Oh Give Me a Floodplain: Comparison of Food Web and Juvenile Salmon Growth across Four Central Valley Floodplains

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Floodplain restoration is a management priority in the Sacramento-San Joaquin Delta region because floodplains provide critical growth benefits to juvenile salmon. However, Central Valley floodplains include various landscape types, from farmland to wildlife areas. These habitats may provide a range of benefits for fish, but little work has been done to evaluate variability among habitats in their capacity to support juvenile salmon. In February 2015, we compared food web and juvenile salmon growth among six floodplain sites located in Sutter and Yolo Bypasses, Cosumnes River Preserve, and Dos Rios Ranch at the confluence of the San Joaquin and Tuolumne Rivers. These sites produced rice or wheat, or had natural vegetation during non-flooded periods. During managed inundation, we collected weekly zooplankton samples at each site. We held juvenile fall-run Chinook Salmon in replicated cages at Sutter, Yolo, and Dos Rios locations to compare growth rates. We observed diverse invertebrate assemblages across all sites in a broad range of densities (~25,000 – 175,000 total organisms/m^3). Rice fields in the Yolo Bypass were dominated by cladocera, while an adjacent fallow site in the Yolo Bypass had a mix of ostracods and midges. Sites in Sutter, Cosumnes, and Dos Rios locations had a higher presence of copepods. Salmon diets were variable, with some suggestion of selectivity for midges. Despite the variation in land use and food web, juvenile salmon growth rates (0.72 – 0.89 mm/day) were comparable among locations, and all were exceptional compared to reports from Central Valley riverine environments.

Statement of Relevance: This work suggests that farmlands and natural floodplain landscapes alike can provide functional and essential nursery habitat for juvenile salmon. For floodplain restoration efforts, focusing on improving access, rather than providing a specific habitat, may be the right emphasis for rapid support to the freshwater rearing phase of juvenile salmon.

Keywords: floodplain, salmon, habitat, growth, food web
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The Knaggs Study – Comparing Food Resources and Growth of Juvenile Salmon between Flooded Agricultural Fields, the Toe Drain and the Sacramento River

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Floodplains have been shown to provide high quality rearing habitat, but due to difficulty in sampling, very few studies have been able to directly compare water quality, food resources and growth of juvenile salmon between river and floodplain habitats. From 2012 to 2016 juvenile fall run Chinook salmon have been reared in flooded rice fields on the Yolo Bypass showing prolific growth rates. To look at a direct comparison between riverine and flooded agriculture lands, in the winter of 2016, juvenile Chinook salmon were reared across a transect of the Yolo Bypass, Toe Drain, and Sacramento River to compare water quality, food resources and growth rates between the habitats. Water temperatures were warmer on the rice fields and Toe Drain compared to the river site for lower flows, but during a storm the last week of the study water temperature were similar. Food resources (invertebrates and zooplankton) were 130 times more abundant in the flooded agricultural fields than in the river habitat. Fish were placed in cages within all three habitats for a total of three weeks. During the three-week study, growth rates diverged greatly between the habitats. Growth rates were five times and three times higher in the flooded rice fields compared to the Sacramento River location and Toe Drain respectively. This direct comparison of food resources and individually marked fish allows for a better understanding of the potential benefits of juvenile salmon rearing on flooded agricultural habitats.

Keywords: floodplain, juvenile Chinook, growth, food web, agriculture, productivity, Yolo Bypass
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Mimicking Hydrologic Process to Restore Ecological Function

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Floodplain-sourced carbon is made available to aquatic food webs when floodplains activate as rivers flood. Today, levees cut off 95% of the Central Valley's floodplains from river channels. So that Central Valley aquatic ecosystems no longer recruit the carbon (stored solar energy) needed to support a robust aquatic food web and sustain abundant fish and wildlife populations. **Put simply, levees are starving salmon and smelt.**

Recovery of endangered fish populations will likely be impossible without first recovering the ecological processes which once supported historic abundances. Each winter and spring flooding in the pre-development Central Valley created a vast mosaic of productive floodplain habitats teeming with fish and wildlife. Nineteenth and twentieth-century investments in a network of dams, canals, and levees transformed the Central Valley into one of the world's most productive agricultural regions. This transformation has also led to the threatened and endangered status of numerous species.

