FISHERIES EVALUATION OF FLOODPLAIN REARING AND MIGRATION IN THE YOLO BYPASS FLOODPLAIN

Prepared by
California Department of Water Resources
Division of Environmental Services, Aquatic Ecology Section

For

California Department of Fish and Wildlife

Ecosystem Restoration Program

FINAL REPORT January 2015

California Department of Fish & Wildlife
National Oceanic & Atmospheric Administration
US Fish & Wildlife Service

Executive Summary

Yolo Bypass is the primary floodplain of the lower Sacramento River. Based on a substantial body of knowledge, the region has become a focus of interest in managing seasonally flooded habitat in the Delta for fishes such as Chinook Salmon. However, there are substantial data gaps for the design and operation of restoration plans, and the development performance criteria for evaluation of restoration actions. Our multi-agency Ecosystem Restoration Program-funded study sought to address several of the key questions for Chinook Salmon rearing and migration in the Yolo Bypass. Note that our study was affected by extended drought conditions, so no new high flow samples could be collected. Nonetheless, the effort managed to address the majority of the study objectives using historical data, archived samples, laboratory work, and collection of additional fish and food web samples in Yolo Bypass perennial channels. The major study components and results are summarized below.

Adult Salmon and Sturgeon Telemetry: Key questions for adult migratory fishes included: 1) What is the residence time of adult migratory fishes (White Sturgeon, Chinook Salmon) in Yolo Bypass? 2) Where do adult fish move to within the floodplain under different conditions? 3) Are there specific areas of the floodplain where there is evidence of increased mortality, stress or holding behavior? The Chinook Salmon results showed that the Yolo Bypass may serve as a sink for a large proportion (~25%) of the adults that enter the floodplain during their spawning migration. Fish migrating through Yolo Bypass showed multiple destinations (i.e. final detection locations) including: Yolo Bypass, the downstream estuary, Sacramento River, Mokelumne River, San Joaquin River, Stanislaus River, and American River. A somewhat unexpected result was that White Sturgeon were found to be present in the Yolo Bypass throughout much of the year. Previous trapping results had only suggested limited seasonal use of the floodplain. White Sturgeon also demonstrated the capability to exit the Yolo Bypass under dry conditions.

Juvenile Salmon Telemetry: The juvenile Chinook Salmon telemetry study was designed to address several important management questions: 1) What is the survival of juvenile salmon in the floodplain as compared to in the Sacramento River? 2) What is the residence time of juvenile salmon in the floodplain as compared to in the Sacramento River? 3) Are there specific areas of the floodplain where there is evidence of increased mortality? Telemetry studies for 2012 and 2013 showed that survival through Yolo Bypass was relatively high for outmigrating late-fall run Chinook Salmon smolts, especially considering the relatively dry conditions in these years. Standardized by river kilometer, estimated survival for 2012 was 0.997/km, or 0.97/10km. Estimated survival for 2013 was 0.994/km, or 0.947/10km. These results are based on releases in the Toe Drain from the I-5 Bridge to the Mouth of the Sacramento River. Overall, there did not seem to be any obvious areas of the Yolo Bypass that represent high mortality for juvenile Chinook Salmon, but in-depth survival modeling will examine this issue further.

Chinook Salmon Genetics: The genetics component of the Yolo Bypass study sought to answer two primary questions: 1) What runs of adult and juvenile salmonids use the Yolo Bypass floodplain? 2) Are there different runs of juvenile salmonids in the Yolo Bypass than the Sacramento River? We successfully genotyped juvenile fish and were able to confidently assign 91% of the samples to a single run. All four runs of juvenile Chinook Salmon were found in the Yolo Bypass and Sacramento River during the sampling period. All three adult runs except spring run were collected in Yolo Bypass. The genetics results also showed no significant difference in run

composition for fish collected in the Yolo Bypass versus the Sacramento River. Instead, Chinook Salmon run was best predicted by sampling date rather than sampling location. Note that this study occurred entirely in drought years, so it is unclear if the results apply in wetter years. Also, this study illustrates the relative inaccuracy of the length-at-date criteria to identify Chinook Salmon runs, and suggests that genetic methods are a more robust way to identify Central Valley runs in future sampling.

Salmon Stress Metrics: Because adult fish passage through Yolo Bypass is limited, there is a potential for fish to become stressed. The objective of the Chinook Salmon stress component was to develop genetic metrics that could be used to assess the status of fish migrating through Yolo Bypass. The primary study question was: Can we develop a panel of molecular markers to test for stress in Chinook Salmon in the Bay-Delta system? The study showed that twenty-eight of the thirty designed assays successfully amplified in the juvenile Chinook Salmon that we tested. The genes that amplified ranged in function from inflammation to changes in protein folding, to pathogen infection and hypoxia. Twenty-three of the twenty-eight working assays showed statistically significant expression levels between the thermal treatment groups. We believe this tool provides the groundwork for future studies to evaluate stress in Chinook Salmon.

Historical Analyses of Juvenile Salmon: Analyses of historical Yolo Bypass salmon data were conducted to answer the following questions: 1) What environmental factors affect residence time, growth, and survival in Yolo Bypass? 2) What is the general timing of emigration from the floodplain? 3) What environmental factors affect emigration from Yolo Bypass? 4) What size categories (runs) of salmon use the floodplain? The basic approach was to use a historical data set of Yolo Bypass juvenile salmon results to examine inter-and intra-annual migration patterns. The historical dataset included coded-wire tagged (CWT) hatchery fish released into both the Yolo Bypass Toe Drain and Sacramento River as well as wild fish captured in the Yolo Bypass rotary screw trap and beach seines. A key finding was that apparent growth (CWT fish only), residence time (CWT fish only) and annual CPUE (wild fish) were all positively correlated with duration of flooding. In contrast, apparent growth rates for both CWT and wild fish were not significantly related to other environmental variables. For wild fish, multiple regression analysis suggested that accumulated temperature units (ATU) and photoperiod were important factors affecting emigration.

Survival of CWT fish to the ocean fishery was not significantly different for fish released in the Yolo Bypass and Sacramento River. The relative survival of Yolo Bypass fish (i.e. Yolo Bypass:Sacramento River CWT release survival ratios) was not significantly explained by a suite of independent variables. However, the data set used was limited by the closure of the ocean fishery in 2008.

Analyses of intra-annual catch of juvenile Chinook Salmon showed that the hydrograph had a substantial effect on emigration patterns through the floodplain. During years with extended flooding, both wild and CWT juvenile salmon appeared to delay emigration until flooding subsided. When flooding was limited, emigration of CWT fish appeared to begin almost immediately after their release. Floodplain residence time of CWT fish was significantly longer for years with extended flooding as compared to lower flow years.

Development of an Isotopic Marker for Floodplain Rearing: Isotopic work was conducted to address several questions: 1) Is there evidence for lighter and distinct sulfur δ34S in the particulate organic matter from the Yolo Bypass? 2) Does the Yolo Bypass food web (invertebrate stomach contents) have a unique sulfur isotopic signature from the mainstem, hatcheries, and tributaries? 3) Does the sulfur isotopic signature of the floodplain get incorporated into salmon muscle tissue? Results from this pilot effort suggest that $\delta^{34}S$ is a promising marker to track the use of the Yolo Bypass floodplain by native fishes such as Chinook Salmon. We observed that juvenile salmon from the Yolo Bypass had isotopically light and distinct $\delta^{34}S$ in their prey content and muscle tissue, consistent with the trends in POM (algae) in the water column. These patterns were significantly different than samples collected in the mainstem Sacramento River. Further work is recommended to determine whether other seasonal habitats (e.g. Sutter Bypass) have similar $\delta^{34}S$ signatures, and to examine the extent to which other isotopic markers (e.g. Sr) may help to provide a better "fingerprint" for Yolo Bypass rearing.

Lower Trophic Level Responses to Floodplain Inundation: The lower trophic study component examined the following questions: 1) What are the general patterns in zooplankton, and drift invertebrate species in Yolo Bypass? 2) How are zooplankton and drift species affected by different environmental conditions? 3) Can specific thresholds be identified for flow, magnitude, and duration of inundation for enhanced lower trophic levels? These questions were addressed using two main approaches: 1) *Supplemental Food Web Sampling*; and 2) *Analyses of Historical Food Web Data*.

Supplemental Food Web Sampling was conducted during all years of the study, with emphasis on lower flow months (summer-fall) not sampled by DWR's long-term monitoring program. The results showed that chlorophyll *a* concentrations were significantly higher in the Yolo Bypass than in the Sacramento River. Sacramento River chlorophyll *a* levels were highest during periods of low flow, while the Yolo Bypass experienced the highest levels during increased flows in the late summer and fall. Summer and fall flow was a significant predictor for adult calanoid copepod abundance in the Yolo Bypass, in contrast to similar months in the Sacramento River when flow correlated well with zooplankton abundance. There were significant differences in the densities of cladocerans and calanoid copepod adults between the Yolo Bypass and Sacramento River. The zooplankton community in the Yolo Bypass was dominated by *Bosmina*, *Pseudodiamptomus forbesi*, and *Sinocalanous doerri*. In the Sacramento River, calanoid copepod adults were dominated by *Ilyocryptus*, *S.doerri*, and *Diaptomidae* spp.. In all years, there were increases in the densities of both cladocerans and calanoid copepods adults in the Yolo Bypass during October. The increased zooplankton densities were observed after increases in rice-field drainage flows and increased chlorophyll *a* concentrations.

Analyses of Historical Food Web Data. For the historical period analyzed, Yolo Bypass chlorophyll *a* concentrations increased through the spring, with the highest concentrations in April. The majority of the "spikes" occurred during the month of March. Stage was a significant predictor of chlorophyll *a* concentrations; chlorophyll *a* concentrations decreased with increasing stage, with the highest chlorophyll *a* concentrations observed for stage values between 6-7 feet (~2000-2500 cfs).

Bottom-up effects (i.e. a relationship between primary producers and primary consumers) were observed for a majority of the represented taxa for Yolo Bypass drift species and zooplankton. Specifically, the abundances of most drift invertebrates and zooplankton increased with chlorophyll *a* concentrations.

Assemblage data for Yolo Bypass drift species indicated that Homopterans were the dominant taxa during the study period, followed by Dipterans and Hemipterans. Assemblage data for zooplankton revealed that Cladocerans were the dominant taxa, followed by *Daphnia* and *Acanthocyclops.* Stage and temperature were the abiotic variables which best matched the pattern of relative abundance and assemblage composition for drift species and zooplankton; however, these patterns were only weakly correlated for drift invertebrates and zooplankton. While there were no clear statistical trends in total organism abundance for either drift species or zooplankton, annual abundances for drift invertebrates and zooplankton tended to be lowest in wet years. NMDS analyses also suggested that assemblage patterns in drier years were more similar than wetter years, although these patterns were less pronounced for the drift invertebrate data.

Management Significance

Despite the lack of high flow conditions during recent years, the study yielded results that are highly relevant to several different management programs such as the Ecosystem Restoration Program, the NMFS Salmon Biological Opinion, and the Bay-Delta Conservation Plan. An overall benefit of the current study is that it is a source of baseline data that could be used to evaluate future habitat restoration actions. Some other potential applications include:

Adult Fish Passage: The study provides strong support for the need for improved fish passage facilities in Yolo Bypass. For example, the telemetry results suggested that Yolo Bypass represents a substantial source of adult salmon mortality in the region. An unexpected result is that White Sturgeon was shown to reside in Yolo Bypass for 8 months of the year, a longer management period than previously understood.

Juvenile Salmon Rearing: The study revealed that all four races of juvenile salmon use Yolo Bypass. This suggests that management actions in Yolo Bypass could benefit not only Fall-Run, but also special status races such as Winter-Run and Spring-Run. Similarly, the telemetry results showed that survival of larger smolts was relatively high through Yolo Bypass, even during extreme drought periods. This indicates that the Yolo Bypass provides is viable and important habitat for larger juvenile salmon such as Winter-Run and Spring-Run. For smaller fish to such as Fall-Run, the analyses of historical data showed that extended Yolo Bypass inundation leads to longer residence times and larger size at emigration. These results support current management actions to extend the duration of floodplain inundation in Yolo Bypass.

Food Web Production: The study provides much more detailed insight into conditions that maximize phytoplankton and invertebrate production in Yolo Bypass. Moreover, some of the new results are relevant to summer and fall, when agricultural flow pulses were found to trigger higher levels of phytoplankton and zooplankton. These results indicate that management actions in Yolo Bypass that achieve net positive flow from the Toe Drain could not only benefit juvenile salmon, but also fishes such as Delta Smelt in downstream parts of the estuary.

New Scientific and Management Tools: Our study revealed that three new tools have the potential to substantially improve Central Valley salmon management. First, the new SNP genetic assays provide new insight into how all four races of Chinook Salmon use different habitats, and represents a much better tool than the standard Length-at-Date method. Second, a suite of genetic markers show promise as a new tool to evaluate salmon stress as a result of multiple factors (e.g. high temperatures, inflammation, pathogen infection, and hypoxia). Finally, this study provides evidence that sulfur isotopes may be used as a fingerprint to identify fish that use the floodplain as rearing habitat. Such a tool would be especially valuable to measure the contribution of floodplain fish to the rest of the estuary, and to the ocean fishery.

1. Introduction

Historically, the northern region of the Sacramento-San Joaquin River Delta (Delta) was a mosaic of floodplain, riverine, and tidal marsh habitats that supported exceptionally high biological productivity and influenced food webs of the entire estuary (Jassby and Cloern, 2000; Kimmerer 2004). In this way, North Delta is like floodplain-riverine systems worldwide that have a critical role in supporting food webs for entire aquatic ecosystems, but whose ecological functioning has been severely hampered by anthropogenic changes to the landscape (Thoms, 2003; Strayer and Findlay, 2010). Since the mid-1800s, the North Delta wetlands have suffered as a result of land reclamation for agriculture, levee construction, invasive species, flow regulation, and flood control (The Bay Institute 1998; CALFED 2001). Recognizing the importance of the North Delta, the Ecosystem Restoration Program (ERP) has committed significant resources to restoring key ecosystem landscapes and processes within the region (CALFED, 2001, 2004), particularly within the Yolo Bypass.

The Yolo Bypass is a 59,000-acre flood bypass structure that diverts floodwaters from the Sacramento River, Cache Creek and Putah Creek around the city of Sacramento and surrounding metropolitan areas (see Fig. 1 on Page 13). The Bypass, which occupies the extensive historic floodplain of the lowermost Sacramento River, is managed for a mix of uses, including farming, riparian and managed wetland habitat, tidal marsh habitat, upland and grassland habitat, and flood control (Sommer *et al.,* 2001a, b; 2005). Given substantial evidence over nearly fifteen years for its benefits to native fishes during flooded periods (e.g. Sommer *et al.,* 1997; 2001a,b; 2002, 2003, 2004, 2005, 2008; Schemel *et al.,* 2004; Lehman *et al.,* 2008; Feyrer *et al.,* 2006a,b), the Bypass has become the focus of interest in managing seasonally flooded habitat in the Delta. Hence, floodplain restoration has become a key part of the ERP Strategic Goals and Objectives based on the importance of Yolo Bypass to special status fishes such as Chinook Salmon (*Oncorhynchus tshawytscha*), Splittail (*Pogonichtys macrolepidotus*) and Green Sturgeon (*Acipenser medirostris*) (ERP Goal 1, Objective 1), key ecological processes (ERP Goal 2, Objective 6), and floodplain habitat (ERP Goal 4, Objective 5). Furthermore, the Yolo Bypass has been identified as a high restoration priority by the National Marine Fisheries Service (Biological Opinion on the Long-Term Central Valley Project and State Water Project Operation, Criteria, and Plan, 2009), the National Academy of Sciences independent review committee (2008), and by the Bay Delta Conservation Plan (BDCP 2010). The restoration projects currently being considered are to: 1) improve passage for upstream-migrating fish such as salmon and sturgeon; 2) provide rearing habitat for native fishes; and 3) improve food web production in the North Delta. Yet, there are substantial data gaps necessary to fill in order to design and operate restoration plans, and develop performance criteria for evaluation of restoration actions. The study effort described in this report was designed to address several of these data gaps for each of the above restoration actions. In addition, the study synthesizes over a decade of previously-collected data on Yolo Bypass Chinook Salmon and food web productivity to enhance our understanding of how the floodplain functions.

