Internal production of methylmercury was inconsequential relative to methylmercury supplied from tributary inflows. The findings from this study and future application of the Delta Mercury Model (DSM2-Hg) can help identify management actions to reduce methylmercury concentrations in the Delta.

3D Modeling of Methylmercury as a Conservative Tracer in the Sacramento-San Joaquin Delta

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Understanding how water availability and management impact water quality is a challenge in coastal ecosystems like the San Francisco Bay-Delta (SFBD), where multiple contaminant sources, hydrologic forcing, and anthropogenic flow manipulations vary across space and time. Mercury (Hg), a legacy contaminant that reduces water quality, is found throughout the SFBD and accumulates through the food web as methylmercury (MeHg) to levels considered dangerous for humans and wildlife. General patterns of MeHg concentrations in the SFBD are known, but it is not well understood how upstream and downstream MeHg sources are transported and mixed throughout the Delta by time-varying freshwater flows, tides, baroclinic processes, and water management actions. Consequently, we do not understand which aqueous MeHg sources are most influential in areas with high fish Hg concentrations, creating a challenge for management entities attempting meaningful, science-based regulation of MeHg sources.

Numerical 3D hydrodynamic and water quality models (Delft3D-FM and DELWAQ) are applied in the SFBD to study the influence of hydrodynamics on the spatial and temporal patterns of aqueous MeHg. This modeling is focused on physical transport of MeHg as influenced by river flow, tides, and infrastructure operations. As such, MeHg is modeled with multiple conservative tracers representing individual sources. Although biogeochemical processes are known to influence MeHg patterns, their neglect in this first modeling phase helps us address the question: To what extent do physical transport processes explain observed MeHg patterns in the SFBD?

Preliminary simulation results for Water Years 2011 and 2012 indicate that MeHg source distributions are seasonally dynamic and strongly influenced by water management and tributary sources but regain a consistent distribution by October during both wet and dry years. These results match the relatively stable long-term Hg pattern in sport fish tissues and highlight the important influence of physical transport on water quality in the region.

Current-Use Pesticides in Zooplankton, Water, and Suspended Sediment Collected from the Sacramento-San Joaquin Delta

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Zooplankton are a key food source for juvenile fishes in the Sacramento-San Joaquin Delta (Delta), including Chinook Salmon and the endangered Delta Smelt. Studies have shown long-term declines in total zooplankton biomass in the Delta as well as changes in zooplankton species composition and linked these declines to reductions in native fish populations. To better understand the potential causes of these changes as well as to understand the quality of zooplankton now available as food for native Delta fish, zooplankton, water and suspended sediment samples were collected from two sites in the Delta and analyzed for a large suite of current-use pesticides and degradates. Samples were collected biweekly in the summer/fall 2017 and 2018, and from May 2019-March 2020 at a site in the Yolo Bypass and at a comparison site on the Sacramento River below Sacramento.

During the three sampling periods a total of 29 pesticides were detected in zooplankton, and 70 of the 73 samples contained multiple pesticides (up to 17 per sample). The most frequently detected compounds in zooplankton were 3,4-dichloroanline, azoxystrobin, bifenthrin, *p,p'*-DDD, *p,p'*-DDE, pendimethalin, and thiobencarb. Water samples collected concurrently with zooplankton samples contained a total of 52 distinct pesticides and all samples contained from 3 to 34 pesticides. Only 12% of suspended-sediment samples contained pesticides. On average, Sacramento River zooplankton samples contained more pesticides than zooplankton from the Yolo Bypass, whereas the opposite was true for pesticides detected in water.

The pesticides detected and their timing of detection often differed between zooplankton, water and suspended sediment, indicating that pesticides in zooplankton are an important piece of the contaminant puzzle. Finally, several pesticides, including the pyrethroid insecticides cyfluthrin, cyhalothrin, cypermethrin, esfenvalerate, and permethrin were only detected in zooplankton, indicating that zooplankton may be an important pathway for these highly toxic pesticides within the Delta ecosystem.

Birds and Their Habitats in the Bay-Delta

Breeding Waterbird Population Declines in South San Francisco Over the Past Two Decades

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Former salt evaporation ponds in South San Francisco Bay support large populations of breeding waterbirds. In 2006, the South Bay Salt Pond (SBSP) Restoration Project began the process of converting 50-90% of these ponds, now managed as wildlife habitat, into tidal marsh. We compared American avocet and black-necked stilt abundance in south San Francisco Bay before (2001) and after (2019) approximately 1300 ha of ponds were breached to tidal action to begin tidal marsh restoration. Over the 18-year period, American avocet numbers declined 13.5% (2765 in 2001 vs. 2391 in 2019) and black-necked stilt numbers declined 30.0% (1184 in 2001 vs. 828 in 2019). Forster's terns were not surveyed in 2001 but numbered 2675 birds in 2019. In 2019, managed ponds accounted for only 25.8% of suitable habitats, yet contained 53.9%, 38.6%, and 65.6% American avocet, black-necked stilt, and Forster's tern observations, respectively. Conversely, tidal marsh and tidal mudflats accounted for 42.9% of suitable habitats, yet contained only 18.4%, 10.3%, and 19.8% American avocet, black-necked stilt, and Forster's tern observations, respectively. Using a separate nest monitoring dataset, we found that nest abundance in south San Francisco Bay declined for all three species during 2005-2019. Average annual nest abundance during 2017-2019 declined 53%, 71%, and 36%, for American avocets, black-necked stilts, and Forster's terns, respectively, compared to 2005-2007. Loss of island nesting habitat due to tidal marsh conversion and an increasing population of predatory California gulls are two potential causes of these declines. All three species established nesting colonies on newly constructed islands within remaining managed ponds, however, these new colonies have not made up for the steep declines observed at other historical nesting sites. Retaining more managed ponds with nesting islands during future phases of the SBSP Restoration Project may help to limit further breeding waterbird population declines.

Seasonal Resource Partitioning among Demographic Groups of Western Sandpipers: Implications for Shorebird Ecology and Conservation in the San Francisco Bay Estuary

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The San Francisco Bay estuary is visited by over half a million wintering and migratory shorebirds each year, accounting for nearly two-thirds of migratory shorebirds along the Pacific Flyway. These shorebirds rely on adequate prey in the estuary to maintain their body condition and prepare for breeding. Increased competition for prey during migration, a period of high energy expenditure and increased shorebird densities, could result in age- and sex-related dietary specialization that would facilitate resource partitioning among demographic groups. We quantified the contribution of biofilm, microphytobenthos, and benthic invertebrates to the diets of western sandpipers (*Calidris mauri*) from different demographic groups during mid-winter (January/February) and at the onset of the breeding migration (April) using stable isotope mixing models. Western sandpipers are sexually dimorphic with females having

significantly greater body mass and bill length than males. Diet composition differed between seasons and among demographic groups. In winter, prey consumption was similar among demographic groups, but, in spring, diet composition differed with bill length and body mass explaining 31% of the total variation in diet composition. Epifaunal invertebrates made up a greater proportion of the diet in males which had lesser mass and shorter bills than females. Consumption of Polychaeta increased with increasing bill length and was greatest in adult females. In contrast, consumption of microphytobenthos, thought to be an important food source for migrating sandpipers, increased with decreasing bill length and was greatest in juvenile males. Our results provide the first evidence that age- and sex-related dietary specialization in western sandpipers facilitate seasonal resource partitioning that could reduce competition during spring at the onset of the breeding migration. Our study underscores the importance of examining resource partitioning throughout the annual cycle to inform fitness and demographic models and facilitate conservation efforts.

Coordinated Mapping to Assess Local, Regional and Coast-Wide Change in Wetlands and Related Habitat Types

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The San Francisco Estuary Institute (SFEI) is coordinating several new inventories of wetlands and other habitat types in the Sacramento-San Joaquin Delta, Bay Area, and along California's coast. Together these inventories will meet the need for standardized maps to assess net change in the distribution, abundance, diversity, and condition of surface water habitats due to management actions and climate change.

These projects will apply the California Aquatic Resource Inventory (CARI; sfei.org/cari) methods. The final maps will be publicly available online through EcoAtlas (ecoatlas.org). The projects are funded by the Environmental Protection Agency and the Ocean Protection Council, and are scheduled to be completed by 2023.

In collaboration with the Sacramento-San Joaquin Delta Conservancy and a multi-agency Bay-Habitat Mapping Workgroup, SFEI will produce the Delta Aquatic Resource Inventory (DARI; sfei.org/dari) for Suisun and the Delta.

The Ocean Protection Council (OPC; opc.ca.gov) and SFEI will develop an inventory of wetlands and other surface waters of all California's coastal HUC-8 watersheds, to help implement the OPC's 2020-2025 Strategic Plan. Development of this coastal inventory will be advised by a new statewide wetland mapping committee of the California Wetland Monitoring Workgroup.

A regional, multi-partner team will update the inventory of Bay Area baylands. The Baylands Change Basemap will be a fundamental component of the San Francisco Estuary Wetlands Regional Monitoring Program (sfestuary.org/wrmp), to help coordinate baylands protection and restoration, detect regional landscape change, and promote a shared view of the regional landscape.

These projects will yield crosswalks among regional aquatic resource classification systems, allowing inventories to be compiled across regions. The results will enable all interests to assess regional and coast-wide net change in the distribution, abundance, diversity, and condition of the resources, in the context of population growth and climate change.

(*IEP) Identifying High Priority Areas for Bird Conservation in the Delta

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The Sacramento–San Joaquin Delta provides habitat to an abundant and diverse community of birds, despite extensive human modifications to the ecosystem over the past 150 years, but is likely only a small fraction of what the Delta's bird community once was. Restoring a healthy Delta ecosystem requires providing habitat for birds year-round, which in turn requires integrating the full diversity of the Delta's bird community in scientific analyses, conservation strategies, and restoration goals. To address this science need and identify areas that are a high priority for bird conservation, we analyzed the spatial distributions of waterbird and riparian landbird populations throughout the Delta. Drawing on extensive bird surveys conducted in the Delta and surrounding areas in recent years, we focused on 5 groups of waterbird species and 9 riparian landbird species that collectively represent the diversity of habitat needs of each group. For each of these taxa, we used boosted regression tree models to identify predictive relationships between the probability of species presence or abundance and covariate metrics representing the surrounding landscape at multiple spatial scales. From these models, we developed maps representing the predicted distribution of waterbird and riparian landbird species on the landscape. We then used the Zonation spatial prioritization algorithm to identify the areas of the Delta's landscape that are the most important to maintaining these bird populations. The results represent the current state of the science on the spatial distribution and abundances of different bird taxa across the Delta and the areas with a high confidence of importance to bird conservation. Our results also provide a baseline from which the effects of observed or projected changes to the Delta's landscape can be compared, facilitating the integration of a broader number of bird species in conservation planning and policy decisions.