This presentation will explore how managing floodplains to create prolonged shallow inundation mimics the Central Valley historical flood patterns to which California's native fish species are adapted. The presentation will synthesize 5 years of results from the Nigiri Project which seasonally manages for the creation of floodplain habitat for native fishes and waterbirds during winter and spring on fields that remain in agricultural production in summer and fall. The presentation will demonstrate how multi-species, multi-benefit land uses can cultivate ecological solutions on working agricultural landscapes while sustaining biodiversity and fostering resilience to climate change.

Keywords: salmon, floodplain, food web, fish, rice, levees, process based reconciliation
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Evidence that Seasonal Floodplain-Tidal Slough Complex Could Support Improved Life History Diversity and Population Resilience

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Habitat restoration practitioners are faced with a knowledge gap when rehabilitating aquatic landscapes for species resilience. Population diversity is a mechanism for resilience and has been identified as an issue for the management of fisheries resources, but restoration ecologists lack evidence for specific features or processes that can be rehabilitated to promote diversity. Since habitat complexity may affect population diversity, it is important to understand how population diversity is partitioned across landscapes and among populations. In this study, we examined life history diversity based on size distributions of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) within the Yolo Bypass, a remnant transitional habitat from floodplain to tidal sloughs in the upper San Francisco Estuary (SFE). We used a generalized least squared model with an AR1 correlation structure to describe the distribution of variation in size from 1998 to 2014, and tested the effect of four possible drivers of the observed variation: (1) environmental/seasonal drivers, (2) prey resources and (3) sampling effort within the Yolo Bypass, and (4) the juvenile Chinook population at large within the Sacramento River and north SFE. We found that the duration of floodplain inundation, water temperature variation, season and sampling effort were influencing the observed size distribution and timing of juvenile salmon. Both floodplain inundation and thermal heterogeneity are features of hydrologic complexity, which is severely limited in the channelized lower Sacramento River and SFE. Data is not available to test if size variation within the Yolo Bypass contributes to population–level life history diversity or resilience, but given the minimal inundation and reduced thermal heterogeneity in adjacent habitats, these mechanisms of juvenile size and timing diversification are primarily available to salmon utilizing the Yolo Bypass. Therefore, enhancement of river floodplain tidal slough complexes and inundation regimes through habitat restoration may affect the resilience of Central Valley Chinook Salmon.

Keywords: juvenile Chinook Salmon, Yolo Bypass, habitat complexity, resilience, habitat restoration
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Yolo Bypass: Potential Refuge for Delta Smelt?

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The Yolo Bypass, the primary flood basin of the Sacramento River, has been shown to provide valuable habitat for various native fish species such as the Sacramento Splittail (*Pogonichthys macrolepidotus*) and Chinook Salmon (*Oncorhynchus tshawytscha*). However, recent data from the Yolo Bypass Fish Monitoring Program (YBFMP) indicates that the Yolo Bypass may also be an important habitat for the imperiled Delta Smelt (*Hypomesus transpacificus*) during non-flood periods via the perennially wetted Toe Drain. We examined Delta Smelt catch data from the YBFMP to identify changes in the distribution and abundance of Delta Smelt within the Yolo Bypass. We found that although Delta Smelt have been captured on an annual basis by the YBFMP since its inception in 1998, the annual Delta Smelt catch for our rotary screw trap has increased nearly ten-fold from pre-Pelagic Organism Decline years (POD) to post-POD years. Unexpectedly, we also observed relatively high annual catches of Delta Smelt during the recent drought years (2012-2015). Moreover, we found that juvenile Delta Smelt caught in the Yolo Bypass appear to be larger earlier in the year than those collected by other monitoring programs within the Interagency Ecological Program. Otolith growth increment data suggest that the larger size of juvenile Delta Smelt in the Yolo Bypass was due to higher growth rates in the region relative to the rest of the San Francisco Estuary. Our results suggest that the Yolo Bypass may provide high quality habitat even during drought conditions and could play a crucial role in the future persistence of this imperiled species.