Adult Fish Migration: Adult fishes such as Chinook Salmon, Sturgeon, and Splittail seasonally enter Yolo Bypass at its base, located north of Rio Vista (Harrell and Sommer 2003). While Splittail will spawn on the floodplain, the consensus is that the area acts like a giant “fish trap” for salmon and sturgeon en route to spawning areas in on the upper Sacramento River because they are drawn

into the floodplain's perennial channels following late fall or early winter flows with no exit from the Bypass at its upstream extent (Sommer *et al*. 2014). Even modest flows (e.g. 1000 cfs) appear sufficient to draw fish into the floodplain. The Fremont Weir is located at the northern tip of the Bypass (Fig. 1), and is only connected to the Sacramento River during brief windows of high flows. Hence, the Yolo Bypass represents one of the most serious passage barriers to migratory fishes in the lower valley (NMFS 2009). However, beyond a general description of the timing and occurrence of large numbers of migrating Chinook Salmon, Sturgeon, Splittail, Striped Bass (Sommer et al. 2014; BDCP 2010), remarkably little is known about what happens to these fishes once they enter Yolo Bypass. It is therefore to be expected that there have not yet been detailed engineering solutions to fish passage issues in Yolo Bypass. Some of the obvious questions that need to be answered to identify specific challenges to fish passage in the Bypass and eventually design appropriate fish passage facilities include the following:

- What is the residence time of adult migratory fishes (White Sturgeon, Chinook Salmon) in Yolo Bypass?
- Where do adult fish move to within the floodplain under different conditions?
- Are there specific areas of the floodplain where there is evidence of increased mortality, stress or holding behavior?

Note that these were all questions that were developed in consultation with resource agencies such as DFW and NMFS that are concerned about addressing adult upstream passage. While the region is known to be a fish passage problem, effective solutions require a more detailed understanding than just simply recognizing that adults are present in the system.

Juvenile Salmonid Rearing: Relative to adult migration, we know much more about juvenile Chinook salmon rearing in Yolo Bypass. Downstream-migrating juvenile salmon enter the Yolo Bypass from the Sacramento River and its tributaries during high flow events in winter and early spring (via flood flows over Fremont Weir). Once inside the Bypass, floodplain rearing results in enhanced growth as compared to juveniles residing in the adjacent Sacramento River (Sommer *et al.*, 2001a,b; Henery *et al.*, 2010), with potential survival benefits (Sommer *et al.*, 2001a). The floodplain feeding ecology of young Chinook Salmon has also been documented (Sommer *et al.*, 2001b), and basic attributes of habitat area and residence time have been described (Sommer *et al.*, 2004a, 2005). Nonetheless, we still have key uncertainties about salmon use of Yolo Bypass that need to be addressed for effective floodplain restoration:

- What environmental factors affect residence time, growth, and survival in Yolo Bypass?
- What is the general timing of emigration from the floodplain?
- What environmental factors affect emigration from Yolo Bypass?
- Which runs of Chinook Salmon (fall, late-fall, spring, winter runs) use the floodplain?
- Are there specific areas of the floodplain where there is evidence of increased mortality?
- What portion of the salmon population currently rear in Yolo Bypass?

Food Web Dynamics: The improved growth rates and survival among salmon rearing in the Bypass appear to be linked to improved feeding success on the floodplain (Sommer *et al.*, 2001a,b; Henery *et al.*, 2010). In general, the food web of the floodplain appears to be much more productive that the adjacent Sacramento River based on high levels of phytoplankton and invertebrate drift

(Sommer *et al.,* 2001b, Schemel *et al.,* 2004; Sommer *et al.,* 2004b; Lehman *et al.,* 2008). Moreover, zooplankton growth appears to be relatively high (Mueller-Solger *et al.,* 2002). Among drift invertebrates, a floodplain chironomid comprises the majority of Yolo Bypass salmon diets (Sommer *et al.,* 2001b; Benigno and Sommer 2009). The degree to which the floodplain environment benefits these key food resources for salmon is at least partially linked with the quantity of flow and hydrologic residence times in the Bypass (Sommer *et al.,* 2004b), but specific thresholds (e.g., flow and inundation criteria) for enhanced lower trophic productivity have not yet been identified. While the extent to which productivity in the Bypass influences downstream areas (e.g., beyond the north Delta) is still not well understood (Sommer *et al.,* 2001a), modeling work by Jassby and Cloern (2000) suggests that floodplain inundation represents one of the most effective approaches to improving primary productivity in the estuary. As a consequence, there is interest in enhancing the productivity of the North Delta by improving connectivity between Yolo Bypass and Sacramento River (BDCP 2010). Major information gaps for the design of these types of restoration projects include:

- What are the general communities of zooplankton, and drift invertebrate species in Yolo Bypass?
- How are zooplankton and drift species influenced by different environmental conditions?
- Are there specific thresholds for the magnitude and duration of inundation for enhanced lower trophic productivity?

This report describes the results of a two year ERP-funded study to address all of the questions listed above to develop baseline monitoring information and guidance for Yolo Bypass restoration projects to be considered by the ERP, BDCP, and the OCAP for federal and state water projects identified in the final NMFS Biological Opinion (NMFS, 2009). The project builds upon the past investment of the ERP in the Yolo Bypass and current and evolving institutional relationships between the University of California, Davis, California Departments of Water Resources (CDWR) and U.S. Bureau of Reclamation (USBR). The effort included a multi-institution effort that used a combination of historical data analyses, new field work, and laboratory studies to address the major issues.

2. Background and Conceptual Models

Physical Setting: The 59,000 acre Yolo Bypass (see Fig. 1 below) is the primary floodplain of the Delta (Sommer *et al.,* 2001a, b), and presently floods in approximately 70 percent of years. The floodplain typically has a peak inundation period during high flows in January-March, but floods as early as October and as late as June. The primary input to the Yolo Bypass is through Fremont Weir in the north, which conveys floodwaters from the Sacramento and Feather rivers. During major storm events (i.e. > 175,000 cfs), additional water enters from the east via Sacramento Weir, adding flow from the American and Sacramento rivers. Flow also enters the Yolo Bypass from several small tributaries on its western margin including Knights Landing Ridge Cut, Cache Creek, Willow Slough Bypass and Putah Creek. During much of the winter, water suspended sediment levels in Yolo Bypass and Sacramento River result in highly turbid conditions (e.g. Secchi depths <0.25m). However, hydraulic residence times are typically longer in Yolo Bypass than Sacramento River, likely contributing to enhanced productivity levels (Sommer *et al.,* 2004b). Floodwaters recede from the northern and western portions of the

Bypass along relatively even 0.09% west-east and 0.01% north-south elevation gradients into a perennial channel ("Toe Drain", eastern boundary of lower Bypass on Fig. 1 below) on the eastern edge of the Bypass, then rejoin the Sacramento River near Rio Vista. The majority of the Yolo Bypass is presently managed for wildlife in a mosaic of riparian, wetland, upland and perennial pond habitats. Agriculture was a dominant land use during the past two decades, but has decreased in recent years because of habitat restoration activities.

Conceptual Models: The primary conceptual model for this project is the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) floodplain conceptual model (Opperman 2008). The model is especially relevant because it was designed specifically to inform ecosystem restoration and public policy decisions within the Delta (e.g. ERP, BDCP and Delta Vision). Moreover, the model is based on data collected within the region, specifically Yolo Bypass. Key components of the DRERIP floodplain model include a food web model ("Model 3A"), which forms the basis for Task 9 in our study, and a species model for juvenile Chinook Salmon ("Model 3C"), the basis for Tasks 4-8 (see next section below). Note that the DRERIP conceptual models explicitly acknowledge that there are substantial uncertainties about many of the linkages. The majority of these are issues of scale and boundary, explicitly identified in the "Model 1" component of the DRERIP floodplain model. For example, the basic conceptual model for salmon ("Model 3C") represents a fairly generalized description of the importance of floodplain to salmon, so our study has been designed to address the need for more detailed information on seasonal, genetic and spatial patterns. Hence, our study questions lay out some of the major unresolved issues for floodplain food web and juvenile Chinook Salmon.

One factor not specifically addressed in the DRERIP floodplain conceptual model (Opperman 2008) is the issue of upstream fish passage. For the purposes of this study, our basic conceptual model is that increases in flow through Yolo Bypass trigger upstream migration of a suite of native fishes (White Sturgeon, Splittail, Sacramento Pikeminnow) into the floodplain (Harrell and Sommer 2003; Sommer *et al*. 2014). These flows can be from either the Sacramento River or the smaller tributaries of Yolo Bypass (Fig. 1). All of these fishes are thought to migrate upstream into the base of Yolo Bypass via the Cache Slough Complex, located near Rio Vista (Fig. 1). Floodplain inundation is not required to draw fish into the Yolo Bypass, due to a perennial channel along the eastern edge of the floodplain. The conceptual model is slightly different for Chinook Salmon, which do not appear to migrate in response to flow pulses (Harrell and Sommer 2003; Sommer et al. 2014). Instead, their upstream migration appears to be seasonally mediated. However, for all species we propose that an unusually large percentage of fishes are drawn into the Cache Slough Complex and Yolo Bypass because of strong tidal currents in the Rio Vista area: recent studies by US Geological Survey (Jon Burau, unpublished data) demonstrate that at the junction between Cache Slough and Sacramento River, approximately *80 percent* of the tidal flow moves through Cache Slough Complex rather than the adjacent Sacramento River channel. As a consequence, we suggest that there may be a strong tidal bias that leads migrating fish towards Yolo Bypass.

For all of the migratory fishes, the major concern in our conceptual model is that passage is impeded under most conditions. The four scenarios in our upstream migration model, along with their repercussions for passage, include the following:

1) No flow over Fremont Weir into Yolo Bypass

a. Minor barriers (e.g. road crossings) in the perennial channel of Yolo Bypass ("Toe Drain") may require increased flows to be passable.
b. Multiple minor tributaries such as Knight's Landing Ridge Cut cause fish to stray from the direct upstream route to Fremont Weir (the upper portion).
c. Fremont Weir is impassable, so there is no upstream exit for any of the fish.
d. Many fishes become trapped in dead-end channels, or must reverse their migration route and face major delays.
e. This scenario often occurs in fall, when water temperatures are relatively high, resulting in thermal stress.

2) Modest inundation of Yolo Bypass via Fremont Weir (e.g. <50,000 cfs in Yolo Bypass)
   a. Small barriers become passable.
   b. Minor tributaries may still cause substantial straying, resulting in entrapment in some locations.
   c. No passage out of Yolo Bypass except perhaps salmonids, which may be able to jump over the head of Fremont Weir.
3) Moderate inundation of Yolo Bypass via Fremont Weir (e.g. 50,000-100,000 cfs)
   a. No passage out of Yolo Bypass except salmonids, which should be able to jump over the head of Fremont Weir.
4) Heavy inundation of Yolo Bypass via Fremont Weir (e.g. 100,000-500,000 cfs)
   a. If they can swim against the fast currents, many of the migratory fishes may be able to pass Fremont Weir at these extreme flows.

The bottom line for the upstream migration conceptual model is that the floodplain is largely impassible most of the time: the typical condition of Yolo Bypass is scenario #1. Even in years where the Bypass floods, flow over the Fremont Weir is often only transient, occurring for only days at a time; thus, scenarios #2 – 4 that allow for some passage represent less than ten percent of the time during migration windows. We hypothesize that the unique hydrodynamics of the floodplain create a giant "fish trap," perhaps the most serious upstream fish passage problem in the lower Sacramento Valley. However, we acknowledge that there are substantial uncertainties about what happens to fish during upstream migration. Our telemetry element is therefore designed to develop detailed information (e.g. spatial and temporal patterns) to test many aspects of the conceptual model.

3. Overview of Scope of Work

The basic approach included five basic tasks using a multi-agency, interdisciplinary effort: 1) adult salmon and sturgeon and juvenile salmon telemetry; 2) salmon genetics and exposure to thermal stress; 3) analyses of historical salmon data; 4) salmon otolith studies; and 5) analysis of historical food web data. The new work was conducted in tandem with the long-term monitoring effort in Yolo Bypass, which currently provides data on fish (rotary screw trap, fyke trap, beach seining, larval sampling), food web (chlorophyll a, zooplankton, drift) and a suite of environmental variables (e.g. water temperature, electrical conductivity, Secchi depth). This long-term monitoring CDWR effort was funded separately from the ERP proposal through the IEP.

The scope of work for the current effort includes eleven major tasks:

Task 1 Project Management and Administration

Task 2 Public Participation
Task 3 Environmental Compliance and Permitting
Task 4 Telemetry
Task 5 Chinook Salmon Run Identification
Task 6 Thermal Stress Investigation
Task 7 Historical Salmon Data Analyses
Task 8 Sulfur Isotope Studies
Task 9 Food Web Studies
Task 10 Draft and Final Project Report
Task 11 Project Close-Out

This draft report focuses on the technical aspect of the study, Tasks 4-9. Our efforts towards Tasks 1-3 have previously been documented as part of quarterly reports to CDFW. The current report represents progress towards Task 10, and Task 11 will be completed at the end of the study.

4. Description of Tasks and Results

Task 4. Telemetry

Task 4.1 Adult Telemetry Study
Project Lead: Myfanwy Johnson, Peter Klimley, UC Davis
Field Assistance: CDWR field staff

Study Questions

- What is the residence time of adult migratory fishes (White sturgeon, Chinook Salmon) in Yolo Bypass?
- Where do adult fish move to within the floodplain under different conditions?
- Are there specific areas of the floodplain where there is evidence of increased mortality or holding behavior?
- Do migratory fish move into areas of maximum flow and use this as a cue to migrate upriver?

Approach

The study approach for this task is described in detail in **Appendix A**. Briefly, coded ultrasonic beacons were surgically implanted in adult Chinook Salmon and White Sturgeon captured in the fyke net operated by CDWR biologists as part of the ongoing monitoring program for the Yolo Bypass (Fig. 1). Additional gill netting was conducted to supplement fyke net catch. Migratory path, residence time, and habitat selection were recorded for each species with an array of tag-detecting monitors deployed throughout the floodplain. Monitors (VR-2W, 69 kHz, Vemco Ltd.) capable of detecting adult beacons (V13 or V16, 5 – 10 year lifespan), were strategically placed at entry and exit points from the Bypass to determine residence time and in a single cross-floodplain array to determine the east-west range of movement under flood conditions. Note, however, that the study period was relatively dry, so no flooding occurred.

Results

The results are described in detail in **Appendix A**. To summarize briefly, the results suggest that Yolo Bypass is a migration "sink" for a large proportion (~25%) of the adult Chinook Salmon that enter the Bypass during their spawning migration. A somewhat surprising result was that White Sturgeon were present in the Yolo Bypass throughout much of the year, and demonstrated the capability to exit the Bypass successfully under dry conditions.