Resilient Staten Island: Pilot Application for Landscape Scenario Analysis

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Most land uses within the Delta continue to erode landscape resilience and associated ecosystem functions and services by perpetuating peat loss and land subsidence and limiting natural processes and habitat for wildlife. Determining what to do where to support landscapes that serve diverse objectives is a central need for planning in the Delta. Doing so requires that land use changes and restoration actions be evaluated together for multiple costs and benefits. To explore this, we conducted a pilot scenario analysis for Staten Island, a 9,200 acre Delta island owned by The Nature Conservancy. Based on physical conditions as well as agricultural and wetland restoration objectives, we developed six potential future land use scenarios. These were then evaluated using existing tools and methods across a suite of metrics relating to expected hydrologic connectivity, subsidence reversal, change in GHG (greenhouse gas) flux, ecosystem functions, and economic impact. This analysis illustrated the importance of rice for maintaining economic viability while also slowing or reversing land subsidence on peat soils. Further, evaluating these factors at the landscape scale showed how introducing managed and tidal wetlands could provide habitat and carbon sequestration benefits, with the loss of agricultural revenue made up in part by carbon market revenue but also crops grown elsewhere on the island. The pilot application also helped identify additional metrics and uncertainties (e.g., levee failure risk reduction, capital costs, additional habitat and recreation benefits) that should be addressed in future evaluations. By envisioning and evaluating new practical approaches to the management of subsided lands in the Delta, this effort supports the continued development and integration of tools and approaches for establishing sustainable Delta futures that recover needed ecosystem functions while maintaining the Delta's economy, culture, and sense of place.

Greenhouse Gas Exchange and Wetland Accretion in the Bay-Delta System: Implications for Science, Policy, and Management in the Sacramento-San Joaquin Delta, Suisun Marsh, and San Francisco Bay

Carbon Greenhouse Gas Fluxes and Water Biogeochemistry in a Restored Wetland with Managed Hydrology in the Sacramento-San Joaquin Delta

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To mitigate the effects of climate change and risks associated with sea level rise, year-round flooding of peat soils to develop freshwater wetlands has been used as an effective management plan to reverse land subsidence and sequester carbon. The capacity of restored wetlands to offset greenhouse gas emissions, although proved significant, is still an active area of research. Specifically, our understanding of how organic matter is mineralized and partitioned into carbon dioxide (CO_2), methane (CH_4), and dissolved organic carbon (DOC) in these systems remains limited. It is particularly uncertain how variable water quality influences carbon greenhouse gas emissions on annual timescales. Changes in salinity are known to reduce productivity and affect CH_4 biogeochemistry, while an increase in DOC concentrations can produce more greenhouse gases through enhanced microbial activity and photochemical transformations. This study explores seasonal changes in water biogeochemistry in a restored freshwater wetland with managed hydrology and assesses the relations between water chemistry and greenhouse gas emissions. We combine the use of high-frequency eddy covariance atmospheric flux measurements with water depth, temperature, dissolved oxygen, dissolved pCO_2, conductivity, turbidity and fluorescent dissolved organic matter, pH, DOC and inorganic carbon data, collected using aquatic sensor and discrete sampling. Using a 4-year long dataset we explore the relationships between DOC and greenhouse gas emissions and the existence of potential hot periods of dissolved organic carbon mineralization that result from the interplay between internal ecosystem carbon cycling and environmental conditions. Preliminary results show that DOC concentrations in surface wetland waters are high and temporally variable (5-79 mg L^{-1}) with a seasonal trend that is compounded by water table depth. Our results will serve to assess the contribution of DOC mineralization to greenhouse gas emissions and the magnitude of the ecosystem carbon budget that remains in the aquatic compartment.

The Delta Blue Carbon and Wetland Resilience Project: Data Synthesis and Scenario Evaluation for the Past, Present, and Future Delta

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Wetland restoration in the Delta has the potential to mitigate the effects of land-surface subsidence by rebuilding marsh elevation via vertical accretion. Restored wetlands may benefit the climate through carbon sequestration while conferring flood protection and resilience to sea level rise and creating habitat for wetland-dependent species. The ability of restored wetlands to provide these benefits, however, depends on the siting and timing of restoration. Benefits to the climate depend on carbon accretion rates, methane emissions, and the magnitude of avoided baseline emissions. The long-term resilience of tidal wetlands in the Delta depends on the rate of sea level rise, accretion rates, and available migration space. Our understanding of these effects continues to improve as more data become available from field and modeling studies. However, the complex set of biophysical and land use factors governing restoration outcomes and opportunities has made it challenging to optimize wetland restoration planning. To inform such restoration planning, the San Francisco Estuary Institute, USGS, University of South Carolina, and HydroFocus, Inc., are using models and data synthesis to generate Delta-wide datasets of wetland elevation, carbon storage, greenhouse gas emissions, and tidal marsh resilience for historical (pre-European settlement), modern, and future (restoration and sea level rise) scenarios. Datasets, models, and associated uncertainties will be added to the Delta Landscapes Scenario Planning Tool, a GIS-based tool for evaluating outcomes of user-defined land use scenarios. With spatially explicit metrics of carbon storage, methane emissions, subsidence, and marsh accretion and migration, this tool offers land use planners a synthetic means to compare the expected climate benefit and resilience of wetlands to sea level rise under different restoration scenarios.

Advancing the Wetland Accretion Rate Model of Ecosystem Resilience (WARMER-2): Improved Parameterization for San Francisco Bay-Delta

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Understanding the rates and spatial patterns of tidal wetland elevation change relative to sea-level is essential for projecting future vulnerability of ecosystems and built landscapes in estuaries. Building from previous approaches and using an enhanced and more flexible modeling framework (WARMER-2), we explored plant community transitions, belowground carbon storage, and sea-level rise impacts to San Francisco Bay-Delta (SFBE) wetlands through 2100. We improved model parameterization for SFBE marshes by incorporating recent experimental results of plant species sensitivity to flooding and salinity gradients as well as site-level estimates of organic matter decomposition. To account for a dynamic tide range under sea-level rise, we leveraged results from a Delta hydrodynamic model. The revised framework includes an improved calibration scheme that accurately reconstructs soil profiles, quantifies parameter uncertainty through Monte Carlo simulations, and provides an estimate of carbon burial rates.

Using WARMER-2 we evaluated the future vulnerability of Petaluma River, Rush Ranch, and Browns Island marshes located along a salinity gradient to varying scenarios of sea-level rise, salinization, and changes in sediment availability. All three marshes were sensitive to changes in sediment availability, but sites with higher starting elevations or space for upland transgression persisted longer under higher sea-level rise scenarios than sites lower in elevation. Using the multi-plant species transition model for organic matter inputs, WARMER-2 predicted increased resilience and higher rates of carbon accumulation compared with projections assuming no temporal change in the plant community. The WARMER-2 modeling framework is a flexible tool for assessing alternative tidal marsh futures under sea-level rise, sediment, and salinity scenarios and providing information to resource managers.

Integration of Science and Implementation of Land-Use Change for Increased Sustainability

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There has been substantial progress in the scientific understanding and quantification of the nature and effects of subsidence, with increasing evidence of unsustainability including decreased arability, increased pressure on levees and water supply vulnerability, large greenhouse gas emissions and declines in native species. There is also increasing evidence of the co-benefits that can come with subsidence mitigation that would increase ecosystem sustainability and resilience. While there is more the learn, there is an urgent need to implement solutions more rapidly that can stop and reverse the Delta's unsustainable trajectory. Alternate land uses such as permanently flooded, managed wetlands and rice provide a substantial net GHG emissions reduction benefit relative to the status quo and mitigate and reverse subsidence. Participation in carbon-offset trading is part of the solution. With the approval of the American Carbon Registry protocol for California deltaic wetlands, there has been an increase in the number of landowners interested in conversion to rice cultivation and managed wetlands to engage the carbon market. The CARB Offset Protocol Development Taskforce has recommended that the ACR protocol be adopted into the AB-32 Compliance Program. This will likely have a significant effect on the value of Delta carbon and result in increased interest in land conversion in the most deeply subsided areas of the Delta. Applied interdisciplinary data collection, analysis and modeling integrated with implementation of land use changes and carbon offset trading is key to successful transition to a more sustainable trajectory and viable ecosystem. This pioneering integrated approach is ongoing on several islands including Staten Island where large scale conversion is heading toward a mosaic of rice, wetlands and other crops that will reduce GHG emissions, provide ecosystem benefits and increased long-term economic viability. We will provide an overview of current projects and progress.

Quantifying Carbon Benefits of Tidal Wetland Restoration in the Delta: Decision Support using a Robust, Integrated and Data-Driven Model

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Planned tidal wetland restoration in the Bay Delta will help restore important ecosystem services including support of pelagic food webs and protection of coastal regions from sea level rise. However, the ability of tidal marshes to deliver these ecosystem services is strongly related to their long-term stability and climate resilience. Because the long-term stability of these habitats is strongly linked to their net carbon balance, we have measured the net carbon balance of two tidal marshes and have used the data to develop a modeling tool to predict carbon sequestration, subsidence reversal, and climate resilience of tidal wetlands. Our first site is a historic tidal marsh in the Suisun complex and the second is an actively restoring polyhaline marsh in the San Francisco Bay. Each site is outfitted with an eddy covariance tower and lateral carbon flux monitoring station allowing us to continuously quantify atmospheric (CO_2 and CH_4) and hydrologic (DIC, DOC, POC) exchange of carbon. Due to the high frequency data collection, we are able look at a wide range of temporal scales to determine how the different carbon fluxes respond to environmental drivers. For example, soil temperature and tidal inundation are strong predictors of DIC export at the daily to monthly scale. We have used these data to parameterize and test a new biogeochemical model MEM-PEPRMT which accurately predicts atmospheric exchange of CO_2 and CH_4 as well as sediment accretion. This tool has been under development with feedback from the Delta stakeholder community. We plan to conduct regional modeling of greenhouse gas exchange from existing and proposed wetlands in the Delta region and project tidal marsh resilience up to 2100. This will improve understanding of how landscape-scale restoration projects in the Delta will affect carbon cycling and sediment dynamics and improve stakeholders' ability to participate in carbon markets.