Keywords: Yolo Bypass, Delta Smelt, Pelagic Organism Decline, Floodplain, Fish Monitoring
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Survival and Travel Time of Acoustically Tagged Juvenile Chinook Salmon in Yolo Bypass during the "Godzilla" El Niño of 2016

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The Yolo bypass is a highly productive floodplain in the Sacramento River valley that consists of wildlife areas and agricultural land. The bypass is accessible to fishes in most years, but not all. Emigrating juvenile salmon that enter the bypass have accelerated growth rates due to increased prey abundance and density; however juvenile fishes have limited access to the Yolo bypass during low flow years or when the Fremont Weir does not overtop. In addition to contributing to growth, access to the bypass may improve survival of emigrating fishes relative to other emigration routes in the Delta such as the interior Delta. During the moderate flow spring of 2016 we evaluated survival and travel time of acoustically tagged juvenile Chinook salmon as they emigrated down the Sacramento River from the Tisdale Weir during different stages of spring floods. Five releases consisting of 240 fish each were made during the study. Fish were released prior to, during, and after the overtopping of the Fremont Weir. Data obtained from the study will provide a comparison between survival and travel times in the Yolo bypass versus the Sacramento River from release to Chipps Island. This comparison will inform management decisions regarding whether and to what extent to make the Yolo bypass more accessible to emigrating juvenile salmonids during drought or low flow years.

Keywords: Yolo bypass, survival, Chinook salmon, telemetry, Fremont weir
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Hydrodynamics in a River Bend Adjacent to the Fremont Weir: Implications for Design of Fish Passage Structures

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A fish passage structure (or notch) has been proposed at the Fremont Weir to partially inundate the Yolo Bypass at lower stages and with greater frequency. Evidence suggests that the Yolo Bypass may provide better habitat and increase through Delta survival of out-migrating juvenile salmon. In WY2016 we collected discharge and secondary circulation measurements near the Fremont Weir on the Sacramento River over a range of flows. These data suggest several salient features relevant for making estimates of fish entrainment into the proposed notch.

First, the discharge in the Sacramento River relative to the notch flow is critical in determining entrainment rates. Yet there is a non-linear relationship between stage and velocity at this location due to backwater effects from the Sutter Bypass and the Feather River, suggesting discharges calculated based on stage at this location will be inaccurate at higher flows, prior to the weir overtopping. Secondly, strong secondary circulation occurs at the apex of the bend increasing the cross-channel velocities downstream of the peak in the secondary circulation, suggesting notch location is critical in maximizing the number of fish entrained for a given amount of water entering the notch. Lastly, we estimate the location of the flow split in the river over a range of measured Sacramento River discharge and notch design flows. When design flows are low, relative to the Sacramento River flows, the flow split is closer to the outside of the bend relative to the fish distribution leading to minimal entrainment for a given volume of water entering the notch.

To integrate these results, we developed an individual-based model based on velocity fields interpolated from data and impose simple behaviors in a particle tracking model. We show that measured fish spatial distributions can be reasonably predicted based on a simple model of behavior.

Keywords: Hydrodynamics, Yolo Bypass, Entrainment, Particle Tracking
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Techniques for Estimating Entrainment Rates in Riverine Junctions under Future Engineering Scenarios

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Recent mark-recapture survival modeling has shown that route-specific survival of emigrating salmonids varies between migration corridors in the Sacramento–San Joaquin River Delta. As a result, through Delta survival can be improved with engineering solutions that change route selection probabilities at channel junctions by increasing entrainment into high-survival routes. Two such solutions under consideration are a Bio Acoustic Fish Fence (BAFF) installed at the mouth of Georgiana Slough, and modifications to the Fremont Weir to allow fish passage into the Yolo Bypass at lower Sacramento River discharges.