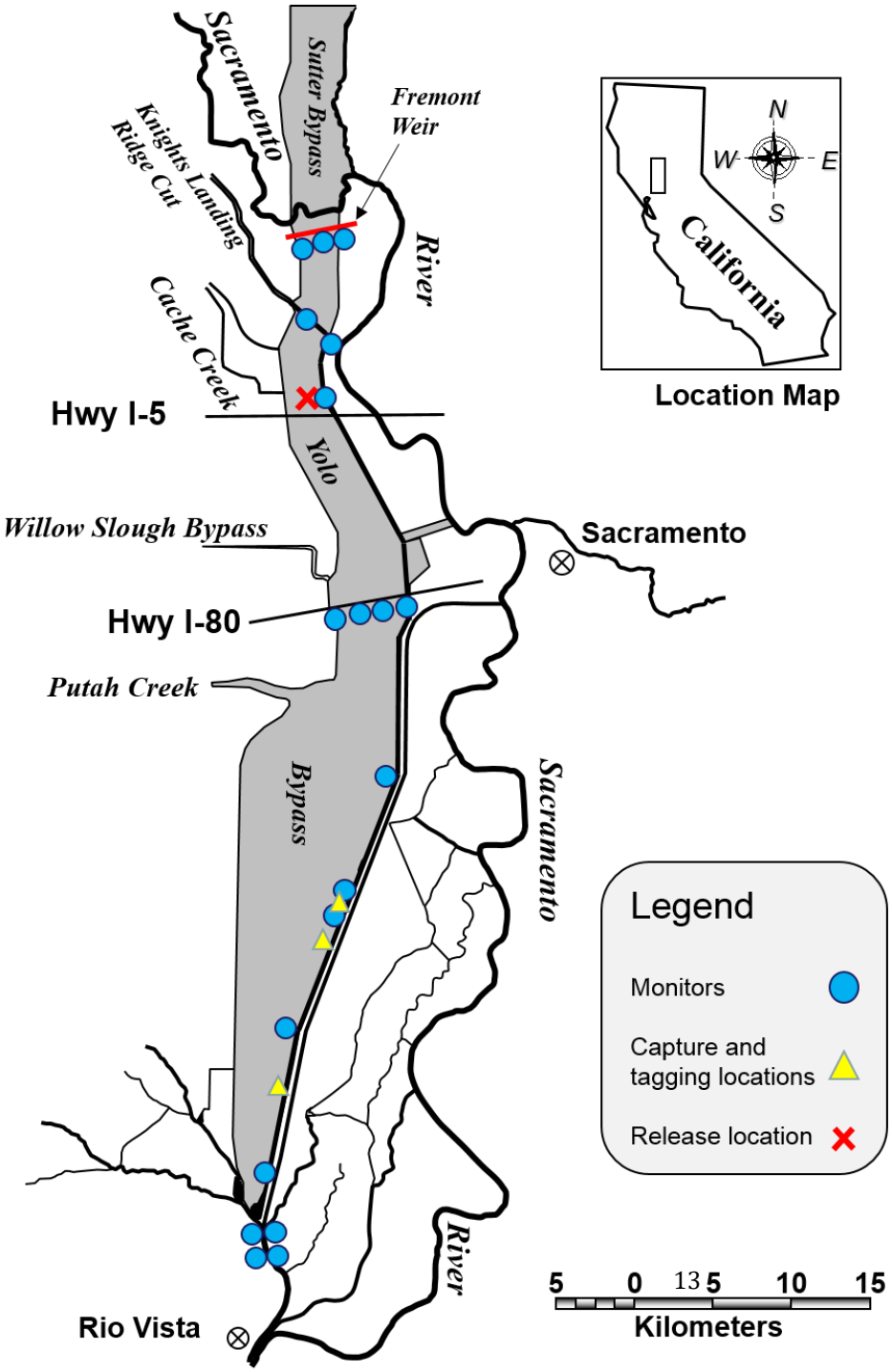


Figure 1.

Figure 1 depicts locations for both our core and flood receiver arrays. The core array includes all those except the monitors placed east-to-west across Hwy I-80 and the Fremont Weir, and is deployed year-round in the Yolo Bypass. The flood array includes the receivers placed east-to-west across I-80 Bridge and the Fremont Weir. We have not yet had to deploy a full flood array. The Toe Drain is a perennial channel along the eastern edge of the Yolo Bypass below I-80.

Task 4.2. Juvenile Telemetry Study
Project Lead: Myfanwy Johnson, Peter Klimley, UC Davis
Field Assistance: CDWR field staff

Study Questions

- What is the survival of juvenile salmon in the floodplain as compared to in the Sacramento River?
- What is the residence time of juvenile salmon in the floodplain as compared to in the Sacramento River?
- Are there specific areas of the floodplain where there is evidence of increased mortality?

Approach

The study approach for this task is described in detail in **Appendix A**. In short, ultrasonic telemetry was used to determine residence time and survival of late-fall run hatchery juvenile Chinook Salmon as they migrated through the Bypass, and to track their specific migration route through floodplain. This technology has proven to be an effective approach to examine juvenile salmon movements through the estuary (Perry *et al.*, 2010).

Results

The major results are summarized in detail in **Appendix A**. Briefly, telemetry studies for 2012 and 2013 showed that survival through Yolo Bypass was relatively high for outmigrating late-fall run Chinook Salmon smolts, especially considering the relatively dry conditions in these years. Standardized by river kilometer, estimated survival for 2012 was 0.997/km, or 0.97/10km. Estimated survival for 2013 was 0.994/km, or 0.947/10km. This conclusion is based on releases in the Toe Drain from the I-5 Bridge to the Mouth of the Sacramento River. Overall, there did not seem to be any obvious areas of the Yolo Bypass with especially high mortality for juvenile Chinook Salmon, but in-depth survival modeling will examine this further.

Task 5: Chinook Salmon Run Identification

Project Leads: Mariah Meek, Bernie May, UC Davis
Field Assistance: CDWR field staff

Study Questions

- What runs of adult and juvenile salmonids use the Yolo Bypass floodplain?
- Are different runs of juvenile salmonids found in the Yolo Bypass as compared to those migrating through the Sacramento River?

Approach

To date, no study has looked at the proportional use of the Yolo Bypass by the different runs (spring, winter, and fall) of Chinook Salmon. Proper identification of salmonids using the Yolo Bypass is necessary to achieve the first ERP goal statement of “recovery of at-risk native species

dependent on the Delta." Genetic tools are invaluable to confidently determine run type of Chinook Salmon, as size-at-time of capture is an unreliable predictor of run in the Sacramento/San Joaquin system (NMFS 2009, Harvey et al. 2014). In this task, we non-lethally collected fin tissue samples from juveniles and adults sampled during this study in order to evaluate the use of the Yolo Bypass by the different runs of Chinook Salmon.

Juvenile sampling—Fin tissue samples from juvenile Chinook Salmon were collected through ongoing sampling efforts in the Yolo Bypass conducted by CDWR (8 beach seine locations throughout the Bypass and the rotary screw trap, Fig. 1). Juvenile salmon were also collected in the mainstem Sacramento River through US Fish & Wildlife Service's ongoing sampling at the Clarksburg beach seine, Garcia Bend beach seine, and the Sacramento trawl sites downstream of the last mainstem river entrance into the Yolo Bypass (the Sacramento Weir). This allowed a comparison of the juveniles using in-river habitat with those present in the Yolo Bypass.

Adult sampling-- Adult fin tissue samples were collected from adults captured in the CDWR fyke net sampling as well as directed gill-netting efforts for Task 4.1 (Fig 1). This information is valuable for interpreting the results of the telemetry studies, as it is necessary to understand the run each individual belongs to properly interpret research findings. Collectively, these analyses are very beneficial for understanding Chinook Salmon use of the Yolo Bypass.

Sampling effort-- We temporally paired sampling in the mainstem sites with the Yolo Bypass sampling, to the best of our ability. This allowed us to compare the diversity of salmonids found in the mainstem Sacramento River with those found in the Yolo Bypass. In both the Yolo Bypass and the Sacramento River sites, our sampling protocol was to take tissue samples and length data from 10 randomly sampled fish in each of the run classes from each site (so up to 40 samples at each site per sampling trip) every 2 weeks from Dec-May 2012-2014, with the exception of sampling weekly during the first flush (i.e. when the river reached at least 400 cms, for ~3 consecutive weeks).

Sample processing--All samples were placed in 95% ethanol and transported back to the California Dept. of Fish and Wildlife Tissue Archive where they were logged and processed before being sent to the University of California-Davis Genomic Variation Lab (GVL) for genotyping. We determined the run type of all samples collected using a newly developed panel of 81 single nucleotide polymorphism (SNPs). These markers have been shown to be very successful at identifying Central Valley Chinook to their run of origin and the UC Davis Genomic Variation Lab has a newly developed and high quality baseline to test unknown individuals for run assignment using this panel (Meek, unpublished data).

Statistical analysis—We used the program ONCOR (S. Kalinowski, www.montana.edu/kalinowski/Software/ONCOR.htm) to assign unknown individuals caught in this study to run type. We assigned run if the assignment probability was greater than 0.80 to one particular run. Individuals whose assignment probabilities were split between two runs were marked as such. To test if the run composition was different between the Yolo Bypass and Sacramento River sites, we constructed five multinomial models using different explanatory variables in each model. The models tested if run composition was primarily determined by: 1) Location (Sacramento River or Yolo Bypass); 2) Date (a combined variable of month and year); 3) Both location and date; or 4) An interaction between location and date. All models were compared to each other and a neutral

model and the best model was determined via Akaike Information Criterion (AIC) scores (choosing the model with the lowest AIC score). Additionally, we compared the genetic run determination to the run designation using the length-at-date criteria, which is commonly used to determine run type in the field (Harvey *et al.* 2014).

Results

We successfully genotyped juvenile fish using the 81 SNP panel and were able to confidently assign 91% of the samples to a single run. All four runs were found in the Yolo Bypass and Sacramento River during the sampling period (Fig. 2). All adult runs except spring run were collected (Fig. 3), which is not surprising since the adult collections were focused on fall months to minimize potential collections of listed fishes. For months when there were parallel salmon collections in Yolo Bypass and Sacramento River sites, we found no significant difference in run composition (Fig. 4). The model incorporating just sampling date had the highest AIC score of all the models tested, including the neutral model (Table 1).

The comparison between genetic run determination and length-at-date determination shows the length-at-date criterion (Harvey *et al.* 2011; 2014) misidentifies a large proportion of the fish in the field (Fig. 5). In the Yolo Bypass, only 11.5% of the juvenile fish identified as being spring run are genetically spring run; this is true of 31% of those identified as spring run in the Sacramento River. In both locations, over 65% of the genetically spring run individuals were classified as Fall run using the length-at-date criteria. There were 16 Late-fall run found in the Yolo Bypass, but none of them were identified as such. They were classified as either Fall or Spring run using the length-at-date criteria.

Conclusions

We found no difference in the run composition of fish collected from the Sacramento River versus the Yolo Bypass. Our study occurred exclusively in drought years when there was very little flooding of the Yolo Bypass, so it is unclear whether the results would apply to flood years when there is more seasonal salmon habitat available. Nonetheless, this study provides useful insight into run composition. Continuation this study to sample in future flood years is highly recommended so that we may further examine floodplain habitat use of juvenile Chinook Salmon and compare differences between wet and dry years. This study also illustrates the relative inaccuracy of the length-at-date criteria. The Yolo Bypass sampling program uses the Delta model of the length-at-date criteria, while the Sacramento R. uses the River Model (see Harvey *et. al* 2014 for descriptions of the two models), yet both models did a poor job of properly identifying fish. Our results show that genetic identification of unknown Chinook Salmon using this 81 SNP panel is a more robust way to identify Chinook from the Central Valley and should be incorporated into future sampling programs.

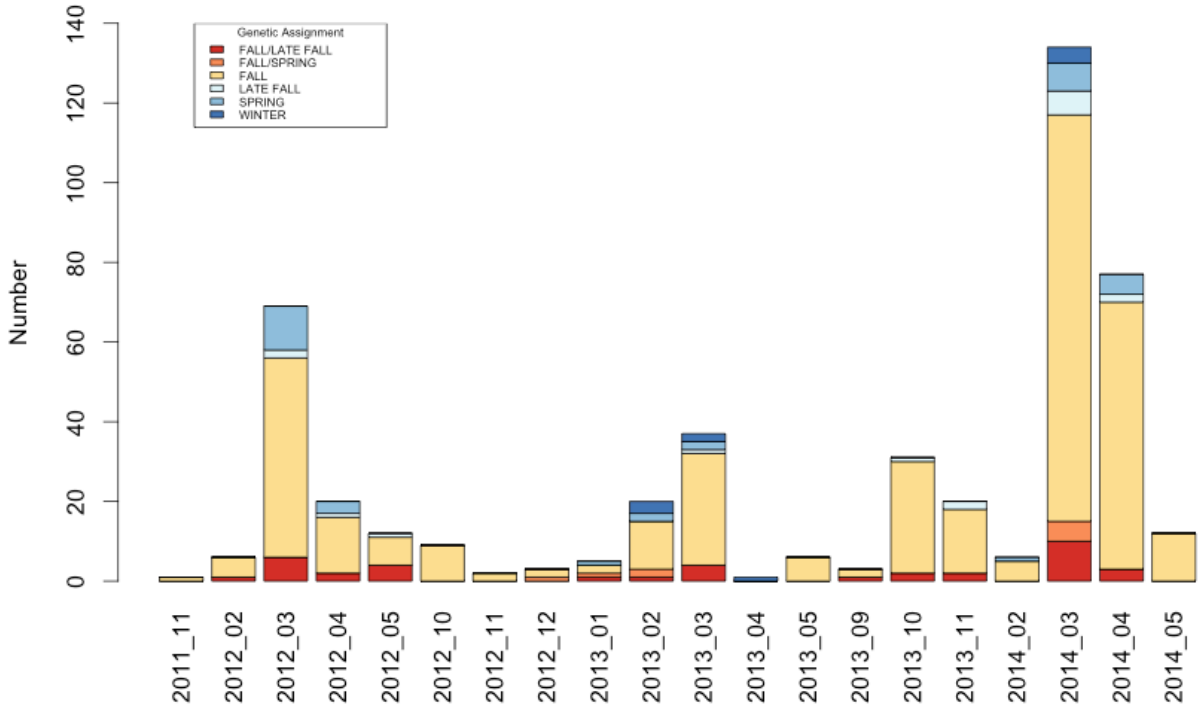


Figure 2: Run composition of all juvenile Chinook Salmon caught in the Yolo Bypass over the study period. The x-axis is the date, with year denoted first, followed by the month. The y-axis is number of fish sampled in that month. The color corresponds to the genetic run assignment. Individuals denoted as "FALL/LATE FALL" OR "FALL/SPRING" could not be distinguished between the two runs. All others had greater than 80% probability of being the assigned a particular run.