IEP Session: Using Aquatic Surveys for Estimation and Communication: Bias, Quantification, and Display

(*IEP) Relative Catchability Bias Among Sampling Gears for Fish Species Within the San Francisco Estuary

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Gears used to monitor fish species can only sample a fraction of available fish habitat, an inherent bias in all fisheries monitoring programs referred to as "catchability." Gear retention efficiency is a component of catchability and is defined as the retention of fishes once in contact with the gear, a source of bias that can be affected by numerous aspects of gear deployment (*e.g.*, net size, deployment speed, mesh size). We assessed relative retention efficiency differences among four long-term fish monitoring surveys from the San Francisco Estuary (SFE): the Bay Study Otter Trawl (BSOT), the Bay Study Midwater Trawl (BSMT), the Fall Midwater Trawl (FMWT), and the Suisun Marsh Otter Trawl (SMOT). We used generalized additive models with a spatio-temporal smoother to predict gear-specific estimates of abundance for 45 different fish species within large and small size classes. We included the survey as a fixed effect with the FMWT as the reference condition (intercept). The slope coefficients then represent a retention efficiency among gear types relative to the FMWT, referred to as a catch ratio. Significant differences in relative retention efficiency were determined by whether 95% confidence intervals of the catch ratio did not include 1.0. We found from catch ratios that 45%, 82%, and 70% of fish species in large size-classes were captured in higher abundance in the FMWT than in the BSMT, BSOT and SMOT, respectively. Fish species in small size classes were similarly captured in higher numbers in the FMWT, where 46%, 73%, and 59% of fish species were captured in higher abundance in the FMWT than in the BSMT, BSOT and the SMOT, respectively. Our results demonstrate that catchability is a significant source of bias among SFE monitoring efforts that must be addressed when developing biological metrics using catch from multiple surveys.

(*IEP) Let's Stop Guessing: Using Quantitative Tools Developed During Long-Term Monitoring Review to Evaluate Survey Regime Alterations

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Evaluating and, when appropriate, modifying sampling regimes is a challenge inherent to all long-term monitoring programs, particularly in the face of reduced resources associated with altered funding, personnel constraints, equipment failures, or even global pandemics. While sensitivity analyses are readily available to evaluate the consequence of altering sampling regimes of single species or univariate monitoring programs, approaches to effectively evaluate spatiotemporally complex community monitoring programs are not. Here we present an analytical framework and associated metrics to assess the consequence of reduced sampling regimes on our ability to understand fish communities. Specifically, we combine spatiotemporally explicit principal tensor analyses and hierarchical cluster analyses to test whether reduced Interagency Ecological Program trawl survey effort influences our understanding of the San Francisco Estuary fish community as detected via otter and midwater trawl gears. We found that, depending on how the monitoring program is altered, the loss of a single station could drastically degrade our understanding of the fish community or the elimination of a suite a stations could have little to no effect. Intuitively, the effect of reduced sampling is highly dependent on *how* a long-term monitoring program is altered. Methods to assess reduced sampling regimes are greatly needed today in the San Francisco Estuary as agencies face reduced resources and limited capacity to maintain sampling programs during the COVID-19 pandemic. While the need to adjust long-term monitoring programs was the impetus for this body of work, our work highlights the risk associated with uninformed change. Our work provides a promising framework to quantitatively optimize resource allocation while minimizing information loss.

(*IEP) Quantifying Changes in Gear Efficiency to Reduce Bias in Estimating Long-Term Abundance Trends

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Long-term monitoring programs were often designed to track temporal trends in abundance. However, the ability of a program to accurately track population trends is dependent on the assumption that catch (or catch per unit effort) is proportional to true abundance. This assumption is often violated because gear efficiency (the proportion of available individuals caught at a given site) is not static over time and may be influenced by site-specific factors, such as water velocity, turbidity, substrate composition, etc. Here we used an N-mixture model, which relied on multi-pass depletion surveys (referred to as efficiency surveys; n = 188 surveys) from 2014-2018, to estimate the effects of site-specific factors on the capture efficiency of juvenile Chinook salmon *Oncorhynchus tshawytscha* sampled in the U.S. Fish and Wildlife Delta Juvenile Fish Monitoring Program beach seine surveys. We identified a negative relationship between seine efficiency and water velocity, indicating that juvenile Chinook sampled at sites with (or during periods of) lower water velocity had a higher chance of being captured than those sampled at sites with higher water velocity. This model was then applied to data collected outside of these efficiency surveys, which used a single seine haul at each site, to estimate weekly juvenile Chinook salmon abundance trends from 2000-2019. Results from this work provide more accurate spatio-temporal trends in juvenile Chinook abundance and use of the Sacramento-San Joaquin River Delta system by reducing systematic bias associated with changes in gear efficiency from site-specific factors, such as water velocity. Further, by incorporating efficiency surveys within long-term monitoring programs we can monitor for changes in gear efficiency and identify other sources of bias.

(*IEP) Real Time Tidal Excursion Mapping and Constituent Tracking, Fishery Surveys and Tools to Support Tidally Influenced Pelagic Habitat Identification

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Problem Statement: Ready access to real time and curated data presented together with tools to place the data appropriately in the tidal transport framework of the Delta will help enhance research, decrease response-time to evaluations of change, accelerate scientific consensus, and improve support for managers.

Approach: One impediment to scientific consensus about the impacts of water operations on endangered species protections in the San Francisco Delta and Estuary is access to real time operations and data simulations that demonstrate and visualize accurate conditions in relation to tidal excursions. For example, accurately depicting conditions from field measurements of salt and sediment concentrations (or turbidity) made from boat surveys (e.g. along-channel transects) often involve campaigns that are long in duration compared to a tidal cycle. As a result, they can provide a spurious picture of the spatial distribution of concentrations and how they vary over time. This project makes use of existing concentration and flow data collected at fixed stations to provide maps of the spatial patterns in the concentration data. In addition we include operations and fish surveys snapshots and make it available through a publicly-available web platform together with tools to visualize, explore and perform basic analyses. In the near term, our findings demonstrate feasible methods and results using the existing monitoring network to better understand constituent fields related to tidal excursions. We will demonstrate methods to replace boat surveys to report and understand turbidity conditions for regulatory analysis. In the long term this project aims to add additional near real time data sources and methods to the decision-making tool box to ensure that fish are protected and exports can be made available to water users.

(*IEP) Web Based Approaches to Fisheries Data Communication

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Juvenile Salmon Acoustic Telemetry System (JSATS) technology is used throughout California's Central Valley to tag and track outmigrating juvenile salmonids to monitor movement and survival rates. Traditional approaches to convey these data can be difficult to access and engage a larger audience. Here, we provide alternative methods to increase accessibility through interactive data visualization in two different ways 1). A real-time tracking website 2). A retrospective Shiny web application. Both are generated using openly accessible R programming code, making the data visualization and analyses reproducible and transparent to users.

A website was developed using R Markdown to provide real-time data of tagged fish in the Central Valley. The website provides summaries and visualizations of detected fish numbers, reach-specific survival, routing probability, survival to the different real-time receivers deployed throughout the Sacramento River, Delta, and Bay, and receiver diagnostics.

A web application was developed using the Shiny package in R. The application gives users the ability to explore retrospective project data for past groups of tagged fish based on user defined parameters. Primary features include: summaries and visualizations of receiver redeployments, outmigration animations, tagged fish metrics, frequency of detections by time of day, survival estimates, and travel times.

Together, these tools provide stakeholders and the general public with immediate data on real-time analytics for current undergoing projects as well as a retrospective look on completed projects in an engaging and accessible online format. The real-time website can be accessed at https://calfishtrack.github.io/real-time and the Shiny app can be accessed at https://oceanview.pfeg.noaa.gov/shiny/FED/telemetry/.

On-demand talks

An Update on Salt Marsh Harvest Mouse Ecology and Future Perspectives (SMHM)

001-SMHM: A New Non-Invasive Genetic Survey Technique for the Endangered Salt Marsh Harvest Mouse

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Salt marsh harvest mice (SMHM; *Reithrodontomys raviventris*) are an endangered species endemic to the San Francisco Estuary (SFE). SMHM habitat has declined by approximately 90% during the past two centuries. The contemporary range of SMHM – one of the most basic pieces of information needed for effective conservation – is poorly understood. Endangered species surveys can be logistically challenging, leaving many parts of their historical range unsurveyed for decades. One additional challenge to SMHM surveys is that genetic verification is required to reliably distinguish SMHM from their congener, the western harvest mouse (WHM; *R. megalotis*). A simple and reliable technique for assessing the occupancy status of marshes is critical to filling long-standing knowledge gaps in the modern range of SMHM. To this end, we developed a non-invasive genetic survey for SMHM and sympatric rodents. We placed bait and bedding into bait stations with permanent openings – allowing mice to enter and exit freely – and placed bait stations along transects at Joice Island in Suisun Marsh. After 7 days, scat samples were collected from the bait stations. Fecal samples were present in 9 of 10 stations deployed at Joice Island. We developed a genetic species identification assay for simultaneous detection of 5 common SFE rodents (SMHM, WHM, house mouse (*Mus musculus*), deer mouse (*Peromyscus sp.*), and vole (*Microtus californicus*).

Using control DNA, we verified sensitivity of each target species with as little as 0.01 ng/uL of DNA, and no false-positives. When Joice Island scat samples were subject to the genetic test, SMHM were detected at 8 stations and WHM were detected at 3 stations, including two stations where both species were detected. This non-invasive survey technique can provide much needed occupancy information for SMHM where live-trapping efforts may be resource-prohibitive.