Although the Georgiana Slough BAFF and the Fremont Weir modifications are being implemented independently, these projects present similar technical challenges with regard to predicting the route selection probabilities that will result from proposed engineering solutions. Individual-based modeling (IBM) shows promise for predicting the behavior of salmonids under proposed scenarios, but the inherent Lagrangian nature of these techniques can amplify errors in the underlying hydrodynamic data and behavioral abstractions driving the models. In order to quantify the cumulative effect of these errors, we present techniques for spatially explicit quantitative calibration and validation of individual-based model results using measured fish tracks. In addition, we present a general technique for estimating future entrainment probabilities using hydrodynamic and biologic data that can be collected prior to junction modifications and can then be used to calibrate and validate IBM predictions. Finally, we apply this technique to estimate future entrainment rates of emigrating salmonids for potential modifications to Sutter Slough and the Fremont Weir.

Keywords: Route Selection Probability, Juvenile Chinook salmonid, Fremont Weir, IBM Modeling
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Integrating Hydrodynamics and Fish Physiology to Estimate Entrainment Rates for Fremont Weir Notch

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Floodplains are important features of rivers that influence interlinked morphological and ecological processes. The Sacramento River cannot access its floodplain due to levees except during high flows at engineered overflow weirs. The 3200 meter Fremont Weir conveys a maximum of 9300 m3/s, which is approximately 80 percent of the flood waters in the Sacramento River. When inundated downstream migrating fish readily pass over the weir onto the floodplain (Yolo Bypass). We used an integrative approach to assess effectiveness of 9 proposed Fremont weir notch alternatives in entraining fish from the Sacramento River and onto the Yolo Bypass. The proposed notches are designed to allow water to access the floodplain at much lower river flows thereby providing consistent and long term floodplain access for migrating juvenile salmon. We used multidimensional hydrodynamic models of the notches built with a combination of engineering drawings, topographical and bathymetric data to describe notch influence on river flow fields. We use measured fish positional data (winter and late fall run Chinook salmon) and multidimensional hydrodynamic models to calibrate modeled fish movement to speed over ground and spatial distribution. We found entrainment is a function of speed over ground, fish swimming capacity, influence on river streamlines and notch design. Through examination of different fish sizes and behaviors we explored alternative fish response to the proposed notches. We conclude the proposed notches vary in terms of entrainment rates and that through an integrated modeling approach we can refine and enhance the overall entrainment rates. The long-term relevance of this work impacts the survival of endangered salmon in the Sacramento through provision of an important habitat component, floodplains, that are largely inaccessible in the Sacramento system.

Keywords: Fremont weir, Yolo bypass, hydrodynamic models, notch, fish movement models
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Ecological Importance of Fall Flows in Yolo Bypass

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Historically, Yolo Bypass lower trophic level research has focused on the benefits of the inundated floodplain habitat during the winter and spring months. However, in 2011, Department of Water Resources (DWR) began a year-round monitoring effort for a suite of lower trophic metrics that include the collection of biweekly: chlorophyll *a* (chl *a*), zooplankton and invertebrate drift samples. The timing of this increased monitoring effort was fortuitous, as it overlapped with significant phytoplankton blooms in fall 2011 and 2012 that occurred downstream of the Yolo Bypass in the lower Sacramento River. Substantial evidence from within region water isotopic studies, ongoing water quality data collection, and Yolo Bypass lower trophic monitoring suggested that these phytoplankton blooms were supported, in part, by elevated fall agricultural drainage flows from the Yolo Bypass. These phytoplankton blooms were unprecedented and of great importance to the Sacramento-San Joaquin Delta, as phytoplankton blooms like these have become increasingly rare in the Delta in recent decades. More importantly, declines in primary productivity have been linked to decreases in both zooplankton and pelagic fish abundance. Since 2013, DWR has been investigating the spatial and temporal trends of phytoplankton (chl *a*), zooplankton, nutrients, flow and water quality conditions before, during, and after increased fall agricultural flows in the Yolo Bypass. The initial results from this study show that the Yolo Bypass in all years has significantly higher chl *a* concentrations (Kruskal Wallis $p < 0.001$) in summer and fall compared to other regions of the Delta. In addition, results showed a significant correlation (Pearson Correlation $p < 0.001$) between increased Yolo Bypass calanoid copepod abundance and summer/fall flow pulses. Our hope is that continued investigation into the processes that facilitate increased fall phytoplankton biomass could yield new water management tools to benefit the Delta pelagic food web.

Keywords: Yolo Bypass, phytoplankton, zooplankton, flow
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