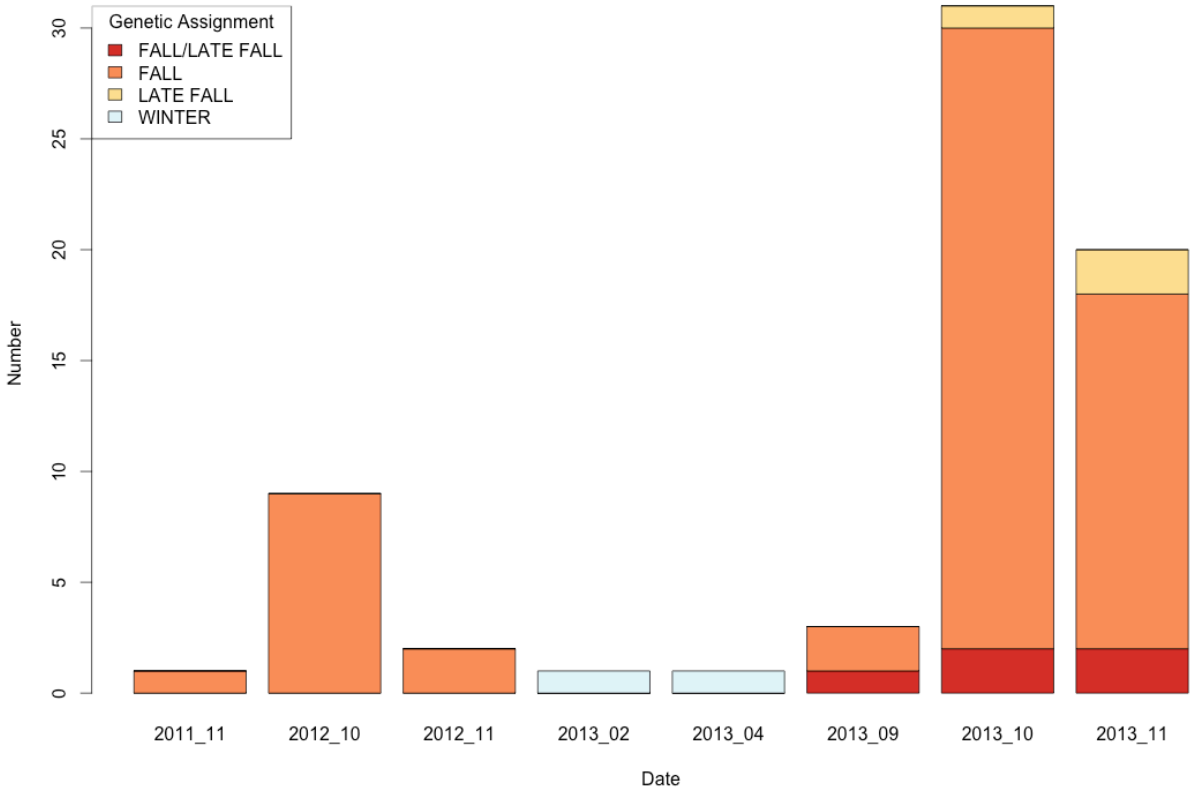


Figure 3: Run assignment of adult samples caught in the Yolo Bypass.

Model	Model Rank	AIC score
Null	4	33.1
Location (Sac. vs Yolo)	3	27.7
Time	1	0
Location + Time	2	6.3
Location x Time (interaction)	5	35.3

Table 1: Model testing to evaluate what determines run composition in the Yolo Bypass and Sacramento River. The model that includes the effect of time has the lowest AIC score, making it the best model for explaining run composition. Location (Yolo Bypass vs. Sacramento River) did not have a significant effect on run composition in this study.

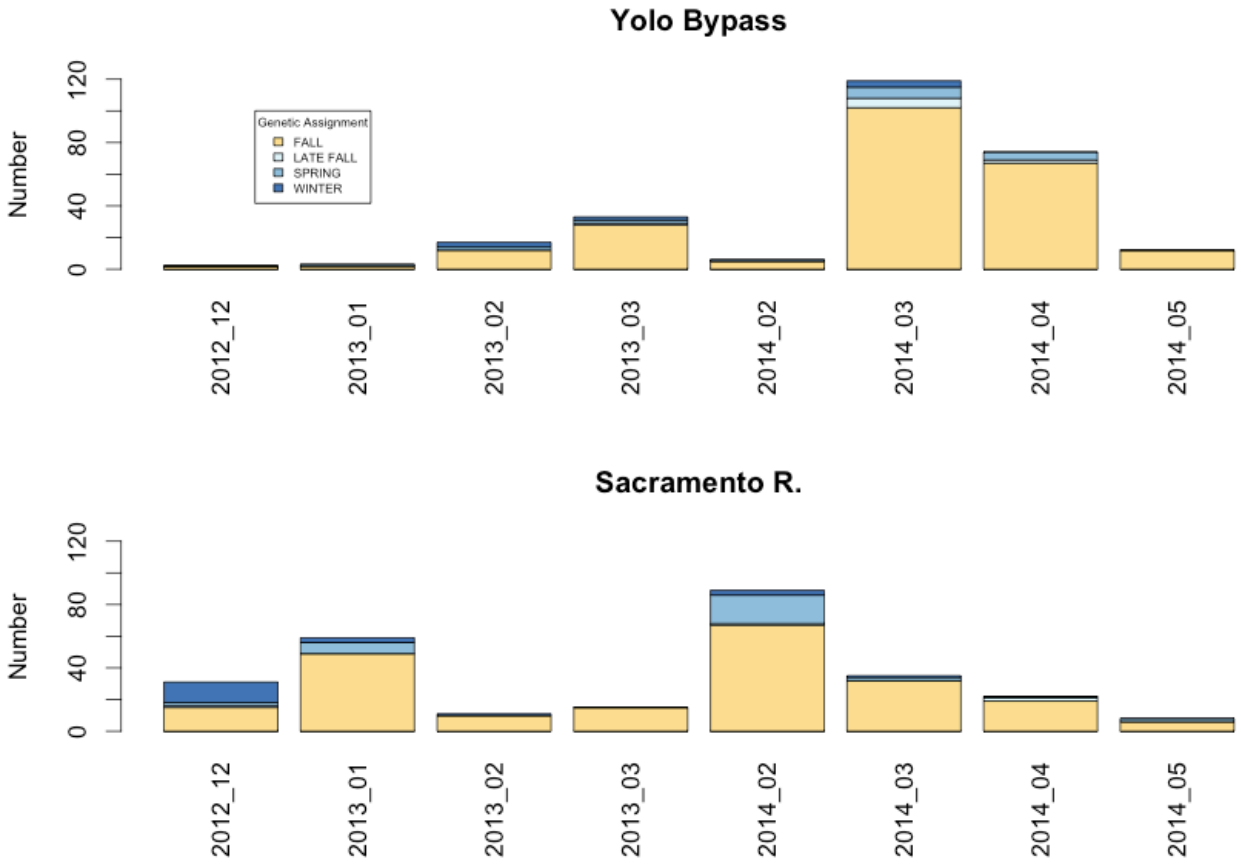


Figure 4: Run composition in months where samples were taken from both the Sacramento River and Yolo Bypass. The x-axis is the sample date, with year denoted first followed by the month. The y-axis is number of fish sampled in that month. The color corresponds to the genetic run assignment. There was no significant difference in run composition between the Yolo Bypass and Sacramento River sites. The biggest determinant of run composition was time.

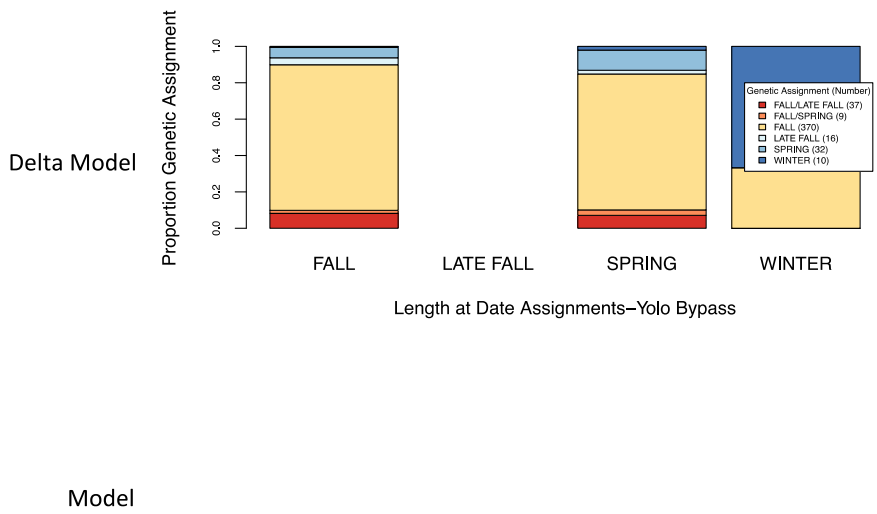


Figure 5: Comparison of genetic run assignment and length-at-date run assignment. The top panel is for samples collected in the Yolo Bypass, using the Delta length-at-date model (Harvey *et al.* 2014). The bottom panel is for the Sacramento River sites, using the River length-at-date model. The x-axis shows the length-at-date run designation, the y-axis show the proportion of those that were identified as the various runs using the genetic data. Color corresponds with the genetic run determination.

Task 6: Chinook Salmon Thermal Stress

Project Leads: Mariah Meek, Bernie May, UC Davis
Field Assistance: CDWR field staff

Study Questions

- Can we develop a panel of molecular markers to test for stress in Chinook Salmon in the Bay-Delta system?

Approach

Thermal stress is known to be detrimental to all life history stages of salmonids (Sullivan *et al.*, 2000, Brett 1995). Adult Chinook found in the Yolo Bypass experience temperature stress as water temperatures in the Bypass can rise above 20˚ Celsius during early periods when adult fall-run Chinook enter the Bypass. For example, temperature data loggers in the Sacramento mainstem and Yolo Bypass show that temperatures in the Yolo Bypass in September are generally higher than in the mainstem Sacramento River. In 2008 the maximum daily temperature was higher in the Yolo Bypass 28 out of 30 days in September, the daily maximum being on average 1.56˚ Celsius higher. In 2009 the temperature differences were stronger, with maximum daily temperatures being higher

in the Bypass for all days in September, the daily maximum being on average 2.2˚ Celsius higher (K. Reece, CDWR, unpublished data). At the mainstem site, there were 4 days in October 2008 and 0 in October 2009 that reached above 20˚ Celsius in the mainstem, while there were 8 and 3 days, respectively, in the Yolo Bypass that reached above 20˚ Celsius. Due to these differences, we hypothesize that salmon found in the Yolo Bypass in September and October will show significantly higher signs of thermal stress compared to those found in the mainstem Sacramento River. Moreover, this thermal stress is exacerbated because of inadequate adult fish passage through the floodplain (see Conceptual Model).

To begin to address this issue, we developed a panel of molecular markers that can be used to quantify stress levels in Chinook Salmon. This panel includes not only markers that indicate thermal stress, but also other stressors such as inflammation, immune response to pathogens, hypoxia, and impending death.

Methods

Marker design--The GVL recently conducted a laboratory study investigating gene expression profiles for Chinook Salmon under different thermal regimes using juvenile fall run Chinook from the Central Valley. We capitalized on this study to investigate the genes found to "up" or "down" regulate in response to thermal stress, with the goal of developing high throughput assays for future use. We identified 12 genes that were good candidates for developing into gene expression assays via the Fluidigm DELTAGene assay system. We then identified salmonid gene sequences for 18 additional genes that are known to be up or down regulated in response to stress. These gene sequences were identified from the National Center for Biotechnology Information (NCBI) genetic sequence repository. We then developed a total of 30 Fluidigm DELTAgene Assays to use in detecting stress response in Chinook Salmon in the Central Valley. We tested these assays on individuals used in the thermal study that were known to have experienced no or high thermal stress (exposed to 12 C or 25 C). We tested 16 individuals from the 12 C treatment and 18 from the 25 C treatment. We extracted RNA from these samples and quantified their expression levels with the new assays on the Fludigm Biomark HD system.

Statistical analysis—In order to validate that the newly designed panel detects thermal stress, we tested for differences in expression level between the two thermal treatment groups using treatment as a predictor variable and expression level as the dependent variable in a liner model. We used a Bonferroni corrected p-value to adjust for multiple tests ($p<0.0127$).

Results

Twenty-eight of the thirty designed assays successfully amplified in the tested juvenile Chinook Salmon. The genes that amplified ranged in function from inflammation to changes in protein folding, to pathogen infection and hypoxia (Figure 6). Twenty-three of the twenty-eight working assays showed statistically significant expression levels between the thermal treatment groups.

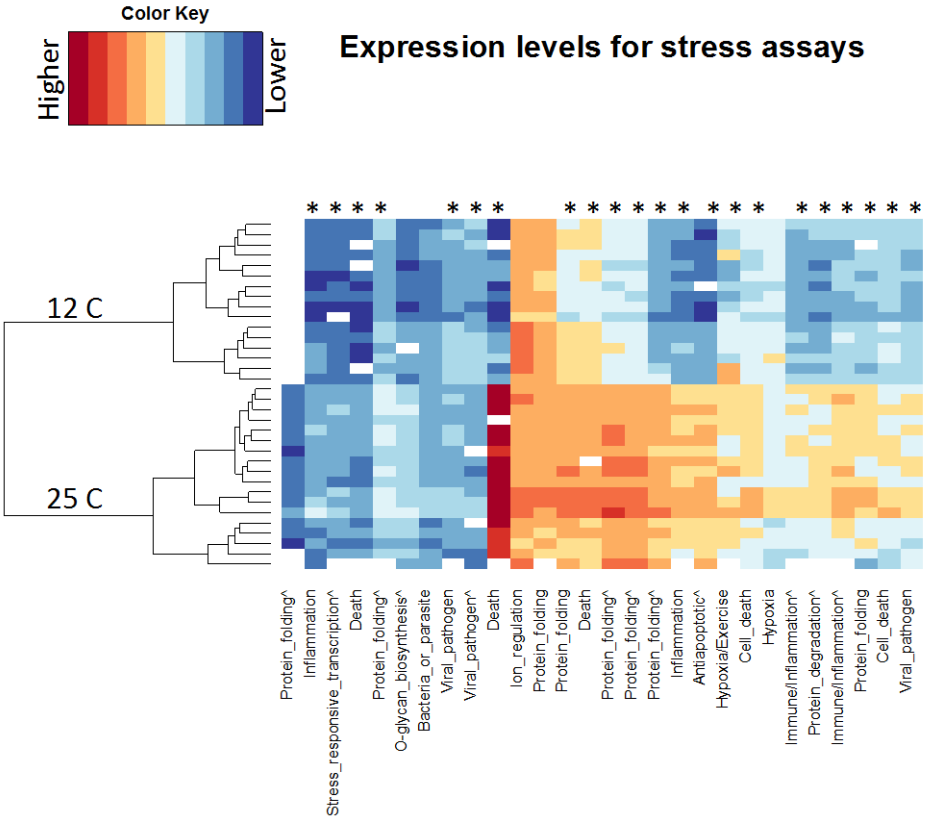


Figure 6: Expression levels at 28 genes related to stress in Chinook Salmon. Each row shows the expression level for an individual; individuals are clustered by their thermal treatment (12 vs 25 C). Each column is a different gene and gene function is denoted on the x-axis. Color corresponds to expression levels. The * denote genes where there was a statistically significant difference in expression level between the two thermal treatments. The ^ following gene functions indicates gene sequences that were obtained from the GVL juvenile Chinook Salmon thermal study. The remaining gene sequences were obtained from NCBI databases.

Conclusions

Our approach to designing gene expression assays has resulted in a promising new tool for testing for stress in Chinook Salmon in the Central Valley. The panel designed provides a comprehensive, quantifiable, and highly sensitive measure of expression level in Chinook Salmon in response to multiple forms of stress, including thermal stress. We believe this tool provides the groundwork for several important future studies and can be used to address a number of unanswered and important questions. Future studies using this panel that will greatly inform management of Central Valley Chinook Salmon include:

1. Determining levels of thermal stress in Chinook Salmon found in the Yolo Bypass.
2. Evaluating overall stress levels of juveniles found on floodplain habitat versus mainstem river habitat
3. Investigating the outmigration routes of Chinook Salmon from tributaries down through the Bay-Delta system to identify areas of highest stress.

Task 7. Historical Salmon Data Analyses

Project Leads: Lynn Takata, Ted Sommer, Louise Conrad, CDWR

Study Questions

- What environmental factors influence juvenile salmon growth, residence time, size at emigration, and emigration timing in the Yolo Bypass?
- What factors influence relative catch of wild (unmarked) juvenile chinook in the Yolo Bypass?
- Are there differences in comparative long-term survival between Chinook Salmon that utilized the Yolo Bypass versus those that utilized the adjacent Sacramento River as juveniles?