002-SMHM: A Bigger Picture of a Tiny Critter: A Range-Wide Assessment of the Salt Marsh Harvest Mouse

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The endangered salt marsh harvest mouse (SMHM; *Reithrodontomys raviventris*) presumably once occurred in virtually all of the marshes of the San Francisco Estuary. Today, the species exists largely as isolated populations with little to no connectivity in many parts of its range. Some of these populations occur in relatively large contiguous marsh areas (e.g., Suisun Marsh), while others persist in smaller marshes (e.g., Santa Venitia Marsh). Research efforts and long-term monitoring has focused largely on contiguous marsh complexes under public ownership (e.g., Suisun Marsh, Don Edwards Wildlife Refuge, Eden Landing Ecological Reserve), and many smaller marshes are rarely even surveyed. This bias in research and monitoring not only leaves holes in our understanding of SMHM occupancy throughout the Estuary, but also potentially fuels misunderstanding about habitat value, as large marshes are more likely to see persistent SMHM occupancy than smaller marshes with identical vegetation, hydrology, etc., simply though stochastic processes. In an effort to better understand the state of SMHM as a species and their habitat requirements, to ultimately make more effective management and recovery decisions, we are conducting a NFWF-funded range-wide survey of SMHM this year. We will also be using historical and recent data to model habitat suitability and occupancy. This presentation will present the results of the initial range-wide habitat model that will guide this survey effort, as well as an overview of the survey plan. Those who are interesting in providing feedback on the survey plan, or who wish to participate in the survey effort are encouraged to attend this talk or contact Katie Smith at ksmith@wra-ca.com.

003-SMHM: Salt Marsh Harvest Mouse Home Range and Habitat Selection in Managed and Tidal Wetlands of Suisun Marsh: Implications for Endangered Species Conservation and Management

Melissa Riley[1|2], Katie Smith[1|3], Sadie Trombley[1], Carla Angulo[4], Monica Zhang[1]

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The salt marsh harvest mouse (*Reithrodontomys raviventris*, SMHM) is endemic to the marshes of the San Francisco Bay Estuary. In the 1970s SMHM were State and Federally listed as endangered, primarily due to habitat loss and fragmentation. Suisun Marsh contains over half of the remaining SMHM habitat, and is critical for future conservation of the species. Management in Suisun Marsh is primarily focused on providing waterfowl habitat through manipulation of managed wetlands, but this was initially thought to be incompatible with SMHM recovery which stressed the need for the preservation and restoration of tidal wetlands with monocultures of pickleweed (*Salcornia pacifica*). Emerging research has shown that managed and tidal wetlands in Suisun can be just as valuable to SMHM, supporting similar population sizes with similar survival and growth rates. In addition, studies have shown that SMHM may be more of habitat generalists within marshes versus specialists keying in on pickleweed. So, what defines "good" SMHM habitat? Are SMHM true specialists? Or are they more adaptable due to their apparent plasticity in places like Suisun? While our understanding of SMHM habitat requirements is evolving, defining "good" SMHM habitat is critical to future conservation and management throughout the species range, especially as tidal restoration is implemented and new threats like sea level rise emerge. To better understand SMHM habitat requirements in Suisun, we conducted a radio-telemetry study in paired tidal and managed wetlands. SMHM were collared and tracked seasonally over the course of three years. Using information from the telemetry study, we evaluated SMHM home ranges and habitat selection. SMHM home ranges were similar in tidal and managed wetlands, indicating the importance of both wetland types in future conservation and management efforts.

004-SMHM: Development of a Morphological Key for the Southern Salt Marsh Harvest Mouse using Genetically Verified Individuals

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The salt marsh harvest mouse (SMHM; *Reithrodontomys raviventris*) is a State and Federally listed endangered species endemic to the coastal marshes of the San Francisco Estuary of California. Of two subspecies, the southern (*R. r. raviventris*) is most endangered and lacks reliable morphological field tools to distinguish from the sympatric western harvest mouse (WHM; *R. megalotis*). We trapped and collected genetic samples and morphological data from 204 harvest mice from 14 locations from across the range of the southern SMHM. Genetic species identification indicated these to be composed of 48 SMHM and 156 WHM, which we compared at ten morphological characters. Most continuous characters overlapped between species. Color characters

were significantly differentiated and we identified a number of species-specific diagnostic pelage categories in both species. A random forest analysis indicated that ventral coloration of the abdomen and the ventral tail hair color were the most useful for differentiating between species. We used these two morphological characters to develop a decision tree which correctly classified 94% of harvest mice to species with 99% accuracy. These findings suggest that our decision tree can be used to reliably identify the species of most harvest mice in the range of the southern SMHM, with a small proportion (6% in our study) needing genetic confirmation. The decision tree should be tested on additional harvest mice that were not used in its development, particularly from novel locations across the range.

005-SMHM: Pathogens and Ectoparasites of Salt Marsh Harvest Mice (Reithrodontomys Raviventris Halicoetes) in Suisun Marsh

Sadie Trombley[1|2], Douglas Kelt[1], Janet Foley[1], Deana Clifford[3], Laureen Barthman-Thompson[3]

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We surveyed pathogens and ectoparasites in the federally endangered salt marsh harvest mouse (*Reithrodontomys raviventris halicoetes*; SMHM) and sympatric rodents in Suisun Marsh. Although SMHM have been well studied, some cryptic threats, such as disease, have largely been ignored in recovery planning. We determined baseline health data on SMHM and investigated the relationships among pathogen and ectoparasite prevalence and environmental variables, including season and habitat management (e.g., naturally tidal grids versus non-tidal diked grids), as well as individual risk factors such as age, sex, reproductive status, and body condition. Due to differences in the biotic communities and abiotic conditions in diked and tidal ponds, we hypothesized that the risks of disease transmission in diked and tidal habitats may differ, with potentially important implications for resource/landscape managers. We tested all rodent species for infection with *Bartonella* spp., *Borrelia* spp., *Rickettsia* spp., *Francisella tularensis*, *Leptospira* spp., *Cryptosporidium* spp., *Giardia* spp., and *Toxoplasma gondii* via PCR. We captured 625 individual rodents, including 439 SMHM. Over one-third of SMHM tested positive for at least one pathogen or ectoparasite. Four percent of SMHM were infected with *F. tularensis holarctica*, a highly virulent bacterium that causes mortality in rodents shortly after infection. Additionally, we detected pathogenic strains of *Bartonella*, *Leptospira*, *Cryptosporidium*, *Giardia*, and an unidentified *Borrelia* sp. among the captured rodents. The prevalence of multiple pathogens varied by season and by host species. The only pathogen that was associated with habitat management was Bartonella spp. in SMHM; this was more prevalent in diked than in tidal grids. The detection of certain pathogens and ectoparasites in this study suggest spillover from non-wetland specialist rodents to SMHM. Understanding the relationships between disease risk and environmental

variables, including the potential risk posed by other rodent species to SMHM, is critical to the conservation and management of this endangered species.

Fish Biology (FB)

006-FB: Lamprey Populations in California's Central Valley: Genetic Analysis of a Multispecies Complex

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Lampreys, a group of jawless, eel-like fishes, are extant representatives of the first known vertebrates. Survival to modern times depended on lampreys' parasitic strategy; however, multiple non-parasitic species have evolved. A current complication to lamprey population genetic research is the difficulty in determining an accurate species identification based on morphological features at the larval life stage. At least six species of lamprey (Entosphenus spp. and Lampetra spp.) occur in California watersheds, and many species' ranges overlap. All are listed as California Species of Special Concern; yet, little is known about interspecific and intraspecific genetic structure of lamprey populations throughout the state. In this pilot study, we applied restriction-site associated DNA sequencing (RADseq) to lamprey samples (N=480) collected opportunistically through several ongoing salmon surveys. Our dataset captures individuals from various species, life stages, and geographic locations throughout northern California. Analysis of 480 individuals genotyped at variable SNPs (single nucleotide polymorphisms) throughout the genome showed high levels of divergence between species and varying patterns of genetic structure within and between populations. Future work includes the development of SNP markers to distinguish between all lamprey species in California. The reported results facilitate the management of genetic diversity in lamprey and may inform management unit delineations in the Bay-Delta region.

007-FB: Clear Water but Murky Understanding: Investigating the Decline of Tule Perch in the Northern SFE

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The UC Davis North Delta Arc project has been studying fish communities in the northern region of the upper San Francisco Estuary using otter trawls, beach seines, and boat electro-fishing since 2012. Trends in the region reflect wider trends observed in the Delta - increases in aquatic weeds and non-native fish species abundance with simultaneous decreases in native fish species. To better understand drivers of these trends we use native tule perch (*Hysterocarpus traskii*) as a case study. Tule perch have become rarer in otter trawl catches since the summer of 2015. Low flows, clear water and high temperatures during the 2012-2016 drought fostered aquatic weed growth. Concurrently, the non-native species largemouth bass, redear sunfish, and bluegill catches increased substantially. Drought, SAV recruitment, and competition and predation by non-native species have all contributed to the decline of tule perch in this region. Tule perch and most native fishes face multiple stressors, and Bay-Delta restoration projects which aim to provide safe refuge for native species must prioritize addressing root issues in order to be successful. These include restoring flows to restored sites, managing invasive species, and reducing water clarity.

Food Web Linkages (FWL)

008-FWL: The Review of Science of Non-Native Species in a Dynamic Delta

Stephen Brandt[1], James Cloern[1], Virginia Dale[1], Harindra Joseph Shermal Fernando[1], Tanya Heikkila[1], Thomas Holzer[1], Jay Lund[1], Diane McKnight[1], Robert Naiman[1], Lisa Wainger[1]

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The San Francisco Bay-Delta is one of the most invaded estuaries in the world. Indeed, non-native species are a large part of what is now the Sacramento-San Joaquin Delta (Delta) ecosystem. The invasion of new non-native species threatens the achievement of the coequal goal of “protecting, restoring, and enhancing the Delta ecosystem.” Reducing the impact of non-native species is a one of core strategies highlighted in the Delta Plan.

As part of its legislative mandate to provide scientific oversight of programs that support adaptive management, the Delta Independent Science Board (Delta ISB) undertook a review to better understand the scientific needs related to this complex issue. The review process included an extensive literature review, two panel discussions each composed of five experts who explored the state of science, and public comments. Additionally, Delta ISB members participated in several workshops and scientific sessions, presentations, and discussions with managers.