The Department of Water Resources has conducted fish monitoring in the Yolo Bypass since 1998, providing insight into juvenile Chinook Salmon growth and feeding ecology in specific years (Sommer *et al.*, 2001a, b; 2005; Henery *et al.*, 2010). However, questions remain about long-term patterns of residency, growth, emigration and survival. The purpose of this effort was to use several different data sets from CDWR's Yolo Bypass monitoring program to evaluate between-year (inter-annual) and within-year (intra-annual) demographic responses of juvenile Chinook Salmon that utilize the Bypass as rearing habitat.

Methods

A detailed description of methods is provided in **Appendix B**. To summarize briefly, we used data from three components of CDWR's Yolo Bypass fisheries monitoring program: 1) a rotary screw trap near the base of the floodplain; 2) a beach seining monitoring program; and 3) paired releases of 50,000-100,000 coded-wire tagged (CWT) juvenile hatchery fish at the north end of Yolo Bypass and in the adjacent Sacramento River from 1999-2009 (Sommer *et al.*, 2001b, 2005). During the same time period, environmental data was collected including flow, duration of flooding, photoperiod, and temperature.

The environmental variables affecting residence time, emigration timing, and growth were addressed by analyzing the dependent (fisheries) and independent (environmental, population data) variables. Multiple regression methods (e.g., Grimaldo *et al.*, 2009) were used to identify the major relationships. For example, one of the dependent variables (e.g. growth) was applied in a multiple regression model to evaluate whether there were significant relationships with the independent predictor environmental variables (flow, flooding duration, photoperiod, water temperature, accumulated temperature units-"ATU"). Environmental metrics used in inter-annual analyses were averaged over time periods when CWT or unmarked ("wild") juvenile salmon were likely rearing in the Yolo Bypass system ("rearing periods").

Results

A detailed description of the study results is provided in **Appendix B**. Key highlights are summarized below.

*Inter-Annual Migration Patterns***:** Several inter-annual dependent variables were significantly related to the duration of flooding in the Yolo Bypass. Apparent total growth (CWT), residence time (CWT) and annual CPUE (wild fish) were positively correlated with duration of flooding ($p=0.002$, 0.005 and 0.027 respectively). The addition of other independent variables did not significantly improve model fits. In contrast, apparent growth rate for both CWT and wild fish were not significantly related to any of the evaluated environmental variables. The multiple regression for inter-annual emigration timing (wild fish) included both ATU and photoperiod in the final model ($p<0.001$ and $p=0.001$).

Overall survival of CWT to the ocean fishery was not statistically different between Yolo Bypass and Sacramento River. Moreover, the relative survival of Yolo Bypass fish (i.e. Yolo Bypass:Sacramento River CWT release survival ratios) were not significantly explained by the independent variables. There were no clear patterns between relative survival in Yolo Bypass and a spring-summer upwelling index. The lack of strong survival signals may be due to several factors including the "loss" of CWT recovery data because of the closure of the 2008 fishery, and the extreme environmental variability in Yolo Bypass.

Intra-Annual Emigration: The hydrographs of the 13 years examined were substantially different based on the timing of Fremont Weir overtopping, inundation duration, and flow levels. During years with extended flooding (1999, 2000, 2004, 2006 and 2011), both wild and CWT juvenile salmon appeared to delay emigration until flooding subsided, then moved out of the Yolo Bypass in a pulse. During CWT release years where flooding was very brief and early (2002, 2003), very brief and late (2005), or non-existent (2001, 2007, 2008, 2009), emigration appeared to begin almost immediately after release. Residence time was significantly longer for CWT releases during years with extended flooding in comparison to CWT releases during non-flooding years. Neither temperature nor flow emerged as strong predictors of bi-weekly CPUE at the rotary screw trap based on generalized linear modelling.

Task 8. Salmon Isotope Studies

Project Leads: Rachel Johnson, UC Davis/NMFS
Field Assistance: CDWR field staff

Study Questions

- Is there evidence for lighter and distinct sulfur $\delta^{34}S$ in the particulate organic matter from the Yolo Bypass?
- Does the Yolo Bypass food web (invertebrate stomach contents) have a unique sulfur isotopic signature from the mainstem, hatcheries, and tributaries?
- Does the sulfur isotopic signature of the floodplain get incorporated into salmon muscle tissue?

Approach

While the benefits of floodplain rearing for salmonids have been shown (Sommer *et al.*,, 2001b, 2005, Henery *et al.*,, 2010), the population-level benefit in terms of increased survival

during downstream migration and adult return rates are still unclear. Physical tags and/or telemetry can be used to estimate survival of juveniles on the Yolo Bypass. However, the proportion of juveniles or adults in the population that reared in the Bypass cannot be quantified with these methods. To assess the population-level "fingerprint" of floodplain juvenile rearing for wild fish, it is necessary to develop a tool that will allow retrospective analysis of rearing history for both outmigrating smolts and returning adults. Recent evidence shows a unique sulfur isotopic composition of water in the Yolo Bypass. Since sulfur isotopes can be measured in fish on a daily basis in otoliths, a promising approach is to investigate sulfur isotopes in otoliths as a floodplain marker to determine use, growth, and residence time in the Bypass. This task will assess the feasibility of this approach.

The sulfate in the water in the Yolo Bypass has been shown to have a uniquely light sulfur isotopic composition ($^{34}S/^{32}S$, herein $\delta^{34}S$) reflective of a difference in the base of the food web (Carol Kendall, USGS, Bay-Delta Science Conference, 2010). Like carbon isotopes, sulfur isotope ratios do not change as they move up the food web (Michener and Schell 1994; Hobson *et al.*, 2010). Thus, differences at the energy sources at the base of the food web propagate up the trophic hierarchy from the water, to invertebrate prey, and into the muscle, and ear bone (otolith) protein of fishes feeding on that food web (Weber *et al.*, 2002; -Johnson *et al.*, 2010; Godbout *et al.*, 2010). If the food web signature of the Yolo Bypass is unique, temporally, and spatially robust, then it could be used as a quantitative tool to assess and reconstruct floodplain habitat use and residence time for different native fish species (e.g., salmon, steelhead, sturgeon, splittail). For example, the sulfur isotopic composition of salmon otoliths could be measured from juveniles collected at a downstream sampling location (e.g., Chipps Island) to determine the proportion of fish that used the floodplain habitat. Similarly, adult Chinook Salmon otoliths from the ocean fishery or from spawning populations could be sampled to reconstruct whether these adult survivors used the floodplain as juveniles. Thus, this tool could be used to quantify a population-level benefit of the floodplain.

Methods

Particulate organic matter (algae) was collected by filtering water samples from stations for the San Francisco Bay Estuary up the mainstem Sacramento River and analyzed for $\delta^{34}S$ per established techniques at US Geological Survey, Menlo Park (C. Kendall). Juvenile Chinook Salmon were collected by the Department of Water Resources from the rotary screw traps operated in the Yolo Bypass between February and April 1999. Since no flooding occurred during the period of our ERP project, we used these archived samples as an indicator of juvenile salmon responses to seasonal inundation. For comparison, juvenile Chinook Salmon were collected on the mainstem Sacramento River at Verona, Discovery Park, Sherwood Harbor, and Garcia Bend as part of the USFWS Delta Juvenile Fish Monitoring Program between February and April 2012-2014. For each individual fish sample, stomach contents, muscle tissue, fin tissue, and otoliths were collected for isotopic analyses.

Stomach contents were taxonomically identified and grouped into zooplankton, diptera, terrestrial insects, other aquatics, and assessed for their relative importance to the diet of Yolo Bypass vs. mainstem Sacramento River fish per established techniques (Sommer et al., 2001b). Gut contents, muscle and fin tissues were then analyzed for sulfur isotopic composition as per

established techniques at the University of California Davis, Stable Isotope Facility (Goodbout *et al.,* 2010; Weber *et al.,* 2001). Stomach contents among individuals on the Yolo Bypass were pooled to achieve a dry weight of 2 mg of sample required for robust analysis on the Elemental Analyzer. The sulfur isotopic composition of muscle tissue and prey items in the stomachs of juvenile salmon collected on the floodplain captures potential variation in $\delta^{34}S$ over space, time, and individual residence time among individuals.

Results

The particulate organic matter (POM) from the Yolo Bypass showed significantly different and lighter $\delta^{34}S$ relative to the San Francisco Bay and mainstem Sacramento River ($\delta^{34}S$ =-4 ‰; Figure 7). This isotopically lighter water is consistent with anoxic microbrial reduction of sulfate (e.g., rice decomposition; Limburg *et al.,* 2014). The isotopically low $\delta^{34}S$ in the organic matter has the potential to pass through the foodweb into invertebrate prey, fish muscle, and otoliths of fishes (Limburg *et al.,* 2014).

The stomach content of fish collected on the Yolo Bypass and the mainstem Sacramento River showed some taxonomic differences. The fish collected on the Yolo Bypass had stomachs that were dominated by zooplankton (IRI=75%), while the Sacramento River mainstem fish had more diverse prey items including a slightly larger contribution from dipterans and other aquatic insects (Figure 8). The sulfur isotopic composition of the prey items of fish from the Yolo Bypass were isotopically lighter than those of the Sacramento River. The pooled contents (N=20) from the Yolo Bypass fish had a mean $\delta^{34}S$ value of -0.7 in contrast to the $\delta^{34}S$ from the Sacramento River, 2.6 (± 1 SD=2.7). We are unable to statistically compare these differences because the Yolo Bypass samples were pooled and thus we don't have a measure of variance. However, the mean values between the Yolo Bypass and the Sacramento River are consistent with the differences observed in the POM data for the two habitats (Figure 9).

The muscle tissue from fish between the Sacramento River and the Yolo Bypass were significantly different from one another ($p<0.001$; Figure 10). Similar to the POM and the prey items in the two habitats, the muscle tissue from fish in the Yolo Bypass were isotopically lighter ($\delta^{34}S$= -1.7±2.9) than the Sacramento River fish ($\delta^{34}S$= 4.3±4.7). Two individuals caught in the Yolo Bypass were outliers and have isotopic values more similar to fish caught in the Sacramento River. Muscle tissue has a tissue turnover rate of approximately 50 days (Heady and Moore 2012), thus the outliers may have recently entered the Yolo Bypass or have experienced a shorter residence time than the other sampled individuals. The difference in muscle isotope values between the majority of Yolo Bypass fish and Sacramento River mainstem fish suggests the majority of the fish spent a significant amount of time rearing in the two habitats prior to capture.

Conclusions

Results from this pilot effort suggest that $\delta^{34}S$ is a promising marker to track the use of the Yolo Bypass by native fishes. We observed fish from the Yolo Bypass having isotopically light and distinct $\delta^{34}S$ in their prey content and muscle tissue, consistent with the trend in POM. However, it is unclear the extent to which other floodplains like the Sutter-Butte Bypass or the

San Joaquin Rivers have similar $\delta^{34}S$ to the Yolo Bypass. Further work is proposed to investigate the $\delta^{34}S$ in other salmon rearing habitats that may also have sulfate reduction and the extent to which other spatial markers (like Sr isotopes) may help to unambiguously characterize the Yolo Bypass. Moreover, additional work is needed in high flow years to provide a concurrent comparison of isotopic signatures in Yolo Bypass versus Sacramento River.

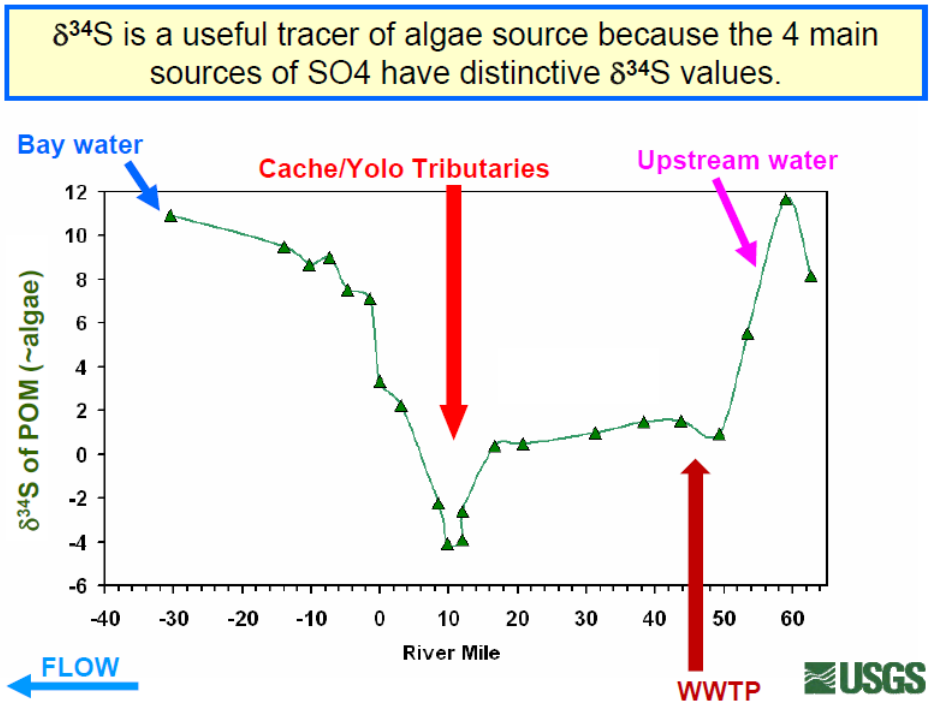


Figure 7. Particulate organic matter filtered from water samples collected in the San Francisco Bay Estuary and up the Sacramento River (Carol Kendall, unpublished data). River mile '0' is the confluence of the Sacramento and San Joaquin Rivers. "WWTP" is the Sacramento Regional Waste Water Treatment Plant.

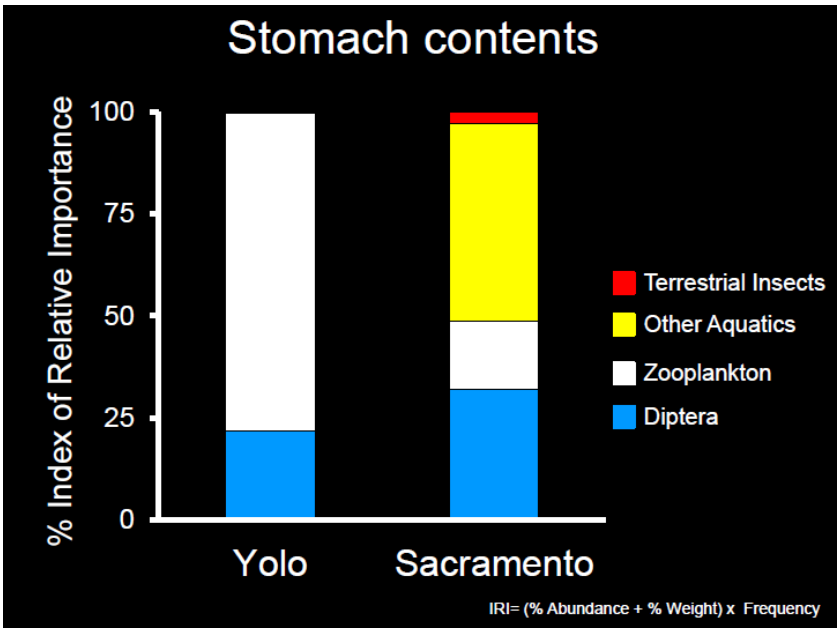


Figure 8. Index of relative importance (IRI) of prey items from juvenile Chinook Salmon collected in the Yolo Bypass (1999 archives) and the Sacramento River (2012-2014).