In the presentation, the Delta ISB will present key findings and recommendations from the review, such as the need to develop a comprehensive, spatially explicit, food-web model for the Delta. One of the primary impacts of non-native species is to disrupt or change food webs and nutrient cycling. Understanding the role of non-native species in the food web is fundamental for predicting and evaluating impacts. The review also stresses that the ongoing threat assessments for invasive species should be evaluated considering a changing environment and multiple drivers, especially climate.

Management needs to move beyond individual species management to address how to set ecosystem goals in recognition of an ever-changing species pool and high uncertainty. The Delta ISB encourages a broader, more forward-looking, integrated approach to non-native species science in the Delta to inform management goals.

009-FWL: Managed Floodplain Fish Food: Bringing Dry-Side Food Webs to Wet-Side Fish

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One primary benefit a fish gets from a floodplain is abundant food resources. Floodplain habitat restoration for salmon in California's Sacramento Valley fall into two strategies: wet-side floodplain access and dry-side floodplain management. "Wet-side" indicates floodplains within the levee footprint of the Sacramento Valley. During flood conditions, fish in rivers can pass volitionally on and off wet-side floodplains to access foraging and rearing habitat. "Dry-side" indicates floodplains beyond the levee footprint of the Sacramento Valley. Fish in the rivers are completely cut-off from these habitats, regardless of environmental conditions. While restoration to increase the frequency and duration of wet-side floodplains is critical for the Sacramento Valley's salmonid populations, including dry-side managed floodplains in the conservation strategy may also contribute to achieving population goals. In the winter and spring of 2018-2019 and again in 2020-2021, managed floodplain export pilot management actions were conducted on 5,000 acres of flooded agricultural land in Yolo County, California. Our hypothesis was that in-river zooplankton abundance and fish growth rates would be elevated at the managed floodplain outfall, relative to upstream. We measured water quality, zooplankton species and abundance, and juvenile Chinook salmon growth rates with PIT-tagged, hatchery-origin fish in enclosures. Fish growth rate analysis showed fish experienced growth rate benefits at least up to a mile downstream from the managed floodplain outfall location. Multiple water management companies and utility districts across the Sacramento Valley maintain similar infrastructure to what was used in these pilot actions and service up to 300,000 acres of potential managed agricultural floodplain. Incorporated into winter environmental water management practices, this unused resource may provide substantial food resources to rearing and out-migrating juvenile salmon in the Sacramento Valley system.

010-FWL: High Primary Production in Seasonally Managed Wetlands of Suisun Marsh

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Suisun Marsh encapsulates a mosaic of novel, working landscapes, in which the hydrology of formerly open tidal wetlands is replaced with managed wetlands. The managed wetlands are characterized by seasonal flooding for waterfowl, which typically occurs between fall through spring, followed by drying periods through summer for land maintenance. Major restoration projects are currently underway to restore tidal flow to these managed to create shallow habitat for threatened and endangered fishes. Nonetheless, managed wetlands will continue to comprise most of the Suisun Marsh landscape while their ecological contributions to the San Francisco Estuary remain largely unknown.

The goal of the UC Davis Suisun Ponds Project is to develop a baseline understanding of pelagic food production in managed wetlands. To characterize phytoplankton production and its drivers, we monitored phytoplankton community composition, chlorophyll *a* concentration, nutrient concentration, and physical conditions throughout two hydroperiods in the eastern marsh at the Potrero Duck Club and Meins Landing, and one hydroperiod in the western marsh at Wings Landing. We sampled 8-11 stations in each wetland and 1 station outside of the wetland in the parent sloughs near the control structure between 2018 and 2020.

Our data suggests that the Suisun managed wetlands can be major hotspots for phytoplankton productivity shortly following fall inundation. In all three managed wetlands, bursts of exceptionally high productivity persisted into the winter months until seasonal decreases in water temperature or freshwater flushes from precipitation decreased concentrations. The capacity for high production in these wetlands provides an opportunity for active management of lower food web production to support native fish in adjacent sloughs during critical feeding periods.

Franks Tract Reimagined: Integrating Recreation, Navigation, Ecology and Water Quality for Landscape Redesign in the Heart of the Delta (FT)

011-FT: Franks Tract Futures Reimagined, Habitat Restoration in a Novel Ecosystem

Carl Wilcox[1]

[1]California Department of Fish and Wildlife

On-demand talks: Franks Tract Reimagined: Integrating Recreation, Navigation, Ecology and Water Quality for Landscape Redesign in the Heart of the Delta (FT)

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Franks Tract Futures Reimagined is a collaborative planning process initiated by the California Department of Fish and Wildlife as a follow up to the Delta Smelt Resiliency Strategy 2018 Franks Tract feasibility study. The process prioritized working with the local community, local agencies, and interested stakeholders to develop a habitat enhancement plan for Franks Tract using a transparent and collaborative process to navigate tradeoffs between interests. The process and proposed changes embody conservation guidance for the region described in the 2018 A Delta Renewed and 2019 Delta Conservation Framework.

Franks Tract, a shallow flooded island, is a popular recreational and fishing destination in the Delta, with associated benefits to the local economy. Currently dominated by aquatic weeds and non-native fishes, it also significantly affects hydrodynamics and water quality in the central Delta. As one of the least subsided islands in the central Delta, it is a strong candidate for improvements to navigation, shoreline recreation, water quality and ecosystem function. The planning effort focused on how best to modify Franks Tract to increase habitat heterogeneity and ecological function while meeting multiple objectives. Planning recognized Franks Tract and the greater Delta as a novel ecosystem. Given the novelty of the system, both biologically and sociologically management actions to recreate historical habitat attributes must be considered in that light. The planning effort along with ongoing evaluation of trends in change within the Delta make it apparent that future ecosystem restoration be approached from both ecological and social perspectives. Aquatic weeds are a primary driver in determining the value of Delta habitat for native fish species and projects must design to minimize them, while social perspectives of what is good habitat in the Delta must be reconciled to gain broader support.

012-FT: Co-Design and Franks Tract Futures

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In the Delta, large-scale ecological restoration and water quality improvement projects can impact local communities and stakeholders in a variety of ways. When these communities are not integrated into the planning and design of such projects, the results are often unsupported and limited in function. Co-design refers to design approaches that attempt to involve all stakeholders in a project's planning and design process to ensure that the results meet the interests and needs of all involved. Franks Tract Futures (FTF) is an example of a large-scale restoration project in the central Delta (over 3,000 acres) that utilized an integrative co-design process to try address diverse and competing stakeholder interests.

This presentation will illustrate the FTF co-design process. Sequenced over a year, this process included public meetings, stakeholder interviews, on-line geo-spatial public surveys (SoftGIS), structured decision making (STM), and a series of in-person design workshops. Extensive stakeholder input at the beginning of the project ensured that local and public interests – including the provision of recreational features and sustainment of boating navigability - were integrated into technical and ecological project objectives. STM served to transparently establish and measure diverse project performance criteria. Through an iterative process of testing, evaluation and refinement, multiple design concepts were whittled down to a preferred concept with wide support across public and state interests.

The results of the FTF design process demonstrate that Delta conservation and climate adaptation projects can garner support from the publics they effect, if those communities and their needs are integrated into the design process. Likewise, co-design should be approached as a co-learning effort for all involved, which in this example, showed how recreational, ecological and water quality improvements could be welded together and advance what ‘multi-benefit’ landscape projects can be.

013-FT: Modeling Franks Tract Futures: Quantifying Diverse Stakeholder Interests

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The Franks Tract Futures project nested well-resolved 3D hydrodynamics modeling within a structured decision-making framework in order to find a suitable and more sustainable landscape design for Franks Tract. Modeling provided both a means of iterative refinement of designs as well as an aid in crafting metrics to represent diverse stakeholder interests such water quality improvement, fish entrainment reduction, navigability, drought protection and resilience to flood and sea level rise. A key finding of the modeling was that many of the designs achieve water quality and entrainment reduction goals sought by agency participants and perform well under sea level rise. The degree of improvement depends not only on large scale decisions such as placement of large landforms but also on finer configuration decisions such as the sizing of channels through the region. Modeling was used to explore the trade-offs between navigability and water quality, and the extent to which both objectives could be met simultaneously.

014-FT: Project Evaluation with Structured Decision Making and Map-Based Surveys

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Large scale multi-benefit projects that affect many and varied stakeholders are challenging to evaluate. The 2020 Franks Tract Futures Reimagined project relied on two primary methods for evaluation of the design concepts, structured decision making (SDM) and map-based survey. In this presentation, we will introduce the SDM and map-based concept design survey, describe the overall performance criteria, identify key tradeoffs, and discuss results. We will also discuss adaptations made to solicit local and public input due to the COVID-19 related shelter in place. We will compare and contrast the results between SDM, which relied heavily on input from the stakeholder and advisory committees, and the map-based survey which gathered public feedback on positive and negative perspectives on the features, location, and access components of the design concepts. Lastly, we will discuss how the combination of methods enabled local stakeholders to collaborate with technical experts throughout the co-design process, how perceptions shifted during the process, and how a broadly supported alternative emerged to move forward to the next stage of detailed planning.

Monitoring (M)

015-M: Automating the Drudgery: Using Artificial Intelligence to Detect Trash and Tobacco Product Waste

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With the advent of the State Water Board's *Trash Amendments* in 2015, cities, counties, and state agencies have set their sites on a target of zero waste escaping into our receiving waters. Most recognize, however, that this progress will take work. And that work will require evidence. For many municipalities interested in monitoring their management actions designed to reduce the release of trash, automation is an attractive proposition. After all, monitoring trash over broader areas with greater frequency is challenging and often costly.

With funding from the Ocean Protection Council and the California Department of Public Health, the San Francisco Estuary Institute and Southern California Coastal Water Research Project developed two new publicly available machine learning algorithms that can advance the detection of trash in general and cigarette butts in particular. The team leveraged both aerial imagery and coordinated fieldwork to measure the effectiveness of the algorithms in identifying the target items. The results are very promising and have been featured in a Trash Monitoring Playbook, issued by the Ocean Protection Council, which provides guidance for the adoption of trash monitoring methods to complement programmatic objectives.

During development, the team shared information and approaches with colleagues conducting similar work in West Sacramento, the Central California Coast, and across the state. This sharing of approaches from the State Water Board, 2ndNature, and

Caltrans has opened the field of artificial intelligence to new audiences as public agencies seek to implement solutions that can benefit from these technological advances.

The team will also share the results of the specific trash studies while also discussing the implications for the refinement and operationalizing of this work on trash monitoring in the Bay-Delta region and beyond.

016-M: A Path Forward for Environmental DNA Methods in the Bay-Delta

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Environmental DNA (eDNA) methods have the potential to complement existing monitoring and support management decision-making in the Bay-Delta. However, there remains a need to communicate the strengths and limitations of these methods, especially in the context of complex environments like estuaries. The eDNA symposium held at UC Davis on January 29, 2020, brought together regional scientists, managers, and worldwide leaders in the field to explore the potential for eDNA methods in estuaries. Following up on the success of this well-attended event, the organizing committee and presenters are drafting a manuscript to summarize insights from the symposium and explore how eDNA methods can be applied to estuaries in general and specifically to the management challenges found in the Bay-Delta. Here we present key findings from this work. First, we will briefly review critical considerations for eDNA studies in general and attempt to distill the “state of the science”. In addition, the unique challenges of applying eDNA methods in complex estuarine environments will be examined and the current status of eDNA resources and published studies in the Bay-Delta will be reviewed. We will also present the results of a poll asking regional agency scientists to list species of management concern and illustrate how eDNA methods can be applied for these species and suggest where more research is needed. Finally, we will provide recommendations for enhancing communication and collaboration between eDNA scientists and managers, and outline some best practices that will build confidence in eDNA methods as complementary tools for estuarine ecosystem management.

017-M: Taking Stock of the “monitoring Enterprise” to Support Adaptive Management of the Delta

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Climate change, aging water and levee infrastructure, growing human population, threatened native species, exotic species invasions, and balancing human and ecosystem needs for water create major challenges for achieving the Delta’s co-equal goals. A comprehensive and integrated network of monitoring, with open access to data, and strong linkages to decision-making are important for reliably measuring and detecting changes in the Delta, and understanding how to respond to these rapid transitions.

To understand the relevance, efficiency, and level of coordination, the Delta Independent Science Board completed the first phase of a comprehensive review of the “monitoring enterprise” to document activities and develop recommendations around how data collection can better meet the needs of agencies and support adaptive management. This review was guided by the following questions:

Are there potential gaps / redundancies in serving the relevant needs of decision makers?
What is the level of coordination of data collection across different organizations?
Are there other opportunities to increase efficiencies in monitoring?
What is the data quality of monitoring to address purposes and needs for data?
Are data accessible to the public, decision makers, and other scientists?
What resources are being dedicated to monitoring?

To answer these questions, metadata were collected for over 150 monitoring activities that serve the needs of decision makers as reflected by 7 management themes inherent in the Delta Plan and 23 science themes that represent the complex socio-economic, environmental, habitat, and species components of the Delta.

This presentation will highlight initial insights around these questions, alongside the importance of and pathways for making progress around three “big moves”. These “big moves” represent more transformative changes that may be difficult to implement, but are fundamentally necessary since the complexity, urgency, and long-standing nature of many challenges facing the Delta dictate an urgent need for doing things differently.

Salmon Biology (SB)

018-SB: (*IEP) Investigation of a Potential Mortality Hotspot for Juvenile Chinook Salmon

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Previous acoustic telemetry studies suggest a high mortality risk for juvenile Chinook salmon within flooded island habitats of the interior San Francisco Bay-Delta. We performed predation experiments using a field tethering approach combined with an experimental release of 100 acoustically tagged salmon to quantify mortality risk of juvenile salmon in the mainstem San Joaquin River compared to an interior putative hot spot for mortality (i.e. Franks Tract). Following deployment of tethered fish, predation events occurred at an average depth of 2.5m and after 66 minutes of deployment. Overall, predation rates were low at all sites, and there was no difference in relative predation risk between vegetated and unvegetated sites. Overall, outmigration survival of acoustically tagged fish to the ocean was low (2%), presumably because of reduced flows. However, the fact that some fish successfully egressed Franks Tract and emigrated to the ocean indicates Franks Tract is not always a complete mortality sink. Additional research is needed in multiple water years to investigate temporal variability in mortality risk associated with flooded island habitats of the interior Delta.

019-SB: American River Chinook Salmon Survival in Relation to Redd Water Quality: The Role of Spatial and Temporal Variability

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River management to support Central Valley salmonids often focuses on releases of cold water from dams to maintain temperatures within a tolerable range. Several modeling and laboratory studies, however, suggested that recent high embryo mortality of winter run salmon may be due to interactions between warm water temperatures, low dissolved oxygen, and low flows. Understanding the impact these stressors have on salmon embryos in natural incubation habitats is difficult because there is a lack of data on the abiotic conditions salmon embryos experience in Central Valley rivers. To study the relationship between environmental conditions and salmon embryo survival in the American River we measured several abiotic variables across spatial, temporal, and seasonal scales relevant to fall-run Chinook salmon. We created 24 artificial redds in the American River in November (12 redds) and December (12 redds), spanning the

spawning season. Each redd had three tubes of 200 fall-run Chinook salmon embryos and a logger continuously recording dissolved oxygen and temperature within the gravel. We measured temperature, dissolved oxygen, pH, turbidity, salinity, and conductivity above and within the gravel at each redd as well as water flow and depth weekly. When lab-reared controls reached the swim up stage the egg tubes were retrieved from the river. We measured hatching success and evaluated the developmental stage of dead eggs. Overall, embryo survival in the field was low and highly variable, potentially due to periods of hypoxia and variable egg quality. Variables including mean dissolved oxygen, maximum temperature, water velocity and depth, substrate size, site, and spawning month significantly influenced hatching success. By determining which water quality variables, in addition to temperature, have the greatest effects on survival these results can inform water management strategies to promote salmon survival for sensitive early life stages.

020-SB: Targeted Application of 3D Routing in a Full-Delta PTM

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Particle tracking models (PTMs) have proven to be invaluable tools for predicting the survival of outmigrating Chinook salmon smolts through the Sacramento-San Joaquin Delta. By coupling hydrodynamic, salmon behavior, and predation models, PTMs enable prediction of smolt travel time and routing, and consequently survival, under a wide a range of environmental conditions and water management scenarios.

However, full-Delta PTMs have been largely limited to 1D hydrodynamic models due to the prohibitive computational requirements of 3D models. While 1D models are suitable for some applications, certain dynamics cannot be captured by their simplified hydrodynamic and spatial structures, such as the effects of local flow on fish entrainment at key junctions where fish are routed from the mainstem Sacramento River into the low-survival interior Delta. There is a pressing need for models that improve prediction of such critical aspects while remaining computationally tractable.

Towards this end, we are developing the next version of DWR's ECO-PTM to accommodate either a 1D hydrodynamics model (DSM2), a fully 3D unstructured grid model (SCHISM), or a hybrid combination of 1D and 3D grids. The hybrid structure leverages SCHISM to improve prediction of routing in a few key junctions, obtaining much of the benefit of the 3D model with only a modest increase in computational expense.

We will describe the design of the hybrid DSM2/SCHISM-based model, present initial model results using the SCHISM junction model in lieu of the original ECO-PTM's statistical entrainment models, and compare the qualitative behavior of particles to 2D acoustic telemetry fish track data we used to inform particle behavior.

This work represents an important advance towards a modeling platform that will improve estimates of smolt survival under different environmental and water management scenarios, enhancing our ability to promote the survival of endangered salmonids in the face of climate change and other stressors.

021-SB: Validating Feature Level Habitat Use with Acoustic Telemetry: 2-Dimensional Positioning Capabilities of Vemco V3 Tags and HR3 Receivers

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In 2008 the National Marine Fisheries Service issued a Russian River Biological Opinion (RRBiOp) compelling Sonoma Water and the USACE to implement habitat enhancements along 6 of the 14 miles of mainstem Dry Creek downstream of Warm Springs Dam (Lake Sonoma). Storage and releases from Lake Sonoma provide flood protection and a source of water which is conveyed through Dry Creek to Sonoma Water's collection system along the mainstem Russian River. Off-channel habitats (backwaters, alcoves, and side channels) have been constructed with the aim of providing low-velocity, high-cover rearing habitat while allowing continued use of mainstem Dry Creek for water conveyance. Validating the use of constructed enhancement sites has primarily been accomplished through traditional monitoring methods such as snorkel surveys and PIT (Passive Integrative Transponder) systems, both of which provide a snapshot in time of habitat use at the site scale. With the use of Vemco V3 acoustic tags paired with an array of multiple HR3 receivers, we sought to obtain additional data on habitat use at the feature scale in one of the constructed side channels. We tagged 150 (100 natural and 50 hatchery origin) juvenile steelhead (85-193 mm) and released them after a 2 to 11 day acclimation period in live boxes in the channel. Prior to fish release, we deployed stationary receivers to facilitate creation of 2-dimensional tracks of tagged salmonids within the array. Preliminary results showed natural origin fish remaining in the site longer than hatchery fish, diel movement patterns, and use of constructed features such as log jams, root wads, pools, and riffles on a continuous basis. To assess the utility of this approach for similar evaluations elsewhere, we plan to utilize the data to calibrate various models and inform future habitat designs.