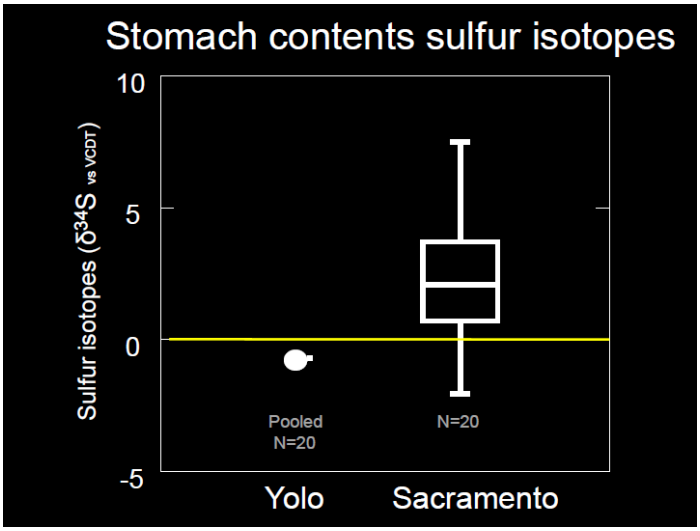


Figure 9. Sulfur isotope composition of prey items from juvenile salmon caught on the Yolo Bypass and Sacramento River.

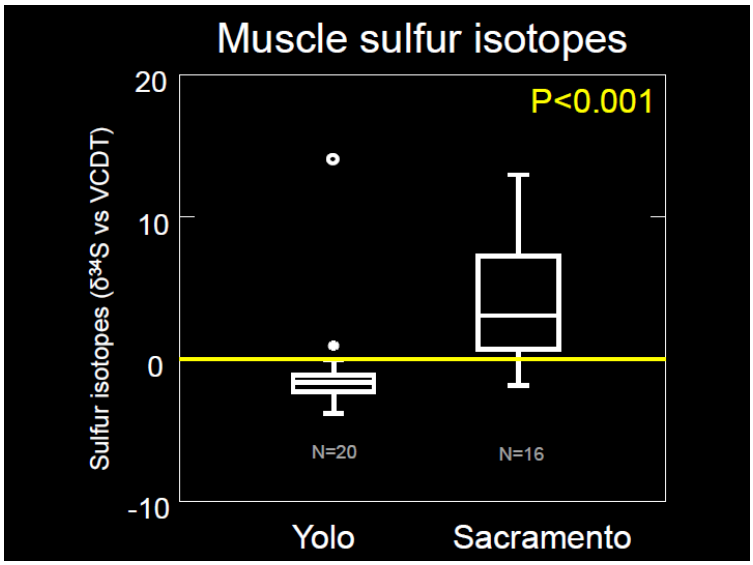


Figure 10. Sulfur isotope composition of muscle tissue from juvenile salmon caught on the Yolo Bypass and Sacramento River.

Task 9. Food Web Studies

Project Leads: Kris Jones, Jared Frantzich, Louise Conrad, Ted Sommer, CDWR

Study Questions:

- What are the general patterns in zooplankton, and drift invertebrate species in Yolo Bypass?
- How are zooplankton and drift species affected by different environmental conditions?
- Can specific thresholds be identified for flow, magnitude, and duration of inundation for enhanced lower trophic levels?

CDWR has conducted food web studies in Yolo Bypass since 1998. The major components of the long-term sampling program include chlorophyll a, zooplankton, and drift sampling. While some of the data have been analyzed (Schemel *et al.*, 2003; Sommer *et al.*, 2004b; Benigno and Sommer 2008), most of the information has yet to be examined in a detailed way. Moreover, the sampling was done only during winter and spring, so there is not information about food web dynamics during other seasons. This information is particularly important to understand the possible contribution of ERP improvements to the estuarine food web during other months. To address this need, we describe the results of two ERP-funded food web study components: 1) *Supplemental Food Web Sampling*; and 2) *Analyses of Historical Food Web Data*.

Methods

Supplemental Food Web Sampling: The Methods for this study component are described in detail in **Appendix C**. Below we summarize the supplemental physical and food web sampling, which focuses on the low-flow season sampling supported by the ERP. To provide a more comprehensive evaluation of the supplemental food web sampling, we include physical and chemical data that were collected during other seasons and years by DWR's core Yolo Bypass

sampling program. Although this work was not supported by the ERP, it is allows a more complete interpretation of the newer results.

Flow, velocity, and stage measurements in the Yolo Bypass were obtained from gauges operated by DWR below Lisbon Weir. Continuous water temperature data for the sites in the Yolo Bypass and Sacramento River were collected using temperature recorders. Additional discrete water quality measurements were collected at all study sites for conductivity, pH, and dissolved oxygen. Turbidity (NTU) was also measured in 2012. The photosynthetically active surface irradiance (PAR) was measured in the water column by vertical profiles of a spherical quantum sensor and total irradiance in the euphotic zone was computed by integration over depth.

In 2012, we installed a multi-parameter water quality sonde at Lisbon Weir in Yolo Bypass to provide continuous data on water temperature, specific conductance, pH, dissolved oxygen, turbidity, and chlorophyll data for the Yolo Bypass. In 2013, we added water quality sondes to measure water temperature, specific conductance, and chlorophyll at several other Toe Drain locations during low flow months. In 2013, discrete water samples were collected from late July through October at eight sites in a north to south transect along the eastern edge of the Yolo Bypass to the Sacramento River at Rio Vista

To investigate the interannual responses of two trophic levels: primary producers (phytoplankton) and primary consumers (zooplankton) to changing physical conditions, samples were compared between the Yolo Bypass and the Sacramento River. In 2013, there was further collection of water samples for chlorophyll a and phytoplankton enumeration and identification along much of the extent of the Toe Drain to obtain data on spatial and temporal variation during periods of increased agricultural drainage flows.

Analyses of Historical Food Web Data: Similar to the historical studies for juvenile salmon (Task 7), Task 9 focused on statistical analyses of the archival data for plankton and invertebrates to describe community composition and relationships with environmental variables. A detailed description of these methods is described in detail in **Appendix D**. This study used sampling data for chlorophyll *a*, zooplankton, and drift sampling collected since 1998. Discrete water quality measurements were collected concurrently with the biological sampling. Continuous water temperature data were also collected. Stage measurements were obtained from gauges operated by DWR below Lisbon Weir.

In order to examine the relationship between flow and primary productivity, generalized additive models were performed to study the relationship between stage and chlorophyll *a*, and to identify specific thresholds. Change point analyses were performed using binary segmentation (Edwards and Cavalli-Sforza 1965, Scott and Knott 1974, Sen and Srivastava 1975) to detect abrupt changes in mean chlorophyll *a* concentration over the time series.

To test for bottom-up effects, monthly averages were calculated for all biological data so that monthly data for primary producers (chlorophyll *a* concentrations) could be paired appropriately with monthly data for primary consumers (zooplankton and drift invertebrates CPUE). Negative binomial models were performed to evaluate whether chlorophyll *a* was a good predictor for zooplankton and drift invertebrate relative abundance (i.e., CPUE).

Multivariate analyses were carried out on drift invertebrate and zooplankton assemblage data using the statistical package PRIMER (Clarke and Gorely 2006). Assemblage similarities were explored using non-metric multi-dimensional scaling (NMDS; Clarke and Green 1988; Clarke 1993) on Bray-Curtis dissimilarity indices computed from square-root transformed annual abundance data.

Results

Supplemental Food Web Sampling: The Results for the supplemental food web sampling study component are presented in detail in **Appendix C**. Highlights of the effort include the following. Chlorophyll *a* concentrations were significantly higher in the Yolo Bypass than in the Sacramento River. The levels in the Sacramento River were highest during periods of low flow, while the Yolo Bypass experienced the highest levels during elevated flows in the late summer and fall. Flow was a significant predictor for adult calanoid copepod abundance in the Yolo Bypass, while flow did not seem to correlate well with Sacramento River zooplankton abundance during the summer and fall.

The zooplankton community in the Yolo Bypass was dominated by *Bosmina* (95% of the cladoceran community), *Pseudodiamptomus forbesi* (53% of calanoid copepod adults), and *Sinocalanous doerri* (45% of calanoid copepod adults). In the Sacramento River, calanoid copepod adults were dominated by *Ilyocryptus* (83%), *Sinolcalonus doerri* (10%), and Diaptomidae spp. (4%). The Sacramento River cladoceran composition was more evenly dispersed than Yolo Bypass, with *Bosmina* (39%), *Ceriodaphnia* (25%), *Daphnia* (18%), and *Chydorus* (15%). There were significant differences in the densities of cladocerans and calanoid copepod adults between the Yolo Bypass and Sacramento River. The Sacramento River had much lower volumes than the Yolo Bypass in all years. Flow was a significant predictor for adult calanoid copepod adult abundance in the Yolo Bypass, while flow did not seem to correlate well with Sacramento River zooplankton abundance during the summer and fall. In all years, there were increases in the densities of both cladocerans and calanoid copepods adults in the Yolo Bypass during the month of October. The increased zooplankton densities were observed after increases in rice-field drainage flows and increased chlorophyll *a* concentrations. Specifically in 2012, we saw exceptional densities of both cladocerans and copepods adults in October with *Bosmina* (3.20E+05 /m^3) and *Pseudodiaptomus forbesi* (1.79E+04) as the dominant taxa.

Analyses of Historical Food Web Data: A detailed write-up of the *Historical Food Web Data Analyses* is provided in **Appendix D.** Some of the key findings are summarized below.

Chlorophyll *a* data were evaluated for the period of January to April between the years of 2001 and 2012. During our study period, chlorophyll *a* concentrations increased through the spring, with the highest concentrations observed in April. The majority of the first "spikes" in chlorophyll *a* occurred during the month of March, and were associated with a broad range of stage values. Stage was a significant predictor of chlorophyll *a* concentrations; chlorophyll *a* concentrations decreased with increasing stage, with the highest chlorophyll *a* concentrations observed for stage values between 6-7 feet (approximately 2000-2500 cfs). Furthermore, there was a significant interaction between temperature and stage ($P < 0.001$). Separate analyses of the lowest and highest temperature data (Low: minimum temperature to the median; High: median temperature to the maximum) revealed that stage had a significant negative effect on chlorophyll *a*, but only at higher temperatures

(P = < 0.001; 14.4-23.5^{o}C); no significant effect of stage was detected for chlorophyll *a* at lower temperatures (P = 0.155; 7.5-14.4^{o}C).

Bottom-up effects (i.e. a relationship between primary producers and primary consumers) were explored using data from 2001-2012. For drift species, 26 taxa accounted for the lowest 3% of the total catch, whereas 9 taxa accounted for the lowest 1.5% of the total catch for zooplankton. In support of the role of bottom up effects, chlorophyll *a* was a good predictor for a majority of the represented taxa for drift species and zooplankton. For a majority of represented drift invertebrates and zooplankton, we found that their abundances increased with chlorophyll *a* concentrations.

Assemblage patterns for primary consumers were explored for data from 1999-2012. Assemblage data for drift species indicated that Homopterans were the numerically dominant taxa during the study period, followed by Dipterans and Hemipterans; these three taxa together accounted for 76% of the overall abundance over the study period. Dipterans were consistently the dominant taxa for the drift species represented in our analyses; however, Homopterans were the numerically dominant taxa across study years due to a particularly abundant year in 2008. Assemblage data for zooplankton revealed that Cladocerans were the dominant taxa represented in our analyses, followed by *Daphnia* and *Acanthocyclops*; these three taxa together accounted for 79% of the overall abundance over the study period. Zooplankton abundance was highest in 2008, with *Acanthocyclops* consisting of the largest percentage of the taxa during that year (38%).

The abiotic variables which best matched the pattern of relative abundance and assemblage composition for drift species and zooplankton were stage and temperature; however, these patterns were only weakly correlated for drift invertebrates and zooplankton. While there were no clear statistical trends in total organism abundance for either drift species or zooplankton, annual abundances for drift invertebrates and zooplankton tended to be lowest in wet years. Conversely, the highest annual abundances observed for both drift species and zooplankton were in 2008, which was a critically dry year. NMDS analyses also suggested that assemblage patterns in drier years were more similar than wetter years, although these patterns were less pronounced for the drift invertebrate data.

5. Relevance of the Results to Salmon Management

Relevance to ERP. Floodplain restoration has become a key part of the ERP Strategic Goals and Objectives, based on the importance of Yolo Bypass to special status fishes such as Chinook Salmon (ERP Goal 1, Objective 1), key ecological processes (ERP Goal 2, Objective 6), and floodplain habitat (ERP Goal 4, Objective 5). This project addressed both Priority 1 (restoration projects to enhance aquatic habitat in the Delta) and Priority 2 (research to test hypotheses regarding conservation measures) listed in the PSP. Based on previous research (Sommer *et al.*, 2004b, 2005), the Yolo Bypass presents an excellent opportunity for floodplain restoration within the Delta. Our research helps to inform restoration actions in the Yolo Bypass by highlighting conditions that support key food resources and habitat characteristics for juvenile salmonids. Understanding current movement patterns of adult salmon and sturgeon in the Bypass and impediments to their passage to spawning areas in the Sacramento River or tributary streams is another critical component of restoring habitat for native fish in the Bypass.

Relevance to Salmonid Restoration. Floodplain restoration and improved passage of adult

salmon and sturgeon through the Yolo Bypass are key restoration actions specified within the NMFS Biological Opinion and RPA for salmon, steelhead, and green sturgeon. The National Research Council's Committee on Sustainable Water and Environmental Management in the California Bay-Delta has reviewed these actions, supports them as scientifically justifiable, and recommends them for early implementation (NAS, 2010). Evaluation of the success of future restoration projects such as increased area or duration of inundation, or modifications to structures that impede passage, will require baseline data on pre-project conditions such as that collected by this study.

6. Recommendations for Future Studies

The current study provided insight into several key aspects of Chinook Salmon and Sturgeon life history in the Yolo Bypass, with several important lessons for management of the floodplain. However, the primary challenge for the field-oriented components of this study (Adult Telemetry; Juvenile Telemetry; Chinook Salmon Genetics; Isotopic Markers; and Food Web Sampling) was that our study occurred during a historic drought, so no new high flow samples or data could be collected. Some of the elements such as Isotopic Markers and Chinook Salmon Genetics were possible to address using archived historical samples. Nonetheless, a key recommendation for future work is that similar work be conducted during high flow years. Some specific recommendations for follow up work to each task include the following.

Adult Salmon and Sturgeon Telemetry: The low flow data provided insight into how the system functions as a relatively "linear" migration corridor. However, the original study was designed with a network of receivers to also investigate of the behavior of fish when the broader floodplain is inundated. Additional work is needed to examine how well these high flow periods conform with our conceptual model for adults. This information is critical to address passage issues during high flow periods.

Juvenile Salmon Telemetry: The recommendations for juvenile Chinook Salmon telemetry are similar to those provided for adults. Specifically, better telemetry data is needed to describe how fish use the expanse of the floodplain during wetter conditions. In the meantime, more in-depth survival modeling should be done using the existing data to examine whether there is any evidence of mortality "hot spots". Finally, current tagging technology limited our study to relatively large smolts. The technology is improving rapidly, so future work should examine the survival and behavior of smaller juvenile Chinook Salmon.

Chinook Salmon Genetics: To the degree possible, genetic methods such as those used in this study should increasingly be used to examine floodplain habitat use by different races. The current reliance on length at data (Harvey et al. 2014) is clearly not a reliable approach to identify each of the runs. As noted above, this study occurred entirely in drought years, so it is unclear if the results apply in wetter years. Hence, we recommend continued application of these genetic tools in multiple water year types.

Salmon Stress Metrics: The panel of molecular markers developed in this study suggest that this tool may be an effective approach to test for stress in Chinook Salmon in the Bay-Delta system. The obvious next step is to apply the tool to specific management questions such as whether passage impediments in Yolo Bypass cause stress in migrating Chinook Salmon.