022-SB: Understanding the Impacts of Floodplain Availability on Chinook Salmon (Oncorhynchus Tshawytscha)

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Climate change is having widespread effects on environments, including an increasing frequency and severity of droughts. This can be problematic for species with dependent on specific environmental conditions and can lead to an overall loss in biodiversity. California's Central Valley is predicted to be one of the most water scarce areas in the world in the face of climate change, which could lead to negative consequences for the native and endemic species that live there. Drought conditions present unique challenges for the federally listed Central Valley Chinook Salmon (*Oncorhynchus tshawytscha*), which use the already limited floodplain in the Central Valley as rearing habitat. Flood plains, such as the Yolo Bypass, can be disproportionately affected by drought and stream flow changes, affecting the fitness of Chinook salmon. We are interested in understanding how different water conditions (drought versus flood) and specific environmental conditions (water flow, temperature, pH, DO) influence the run composition and abundance of juvenile Chinook salmon in the floodplain (Yolo Bypass) versus the mainstem of the Sacramento River. Chinook from the Yolo Bypass and areas along the Sacramento River were sampled and genotyped with an innovative genetic panel and identified at the run level (Fall, Late Fall, Winter, and Spring) from 2012-2019. These data were then combined with specific environmental conditions obtained from cdec.water.gov and input into a linear regression with the environmental data used as predictors. Initial data analysis suggests that the abundance of all runs are impacted negatively by poor water conditions in the Bypass. Losing this diversity in the Bypass may have overall negative effects on the sustainability of the species as well as the stability of the ecosystem. Chinook are of enormous economic, cultural, and ecological value in California and understanding how they are impacted by drought is crucial to their survival and persistence.

Smelt Biology (OB)

023-OB: Experimental Contrasts among Otolith, Histological, and Genetic Indicators of Growth and Condition for Critically Endangered Delta Smelt (Hypomesus Transpacificus)

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Accurate inferences of fish growth and condition are imperative for the conservation and management of endangered species, like Delta Smelt (Hypomesus transpacificus). Otoliths are commonly used to estimate fish growth and condition; however, the

sensitivity of otolith-based growth reconstructions in relation to other biomarkers of growth and condition remains unknown. Here, we contrast the sensitivity (in timing and magnitude) of otolith, histological, and genetic biomarkers of growth for adult Delta Smelt. Growth was manipulated over 60 days using variation in food rations. We then contrasted the timing and magnitude of responses of fish in different treatments with respect to their otolith accretion rate, liver glycogen, DNA:RNA, and somatic growth metrics. Condition factor, hepatosomatic index, and otolith accretion rates, each diverged significantly among treatments within a few days of the initiation of the experiment, indicating the highest temporal sensitivity to food limitation, with otolith accretion rates 40% faster in fed versus unfed treatments. Differences in otolith accretion rates were significantly correlated with changes in biomass, but not with fish length, indicating that otolith accretion may serve as a proxy for overall growth, but not length, per se, in older Delta Smelt. These results indicate that otolith accretion rates can provide high-resolution and biologically relevant proxies for reconstructing the growth history of wild adult Delta Smelt.

024-OB: *Presentation withdrawn*

025-OB: The Effect of Substrate on the Spawning Behavior and Egg Fertilization Success of Cultured Delta Smelt (Hypomesus Transpacificus)

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We examined the effect of substrate on *s*pawning behavior and egg fertilization success in cultured *H. transpacificus* under laboratory conditions. Specifically, we asked whether substrate affects the behaviors exhibited during spawning, the frequency of spawning behaviors, or the resulting egg fertilization rate. We addressed these questions by conducting no-choice substrate behavioral trials, in which five ripe females and five mature males were placed into a flow-through tank containing either control (acrylic), sand, or pebble substrates. Fish were allowed to spawn naturally for four days and all behavioral interactions were video recorded. After behavioral trials ended, eggs were incubated for three additional days and then assessed for fertilization success. Videos were analyzed for spawning behavior, in which we quantified the number of spawns (spawning behavior ending in egg release) and attempts (spawning behavior without egg release) that occurred. We found that substrate did not affect the sequence or expression of spawning behaviors, nor did it affect the number of spawns and attempts that occurred. We also found that substrate did not affect either the percentage of total eggs fertilized or the number of fertilized eggs when controlling for the total number of eggs laid. In addition, we documented the first known observation of rare diurnal

spawning in the predominantly nocturnal-spawning population. Our results suggest that cultured *H. transpacificus* can spawn on natural and artificial substrates, regardless of their preferences. In conjunction with the findings of other studies, our results also suggest that, in the absence of choice and under laboratory conditions, substrate may not affect reproductive success. Instead, other environmental (e.g. water velocity) or social (e.g. sex ratio) conditions may be more important. Such findings are important to informing ongoing habitat restoration efforts within the Delta.

026-OB: (*IEP) Improving the Longfin Smelt Larviculture Protocol: Responses of the Early Life Stages of Longfin Smelt to Temperature, Salinity, and Turbidity

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Over the last decade the UCD Fish Conservation Culture Laboratory has been developing a captive culture for the threatened longfin smelt to provide researchers with a sustainable source of individuals to conduct the studies necessary to determine their environmental requirements and to serve as a captive population for supplementation efforts. Prior to 2019, these efforts have been hindered by <1% survival to 80 days post-hatch. However, recent changes to larviculture protocols informed by physiological studies on the early life stages of longfin smelt have led to a marked improvement in culturing efforts, yielding approximately 50% larval survival in 2019-2020. We present two studies, one examining temperature effects and another on salinity effects on the early life stages of longfin smelt, that informed this change to the larviculture protocol. We additionally present a third study examining turbidity effects on larvae that may inform further changes to the culture protocol. In the first experiment, we exposed embryos and larvae to three different temperatures: 9, 12 or 15, and found that hatch success and the final length that yolk-sac larvae achieved are greater at cooler temperatures of 9 and 12. In our second experiment, we exposed yolk-sac larvae to a range of salinities between freshwater (0.4 ppt) and seawater (32 ppt) and found that survival and yolk absorption was highest at intermediate salinities of 5-10 ppt. Finally, in our third experiment we reared larvae at 10, 20 or 40 NTU turbidities and found that survival was highest at the highest turbidity of 40 NTU. Overall, we are encouraged to find that small changes in environmental conditions can improve the survival of longfin smelt and are hopeful that a successful culture for the species will be developed soon.

Water Quality (WQ)

027-WQ: Copy Number Variation of Mutated Ace-1 Gene Involved in Pesticide Resistance in Hyalella Azteca Within the Cache Slough Complex

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The epibenthic crustacean, *Hyalellaazteca* are found throughout the Cache Slough complex of the Sacramento-San Joaquin Delta. They are an important prey item for fish species of concern within the Bay-Delta and are frequently used for sediment toxicity testing to determine environmental health. Due to high pesticide loading, especially during storm events, many *H. azteca* populations throughout the Cache Slough Complex have evolved resistance toorganophosphate pesticides (OPs) through selection *of* a point mutation in acetylcholinesterase (*ace-1*). However, evidence suggests that additional mechanisms may be involved including copy number variation (CNV) in the *ace-1* gene. To better understand this potential mechanism, the number of *ace-1* gene copies of individual *H. azteca* was quantified and correlated to organism resistance and acetylcholinesterase activity.

Using quantitative PCR, we quantified the number of *ace-1* gene copies by comparing its amplification to the quantities of two single copy reference genes. These conserved reference genes, Ran Binding Domain and UracilPhosphoribosyltransferase, were identified as single copy according to a Benchmarking Universal Single-Copy Ortholog (BUSCO) list. We then compared *ace-1* copy number in single individuals to whether they had a resistance mutation as well as the activity of acetylcholinesterase, both in the absence and presence of OP insecticides. By quantifying the number of ace-1 genes in relation to the degree of resistance, we expect to better understand how H. azteca are becoming resistant and provide insight into the relative importance CNV in OP insecticide resistance. Because resistant H. azteca can serve as vector for trophic transfer of OP insecticides to fish species of concern, understanding the mechanisms of resistance in their prey species is important for the overall health of the Bay-Delta.

028-WQ: Identifying Cyanobacterial Harmful Algal Bloom Toxins in Delta Invertebrates: Implications for Native Species and Human Health

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Cyanobacteria harmful algal blooms (CHABs) are a growing water quality problem in the Delta. Filter-feeding invertebrates compound risks associated with CHABs by biomagnifying cyanotoxins; as such, shellfish can serve as both time-integrated samplers of toxin levels in the water column and bio-sentinels of health risks through the food web. Little work has been done to characterize MC concentrations in Delta shellfish. It is critical to determine the extent of MC accumulation in Delta shellfish since these organisms are consumed by native species, including sturgeon, and humans. Our primary goal is to analyze Delta shellfish and water samples to determine when MCs enter the Delta food web, their geographic distribution, and the magnitude and duration of impairment. Sampling began in August 2020 and is continuing to occur monthly. We have collected Asian clams (*Corbicula fluminea*) from 10 sampling sites throughout the Delta and crayfish (*Pacifastacus leniusculus*) from a subset of these sites. Although sampling will continue through August 2022, we have gathered enough data to begin characterizing MC shellfish contamination. MC in water samples have remained relatively low (i.e., max <5 μg/L); however, MC in shellfish have been high and widespread. In August, MC was detected in Asian clams at all 10 sampling sites. In the following months little to no MC was detected in water or shellfish samples at the uppermost Sacramento River sites (i.e., Cache Slough) but the toxin continued to persist in shellfish samples from the other sampling sites. To date, maximum MC measured as high as 1,105 ng/g in Asian clams from Franks Tract and 1,751 ng/g in crayfish from the San Joaquin River near Turner Cut. Ultimately, this work will fill an important data gap concerning MC contamination in brackish and freshwater shellfish and the implications for managed species, their communities, and human health risks.

Wetlands and Floodplains (WF)

029-WF: Elevated Mercury Exposure in Raccoons and Striped Skunks from Suisun Marsh

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Bioaccumulation of environmental contaminants, such as mercury, in mammalian predators can serve as an indicator of ecosystem health. Methylmercury is the most toxic form of mercury for animals and it biomagnifies through food webs and bioaccumulates in mid and upper trophic level predators. Within the San Francisco Bay Estuary, we quantified hair mercury concentrations of raccoons (*Procyon lotor*) and striped skunks (*Mephitis mephitis*) from Grizzly Island in Suisun Marsh. The mean (standard error; range) mercury concentration in adult hair grown from 2015 to 2018 was 28.50 μg/g dw (3.05 μg/g dw; range: 4.46 – 81.01 μg/g dw) in raccoons and 4.85 μg/g dw (0.54 μg/g dw; range: 1.53 – 27.02 μg/g dw) in striped skunks. From a comprehensive review of terrestrial and aquatic mammalian hair mercury concentrations (excluding bats and humans), raccoons from Suisun Marsh were among the highest concentrations observed for wild mammals. Hair mercury concentrations in skunks and raccoons were not related to animal size, but mercury concentrations were higher in skunks in poorer body condition. Large inter-annual differences in hair mercury concentrations suggest that methylmercury exposure to mammalian predators varied among years. Yearly mean raccoon and skunk hair mercury concentrations increased with the amount of wetted habitat (wetlands and channels). Furthermore, during 2017, individual raccoon hair mercury concentrations increased with the proportion of each animal's home range that was wetted habitat, as quantified using global positioning

system (GPS) collars. Estimates of liver mercury concentrations derived from hair concentrations indicated that 19% of adult raccoons in the study may have been close to or above the proposed liver toxicity benchmark of 30 mg/kg (ww) for impaired reproduction in mammals. The elevated mercury concentrations in raccoons and skunks suggest that other wildlife at similar or higher trophic positions may also be exposed to elevated methylmercury bioaccumulation in brackish marshes.

030-WF: Tidal Habitat Restoration at Lower Yolo Ranch

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In conjunction with the California Department of Water Resources (DWR), Westlands Water District, Hallmark Group, ICF, and cbec eco engineering designed, permitted, and constructed a 2,149-acre tidal marsh restoration project in the Lower Yolo Bypass near the Cache Slough Complex. The goal of the project was to benefit native fish, including delta smelt *(Hypomesus transpacificus)* and winter- and spring-run salmonids. The Lower Yolo Ranch Restoration Project, which adjoins the Yolo Flyway Farms tidal marsh restoration project completed in 2018, represents a significant milestone with the completion of a ‘turn key’ tidal marsh restoration project to partially fulfill mitigation obligations associated with the ongoing operation of the State and Federal Water Projects, which both deliver irrigation and municipal water to Central and Southern California. The design development and entitlement of the project was overseen by the multi-agency Fish Agency Strategy Team, or FAST, which is tasked with approving mitigation for the ongoing need. The Lower Yolo Restoration Project was designed to take advantage of the large areas of the site that were at ideal elevations for tidal marsh restoration, and that would contribute to the food web of the Cache Slough Complex quickly and without large amounts of earthwork. Construction of the project, under a compressed schedule, began in August 2020 and was completed in October 2020. DWR, in conjunction with the California Department of Fish and Wildlife, will begin collecting monitoring data at the site in 2021.

031-WF: Mercury Trends in Seasonal Wetlands of the Los Banos Wildlife Area

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Export of mercury and methylmercury from managed seasonal wetlands in the San Joaquin River Basin (SJRB) is a significant but understudied source of water quality impairment to the Delta, and contributions from wetlands in the SJRB, such as those of the Los Banos Wildlife Area (LBWA), are unknown. Water samples were collected during flood-up from August 2019 through November 2019 at multiple locations in the LBWA, including the San Luis Canal (SLC), which supplies water to two seasonal ponds (70A and 71A). Total mercury concentrations in unfiltered samples from the SLC ranged from 0 - 17 ng/L (mean: 8.3 ± 4.9 ng/L), whereas concentrations in filtered samples were lower and less variable (mean: 2.1 ± 1.6 ng/L). In samples collected at the outlets of both ponds, mercury concentrations increased during filling in both filtered and unfiltered samples (1-6 ng/L and 1-10 ng/L, respectively), and filtered mercury concentrations were higher in the ponds than in SLC water. Methylmercury concentrations from pond 70A were higher than SLC concentrations in both unfiltered (0.25 to 5.1 ng/L) and filtered (0.19 to 2.2 ng/L) samples. During flood-up, sulfate concentrations were lower in the ponds compared to SLC water (36 vs. 58 mg/L respectively). During the flood-up period, the ponds behave as a source for methylmercury, likely due to methylation of dissolved mercury from SLC water and flush out from soils under sulfate-reducing conditions. In pond 70A, mercury and methylmercury were mostly present in the water column, rather than sorbed to particulate matter, and therefore more bioavailable and mobile. Understanding the seasonal trends of mercury export from wetlands in the SJRB could allow wetland managers to develop cost effective habitat management practices that improve compliance with San Joaquin River water quality objectives while sustaining wetland habitat productivity.

032-WF: (*IEP) Sources and Sinks! What's Going on with Mercury in Sacramento Valley Tidal Wetlands?

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Legacy mercury contamination is problematic in California waterways because of historic gold and mercury mining. The inorganic mercury from mines is methylated in water bodies throughout California, and tidal wetlands have been suspected to produce and be net exporters of mono-methylmercury (MeHg) into California's Sacramento-San Joaquin Delta and Suisun Marsh. The California Department of Water Resources (CDWR) characterized MeHg and total mercury imports and exports from four Sacramento Valley tidal wetlands to determine net MeHg discharge; three of the tidal wetlands were fresh water, and one was brackish. We collected concentration data from one tidal cycle approximately monthly and collected continuous flow data, which were used to calculate loads; loads were calculated per 25-hour tide and estimated per month using the continuous flow data. CDWR also compared mercury ebb and flood concentrations to determine if there was a significant difference. Based on the collected data and analyses, none of the four wetlands appear to be a significant net exporter of particulate or filtered MeHg to receiving waters. Concentrations of MeHg were not

significantly higher leaving than enter the wetlands and there was not a measurable annual increase in MeHg loads in receiving waters due to the tidal wetlands. Two wetlands were net exporters of total mercury in the particulate or in all forms. The other two wetlands were net importers of total mercury in the filtered and particulate form, depending on the wetland. The current assumption is that tidal wetlands are net exporters of MeHg, resulting in expensive and time-consuming mitigation as well as concern that tidal wetlands export MeHg to the Delta as more acreage is restored. This study shows that tidal wetlands are unlikely to be significant net exporters of MeHg to receiving waters though MeHg concentrations of biota within wetlands still need to be considered.

033-WF: Tracking the Course of a New Restoration: Initial Observations from the Montezuma Wetlands Complex

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Newly restored sites offer unique opportunities to monitor wetland dynamics as they develop over time. As of November 2020, we have begun conducting monthly beach seines, otter trawls, and vegetation surveys in Montezuma Wetlands, a tidal restoration complex near Collinsville, CA which was breached in late October of the same year. Preliminary data show invasive Mississippi silverside (*Menidia audens*) and alligatorweed (*Alternanthera philoxeroides*) are already abundant. While alligatorweed may impede desirable native fish species, including salmon and delta smelt, the abundance of silverside and invertebrates appear to support a diverse array of shorebirds, waders, and other waterfowl, as well as mammals. However, as the site matures, emergent vegetation growth, changing sediment characteristics, and newly colonizing organisms will continue to alter community composition. Evidence from nearby reference sites suggests that native and pelagic fishes may benefit from restored habitats with long or mixed residence times, including managed wetlands, which control the rate of water exchange, concentrate zooplankton, selectively offer passage for fish species, and restrict invasive species access. Observations on the rapidly changing Montezuma Wetlands complex will inform future restoration projects in the Delta, allowing managers to maximize habitat provisioning for target species.

034-WF: Implementation of Multi-Benefit Juvenile Salmonid Habitat Restoration on the Lower Yuba River: The Hallwood Side Channel and Floodplain Restoration Project

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Anthropogenic actions on the Lower Yuba River dating back to the Gold Rush altered geomorphic and hydraulic conditions, and subsequently available habitat for rearing juvenile salmonids. The Hallwood Side Channel and Floodplain Restoration Project was developed to address the United States Fish & Wildlife Service Anadromous Fish Restoration Program's goal to double natural production of anadromous fish in Central Valley rivers. The Project was designed to enhance ecosystem processes to support juvenile rearing fall-run and spring-run Chinook salmon and California Central Valley steelhead. The Project is supported by numerous agencies and stakeholders and takes a novel approach by leveraging relationships with aggregate mining landowners to facilitate economically efficient habitat enhancement. After several years of planning, design, permitting, and pre-project monitoring, 89 acres of habitat was enhanced as Phase 1 implementation was completed in 2020. A network of perennial and seasonal side channels was created and an unnatural constraint separating the main channel from its floodplain was removed. The remaining Phases will proceed over 3 - 5 years and create or enhance up to a total of 157 acres of seasonally inundated floodplain habitat, 1.7 miles of perennial channels, and 6.1 miles of seasonal side channels and alcoves. Beyond habitat enhancement, the project also provides significant local flood benefits by reducing water surface elevations by several feet and also reducing pressure on training walls that bound the floodway. A design based on restoring lateral connectivity and removing unnatural constraints coupled with a robust monitoring program will provide valuable information at a large-scale regarding restoration success and lessons-learned and be applicable in both upslope and Bay-Delta settings.

035: Hindcasting Alviso Slough Pond System Morphodynamics

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Alviso Slough area, South San Francisco Bay, is the site of an ongoing effort to restore former salt production ponds to intertidal habitat. As restoration proceeds and the levees surrounding the former salt production ponds are breached, the increase in tidal prism and associated sediment scour in the sloughs will remobilize legacy mercury deposits. A numerical model that is able to assess patterns of sediment transport, erosion, and the fate of remobilized sediments can improve mercury remobilization estimates and inform management actions.

The goal of the current research is to validate a 2D geomorphic model for Alviso Slough and surrounding ponds using bathymetric surveys, hydrodynamic measurements and observations of suspended sediment concentrations during the 2010-2016 period. The 2D geomorphic numerical model applies the Delft3D Flexible Mesh (software by Deltares) coupled with the SWAN wave model that describes detailed interaction between hydrodynamics, wave action, sediment transport, and geomorphic change on a high-resolution mesh.

The morphodynamic model results shows that observed water levels and erosion and sedimentation patterns can be reproduced with skill. This includes for example the amount of sediment that entered pond A6 after enforced breaches. The associated suspended sediment concentrations are more difficult to reproduce, but are of same order of magnitude as observations. The model reveals tide residual flow and sediment transport patterns throughout the A6-A7-A8 pond system that are usually difficult to measure. These residual flow and transport patterns are the result of subtle, tide residual transports.

Our model shows that we can skillfully reproduce observed morphodynamic developments in the Alviso Slough pond system. This is of particular use to assess future pond restoration scenarios and intervention measures. Future research work may focus on breaching and sea level rise scenarios as well as on including vegetation dynamics to forecast marsh development.