Historical Analyses of Juvenile Salmon: Overall, we believe that there is limited value in further analyses of the historical CWT release data. Recoveries are relatively low, so this approach would not provide substantially more information without much larger sample sizes. This might occur if a substantially larger number of hatchery fish were coded wire tagged (e.g. constant fractional marking) in the future. In the meantime, we recommend that alternative approaches such as telemetry and isotopic markers be used to try and evaluate floodplain residence time and survival.

Development of an Isotopic Marker for Floodplain Rearing: Our study supports the hypothesis that there is a unique isotopic signature for fish that rear in Yolo Bypass. Further work is recommended to determine whether other seasonal habitats (e.g. Sutter Bypass) have similar $\delta^{34}S$ signatures, and to examine the extent to which other isotopic markers (e.g. Sr) may help to provide a better "fingerprint" for Yolo Bypass rearing.

Lower Trophic Level Responses to Floodplain Inundation: Our Supplemental Food Web Sampling provided evidence that flow pulses during fall may help to trigger downstream blooms of phytoplankton and zooplankton. Further work is needed to examine this issue in more detail, perhaps through the use of a test with a managed agricultural flow pulse. The Historical Food Web Data Analyses suggested that there are specific flow thresholds that maximize chlorophyll *a* levels. However, chlorophyll *a* does not necessarily represent how different phytoplankton groups respond to flow variation, especially the presence of desirable versus harmful species. Moreover, analyses are needed to examine whether there are similar flow thresholds for invertebrates, particularly for species groups that provide optimal food sources for young salmon and other species. Similarly, the current analysis did not examine whether the observed flow thresholds for food were consisistent with other critical salmon habitat attributes such as water temperature, velocity, and area of rearing habitat. Lastly, the current analyses identified flow thresholds that maximize the concentration of chlorophyll *a*, but not necessarily the downstream flux of phytoplankton. Hence, additional work is needed to determine the flow levels that provide the greatest downstream flux of high quality phytoplankton.

7. Literature Cited

Bay Institute. 1998. From the Sierra to the Sea: The Ecological History of the San Francisco Bay-Delta Watershed. The Bay Insitute, San Francisco

Bay Delta Conservation Plan 2010. Bay Delta Conservation Plan (BDCP) Working Draft. November 18, 2010. http://baydeltaconservationplan.com/BDCPPlanningProcess/ReadDraftPlan/ReadDraftPlan_copy1.aspx

Benigno, G.M. and T.R. Sommer. 2009. Just add water: sources of chironomid drift in a large river floodplain. *Hydrobiologia* 600:297-305.

Brett, J.R. 1995. Energetics. pp. 3-68. In: C. Groot, L. Margolis, and W.C. Clarke [Editors]. *Physiological Ecology of Pacific Salmon*. UBC Press, Vancouver, B.C.

CALFED (California Bay-Delta Program). 2004. Ecosystem Restoration Multi-year Program Plan (Year 5-8), Sacramento, 29p.

CALFED (California Bay-Delta Program). 2001. Ecosystem Restoration Program, Draft Stage 1

Implementation Plan, Sacramento, 113 p.
Clarke KR. 1993. Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18:117–143.
Clarke KR, Green RH. 1988. Statistical design and analysis for a biological effects" study. Marine Ecology Progress Series 46:213–226.
Clarke KR, Gorley RN. 2006. PRIMER v6: User manual/tutorial, PRIMER-E. Plymouth UK. 192 p.De Maio, A. 1999. Heat shock proteins: facts, thoughts, and dreams. *Shock*. 11(1): 1-12.
Edwards AWF, Cavalli-Sforza LL (1965). “A Method for Cluster Analysis.” Biometrics, 21(2), 362–375.
Fangue, N.A., M. Hofmeister, and P.M. Schulte. 2006. Intraspecific variation in thermal tolerance and heat shock protein gene expression in common killifish, *Fundulus heteroclitus. The Journal of Experimental Biology.* 209: 2859-2872.
Feyrer, F, T. Sommer, and W. Harrell. 2006a. Managing floodplain inundation for native fish: production dynamics of age-0 splittail in California's Yolo Bypass. *Hydrobiologia* 573:213-226.
Feyrer, F, T. Sommer, and W. Harrell. 2006b. Importance of flood dynamics versus intrinsic physical habitat in structuring fish communities: evidence from two adjacent engineered floodplains on the Sacramento River, California. *North American Journal of Fisheries Management* 26:408-417.
Godbout, L., Trudel, M., Irvine, J.R., Wood, C.C., Grove, M.J., Schmitt, A.K., and McKeegan, K.D. 2010. Sulfur isotopes in otoliths allow discrimination of anadromous and non-anadromous ecotypes of sockeye salmon (*Oncorhynchus nerka*). *Environmental Biology of Fishes* 89:521-532.
Grimaldo, LF., T. Sommer, N. Van Ark, G. Jones, E. Holland, P. Moyle, B. Herbold, and P. Smith. 2009. Factors affecting fish entrainment into massive water diversions in a freshwater tidal estuary: Can fish losses be managed? *North American Journal of Fisheries Management* 29:1253-1270.
Harrell, W.C. and T.R. Sommer. 2003. Patterns of Adult Fish Use on California’s Yolo Bypass Floodplain. Pages 88-93 in P.M. Faber, editor. *California riparian systems: Processes and floodplain management, ecology, and restoration.* 2001 Riparian Habitat and Floodplains Conference Proceedings, Riparian Habitat Joint Venture, Sacramento, California.
Harvey, B. N. 2011. Length-at-date criteria to classify juvenile Chinook Salmon in the California Central Valley: development and implementation history. Interagency Ecological Program for the San Francisco Estuary Newsletter, Summer 2011 24(2): 26-36. Available at http://www.water.ca.gov/iep/products/newsletter.cfm
Harvey,B.N. David P. Jacobson & Michael A. Banks 2014. Quantifying the Uncertainty of a Juvenile Chinook Salmon Race Identification Method for a Mixed-Race Stock, North American Journal of Fisheries Management, 34:6, 1177-1186
Heady,W.N. and M.W. Moore 2012. Tissue turnover and stable isotope clocks to quantify resource shifts in anadromous rainbow trout. Oecologia DOI 10.1007/s00442-012-2483-9
Henery, Rene E., T. R. Sommer, and C. R. Goldman. 2010. Growth and methylmercury accumulation in juvenile Chinook Salmon in the Sacramento River and its Floodplain, the Yolo Bypass. *Transactions of the American Fisheries Society* 139: 550-563.
Hobson, K. Barnett-Johnson, R., and Cerling, T. 2010. Isotope tracking of terrestrial and freshwater vertebrates. *In:* West, J. Bowen, G., Dawson, T., and K. Tu (eds.) Isoscapes: Understanding movement patterns and processes on earth through isotope mapping. Springer

Press, Berlin, Germany.
Jassby, A.D., and Cloern, J.E. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). *Aquatic Conservation - Marine and Freshwater Ecosystems* 10: 323-352.
Johnson, R.C., Weber, P.K., Wikert, J.D., MacFarlane, R.B., and Workman, M. 2012. Managed metapopulations: Do salmon hatchery 'sources' lead to in-river 'sinks' in conservation? PLoS ONE 7:2
Kimmerer WJ. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. *San Francisco Estuary and Watershed Science* 2 (1) Article 1. [online serial].
Lehman, P. W., T. Sommer & L. Rivard, 2008. The influence of floodplain habitat on the quantity of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary. *Aquatic Ecology* 42: 363-378.
Limburg, K.E., B.D. Walther, Z. Lu, G. Jackman, J. Mohan, Y. Walther, A. Nissling, P. Weber, A. Schmitt. In search of the dead zone: Use of otoliths for tracking fish exposure to hypoxia. 2014. Journal of Marine Systems. doi:10.1016/j.jmarsys.2014.02.014
Michener, R. and D. Schell. 1994. Stable isotope rations as tracers in marine aquatic food webs. *In*: Michener, R.H. and D.M. Schell (eds.) Stable isotopes in ecology and environmental sciences. Blackwell Scientific Publications, Oxford, UK.
Mueller-Solger, A., A. Jassby, and D.C. Mueller-Navarra. 2002. Nutritional quality for zooplankton (Daphnia) in a tidal freshwater system (Sacramento-San Joaquin River Delta, USA). *Limnology and Oceanography* 47: 1468-1476.
National Academy of Sciences. 2010. A scientific assessment of alternatives for reducing water management effects of threatened and endangered fishes in the California's Bay Delta. March 19, 2010. http://www.deltacouncil.ca.gov/delta_science_program/pdf/workshops/OCAP_2010/National_Academy_of_Science_March_19_2010_report.pdf
National Marine Fisheries Service 2009. NMFS Final 2009 Biological Opinion on the Long-Term Central Valley Project and State Water Project Operation, Criteria, and Plan. June 4, 2009. http://swr.nmfs.noaa.gov/sac/myweb8/BiOpFiles/2009/Draft_OCAP_Opinion.pdf
Opperman, J. 2008. Floodplain conceptual model. Sacramento (CA). Delta Regional Ecosystem Restoration Implementation Plan. http://www.science.calwater.ca.gov/pdf/drerip/DRERIP_floodplain_conceptual_model_final_012208.pdf
Perry, R.W. , J.R. Skalski , P.L. Brandes , P.T. Sandstrom ,A. P Klimley , A. Ammann & B.MacFarlane (2010) Estimating Survival and Migration Route Probabilities of Juvenile Chinook Salmon in the Sacramento–San Joaquin River Delta, North American Journal of Fisheries Management, 30:1, 142-156.
R Development Core Team. 2014. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.
Sen A, Srivastava MS (1975). "On Tests for Detecting Change in Mean." The Annals of Statistics, 3(1), 98–108.
Schemel L.E., T.R. Sommer, A. Mueller-Solger, W.C. Harrell. 2004. Hydrologic variability, water chemistry and phytoplankton biomass in a large floodplain of the Sacramento River, CA, USA. *Hydrobiologia* 513: 129-139
Scott AJ, Knott M (1974). "A Cluster Analysis Method for Grouping Means in the Analysis

of Variance." Biometrics, 30(3), 507–512.
Sommer, T., R. Baxter, and B. Herbold. 1997. Resilience of splittail the the Sacramento-San Joaquin Estuary. *Transactions of the American Fisheries Society* 126:961-976.
Sommer, T.R., W.C. Harrell, M.L. Nobriga, R. Brown, P.B. Moyle, W.J. Kimmerer, L. Schemel. 2001a. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. *Fisheries* 26: 6-16.
Sommer T.R., M.L. Nobriga, W.C. Harrell, W. Batham, W.J. Kimmerer. 2001b. Floodplain rearing of juvenile Chinook Salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 325-333.
Sommer, T., L. Conrad, G. O'Leary, F. Feyrer, and W. Harrell. 2002. Spawning and rearing of splittail in a model floodplain wetland. *Transactions of the American Fisheries Society* 131:966-974.
Sommer, T.R., W.C. Harrell, M.L. Nobriga and R. Kurth. 2003. Floodplain as habitat for native fish: Lessons from California's Yolo Bypass. Pages 81-87 in P.M. Faber, editor. *California riparian systems: Processes and floodplain management, ecology, and restoration*. 2001 Riparian Habitat and Floodplains Conference Proceedings, Riparian Habitat Joint Venture, Sacramento, California.
Sommer, T.R., W.C. Harrell, R. Kurth, F. Feyrer, S.C. Zeug, and G. O'Leary. 2004a. Ecological patterns of early life stages of fishes in a river-floodplain of the San Francisco Estuary. Pages 111-123 in F. Feyrer, L.R. Brown, R.L. Brown, and J.J. Orsi, editors. *Early Life History of Fishes in the San Francisco Estuary and Watershed*. American Fisheries Society, Symposium 39, Bethesda, Maryland.
Sommer T.R., W.C. Harrell, A. Mueller-Solger, B. Tom, W. Kimmerer. 2004b. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. *Aquatic Conservation* 14: 247-261.
Sommer, T, W. Harrell, and M. Nobriga. 2005. Habitat use and stranding risk of juvenile Chinook Salmon on a seasonal floodplain. *North American Journal of Fisheries Management* 25:1493-1504.
Sommer, T., B. Harrell, Z. Matica, and F. Feyrer. 2008. Habitat associations and behavior of adult and juvenile splittail (Cyprinidae: Pogonichthys macrolepidotus) in a managed floodplain wetland. San Francisco Estuary and Watershed Science. Vol. 6, Issue 2 (June), Article 3.
Sommer, T.R., W.C. Harrell, F.Feyrer. 2014. Large-bodied fish migration and residency in a flood basin of the Sacramento River, California, USA. Ecology of Freshwater Fish 2014: 23: 414–423
Strayer, D.L. and S.E.G. Findlay. 2010. Ecology of freshwater shore zones. *Aquatic Sciences* 72: 127 – 163.
Sullivan, K., J. M. Douglas, R. D. Cardwell, J. E. Toll, and S. Duke. 2000. An analysis of the effects of temperature on salmonids of the Pacific Northwest with implications for selecting temperature criteria. Sustainable Ecosystems Institute, Portland, Oregon. 192p.
Thoms, M.C. 2003. Floodplain-river ecosystems: lateral connections and the implications of human interference. *Geomorphology* 56: 335 – 349.
Weber, P. K., Hutcheon, I.D., McKeegan, K.D., Ingram, B.L., 2002. Otolith sulfur isotope method to reconstruct salmon (*Oncorhynchus tshawytscha*) life history. *Canadian Journal of Fisheries and Aquatic Sciences* 59, 587-592.

Appendix A: Yolo Bypass Project Draft Final Telemetry Report

2012-2014

Myfanwy Johnston
Ph.D Candidate, Animal Behavior Graduate Group
University of California at Davis
merowlands@ucdavis.edu

Executive Summary

This report summarizes the tagging and monitoring activities completed as part of Task 4 of the Evaluation of Floodplain Rearing and Migration in the Yolo Bypass ERP project. We have completed tagging activities for the telemetry task, and have begun in-depth analyses in order to address our original research questions. The studies and research questions addressed in this task are:

4.1) Adult Telemetry Study

- What is the residence time of adult migratory fishes (white sturgeon, Chinook Salmon) in Yolo Bypass?
- Where do adult fish move to within the floodplain under different conditions?
- Are there specific areas of the floodplain where there is evidence of increased mortality or holding behavior?
- Do migratory fish move into areas of maximum flow and use this as a cue to migrate upriver?

4.2) Juvenile Telemetry Study

- What is the survival of juvenile salmon in the floodplain as compared to in the Sacramento River?
- What is the residence time of juvenile salmon in the floodplain as compared to in the Sacramento River?
- Are there specific areas of the floodplain where there is evidence of increased mortality?

Detections are available from March 2012 – May 2012 and October 2012 – September 2014. This dataset includes both releases of juvenile Chinook, as well as adult Chinook and white sturgeon movements within those times.

With this dataset, we have estimated values for juvenile Chinook survival and movement rates, adult white sturgeon residence time, and transit time and migration route selection for 64 of the 99 adult Chinook Salmon. These data are reported in the sections below. Also reported are planned analyses and future explorations after the final detections for adult Chinook Salmon migrating in fall 2014 are downloaded in spring of 2015.

Note

All calculations and statistics reported here are the results of on-going analyses and are subject to revision once all the detections have been downloaded (~May 2015) and supplementary environmental data has been included.

Fish Collection, Tagging, and Monitoring Methods

For All Tagging Procedures

All surgical materials and tags are sterilized using a chlorohexadine solution to reduce the chance of infection.

Adult White Sturgeon Fish Surgery and Release Procedure

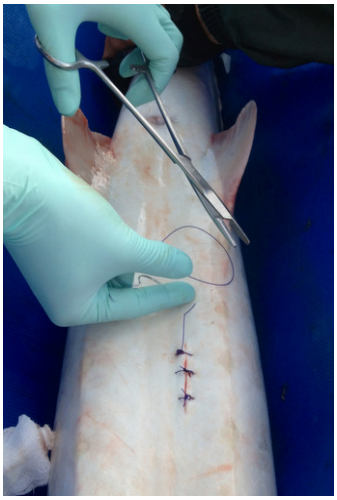


Figure 1: An adult white sturgeon in fish cradle during surgery. The incision is made just large enough to obtain a histological sample and insert the 16x90mm tag, then sutured with three interrupted absorbable sutures.

A sturgeon caught in the fyke net is placed in a two-meter fish cradle with poles for carrying. The cradle is then rested between two sawhorses, with the fish in an inverted position. Water flow across the gills is maintained with a low-flow pump which gently irrigates channel water from the Toe Drain over the gills. The tag used for white sturgeon is a Vemco V16-H, 16mm x 90mm tag, 14g, with a smooth molded casing. A short incision (~2-3cm) is made offset to the left of the midline and anterior to the pelvic girdle, approximately at the third and fourth ventral scute (see Figure 4). The peritoneal cavity is inspected to determine the sex of the fish and stage of gonad development. Because it is extremely difficult to sex all but the most mature fish, a gonad sample is collected using tissue forceps, and preserved in a diluted solution of formaldehyde for histological analysis. The acoustic transmitter is inserted through the incision, which is then closed with three PDS II Violet Monofilament (absorbable) sutures. The transmitter is free-floating in the peritoneal cavity. A blood sample (~3mL or less) is collected from the caudal vein, posterior to the anal fin via hypodermic needle and stored in a vacutainer. The blood samples are later centrifuged and the plasma extracted. The plasma samples are later sent off for steroid profiles, in order to cross-validate the gender determination of the histological analysis. Fish are released immediately following surgery at the site of capture. The tagging procedure takes 3-4 minutes (unpublished data). Only fish larger than 80cm are tagged. Anesthetics are not permitted for this surgery, as white sturgeon are food fish with the potential for human consumption soon after release.

Adult Chinook Salmon Saddle-Back Tag and Release Procedure

Figure 2: Wires are twisted and cut after securing the 9x21mm "backpack" tag at the base of the dorsal fin of an adult Chinook Salmon in the surgery cradle.

Fish are removed from the fyke net using a two-meter fish cradle, and placed on a specially-constructed fish surgery table (the table is lined with foam and coated with stress-coat to avoid disturbing the mucus layer on the fish, and a damp cloth is placed over the fish's head to protect the eyes). A tube is inserted into the mouth of the fish to maintain a gentle flow of water passing over the gills. Once the fish is securely in place, a Vemco V9 tag is "backpacked" into place at the base of its dorsal fin. This involves passing two 3.5", 17-gauge needles completely through the tissue at the base of the dorsal fin so that they protrude on the opposite side of the puncture point. The two ends of a 10"-long, 26-gauge stainless steel wire, with a V9 tag shrink-wrapped to the middle of it, is threaded through the needles so that both ends of the wire are on the same side of the dorsal fin. The needles are then removed, and the wire is pulled to gently cinch down the tag at the base of the dorsal fin. The wires are then twisted together tightly (5-6 twists), securing the tag in place (Figure 2). Excess wire is cut off and the ends of the remaining wire are pushed close to the fish and coated with wax to prevent snagging. After this procedure is complete (approximately 2 minutes), the fish is placed in an oxygenated, cooled recovery tank and observed until normal swimming behavior and orientation returns (typically 3-4 minutes), after which it is carried back to the water in the cradle and carefully released.

On the recommendation of experts at the California Department of Fish and Wildlife who have performed this exact procedure on white sturgeon and striped bass, no anesthesia is used unless absolutely necessary. MS-222 is unsuitable for this procedure because the fish are released immediately after and put at risk for human consumption; the only other FDA-approved anesthetic available is carbon dioxide (CO_2). If we determine that the fish cannot be adequately restrained without the use of anesthesia or sedation, the adult salmon removed from the fyke net is placed in a temporary holding tank (>100 liter capacity) on the bank. Compressed CO_2 from a small cylinder is released into the water bath at a rate such that it does not displace air by more than 20% of the chamber volume per minute, following IACUC dosage recommendations. When loss of equilibrium is achieved, the fish is removed and placed on the surgical table for the procedure.

Fish caught using a gill-net or trammel net follow the same procedures, except they are transferred from the net into a DWR boat for transport to shore. The boat will is equipped with a holding tank (>100 liter capacity) for transport before anesthesia and surgery (transport to shore takes less than 1 minute in the Toe Drain). In order to prevent re-capture in the gill net, fish are released slightly upstream (~0.5km) of where they were caught.

Juvenile Fish Surgery and Release Procedure

The fork lengths of the juvenile Chinook Salmon tagged are between 100 and 130mm. Fish are fasted for up to 48 hours prior to surgery to ensure that they have an empty stomach. Each fish undergoing surgery is transferred from the holding tank into a 5 gallon bucket containing 90mg/L MS-222. This solution anesthetizes the fish within three minutes. The fish is then removed from the bucket and mass and length measurements are made (weight in grams, and fork length in millimeters). Following this, the fish is moved to a surgical table equipped with a foam pad where a tube is inserted into the mouth of the fish to ensure that a gentle flow of anesthetic solution (a maintenance dose) passes over the gills. The maintenance dose of MS-222 is buffered with sodium bicarbonate and monitored with a temperature and dissolved oxygen probe. Once the smolt is securely in place on the foam pad with the tube passing water over the gills, a 7-10mm incision is made in front of the pelvic girdle beside the mid-ventral line with a scalpel. This incision is opened and the ultrasonic tag is gently inserted into the peritoneal cavity and positioned so that the longitudinal plane of the tag is parallel with the fish. The incision is then closed with one suture using an appropriate size (5-0) antibacterial absorbable suture. The tagging procedure takes approximately 2-3 minutes (unpublished data).

Following surgery, the fish is placed into a small recovery tank, where initial recovery is closely watched. After recovery (where proper orientation and swimming is observed), the fish is returned to a holding tank with the other tagged fish, where they are allowed to recover for a period of at least 24 hours before release. After the 24 hours, the fish are transported in an aerated holding tank to the release site (see Figure 3). Fish are slowly acclimated to water from the Bypass (no more than 1 degree Celsius change per hour), before being released into the Toe Drain.

Range Testing

Prior to deploying receivers, preliminary range tests from a boat were conducted to determine the ideal spacing of receivers within cross-section arrays, as well as the longest range for each type of tag for single-placed receivers within the Toe Drain. These mobile range tests will be repeated under inundated conditions. In order to calculate precise detection probabilities for different tag types of varying delays[1], long-term range tests will also be conducted in both the lower and upper Bypass (separated by the Lisbon Weir). To do this, a range test tag for each type of transmitter, identical to the tags used in the fish except that the delay is fixed, will be placed on a mooring with a receiver. Downstream of the range test tag, a line of receivers will be placed 30m apart up to a distance of 330m, followed by a final receiver at 410m. After 7-10 days, we will recover the array and send the receiver data to the manufacturer, who will provide a detailed analysis of detection probabilities for each tag type used in the study. This will enable us to determine whether detection probability changes from night to day, as has been found in other locations in the Delta (personal communication, Steve Tsao).

Receiver Arrays

[1] In order to prevent acoustic interference between tags transmitting in the same area, random delays are incorporated into the programming of each tag. For example, the V9 tags are programmed to transmit every 30 seconds on average, with a random delay of 30-60 seconds. For these tags, a transmission may occur any time in the interval between 30 and 60 seconds. The length of the random delay affects the tag's probability of detection, and must be included in the analysis of range test results.

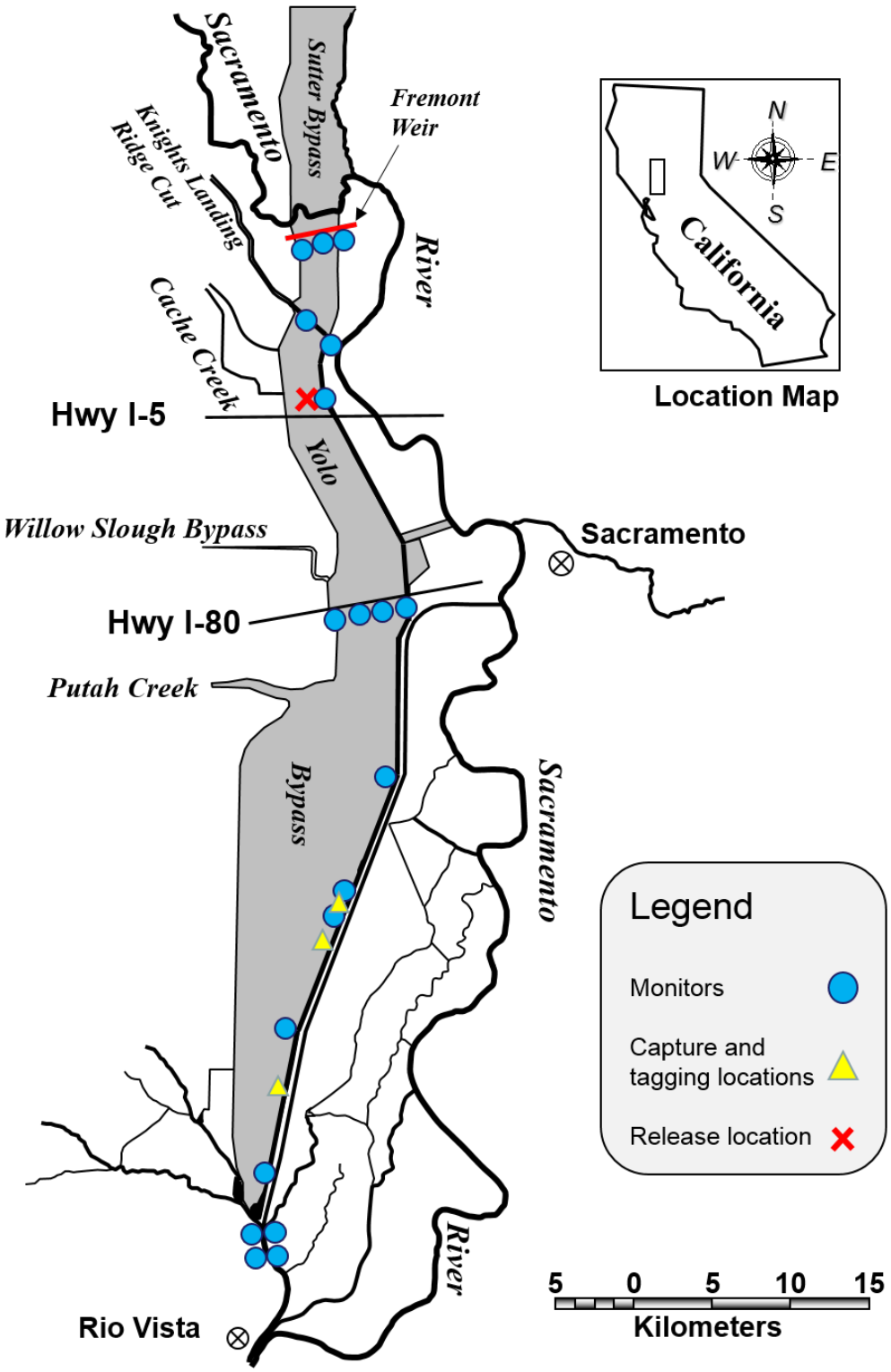


Figure 3.

Figure 3 depicts locations for both our core and flood receiver arrays. The core array includes all those except the monitors placed east-to-west across Hwy I-80 and the Fremont Weir, and is deployed year-round in the Yolo Bypass. The flood array includes the receivers placed east-to-west across I-80 Bridge and the Fremont Weir. We have not yet had to deploy a full flood array.

Receiver Arrays

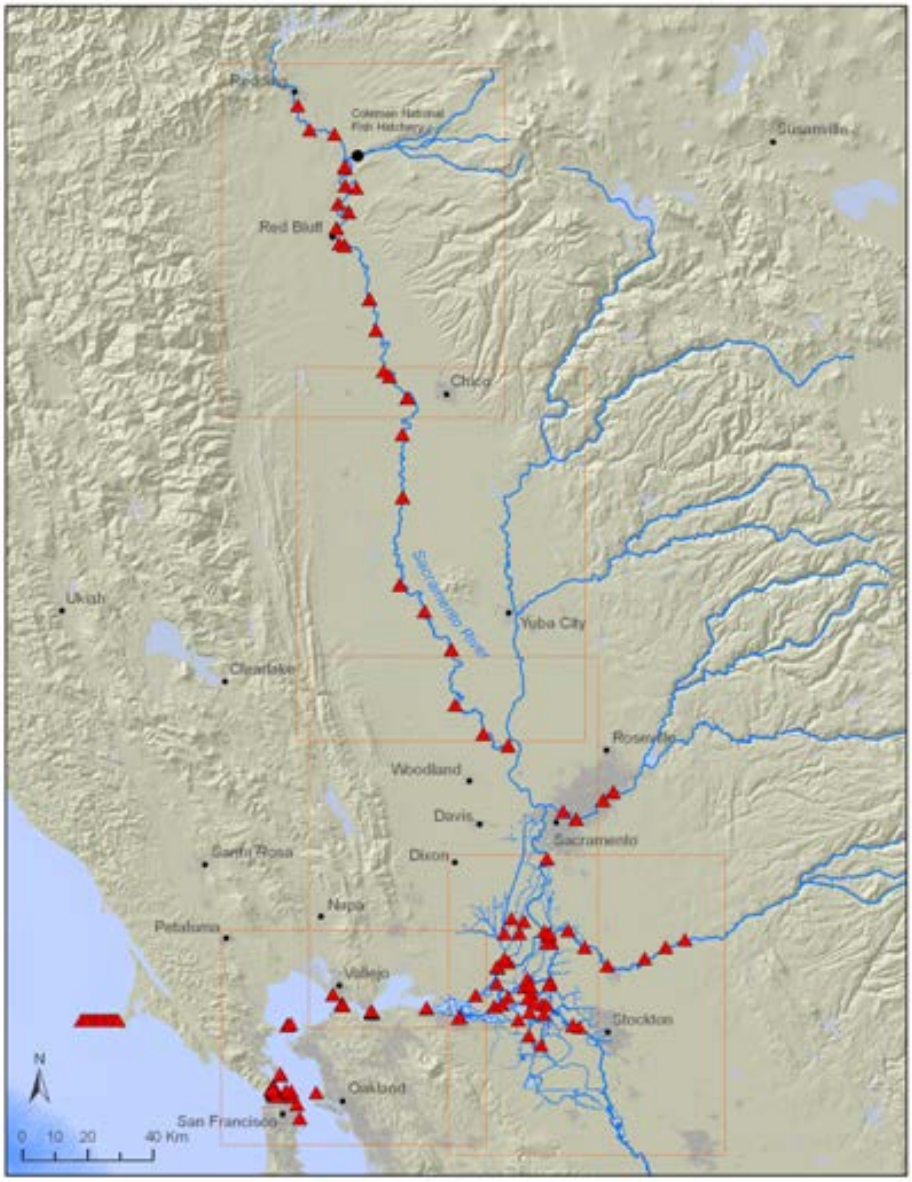


Figure 4.

Figure 4 depicts the locations of ~250 receivers within the larger array maintained by the California Fish Tracking Consortium. We have access to the detections of our fish recorded on these monitors, allowing us to track our tagged fish throughout the Sacramento-San Joaquin Delta after they leave the Yolo Bypass.

Tagging Summaries

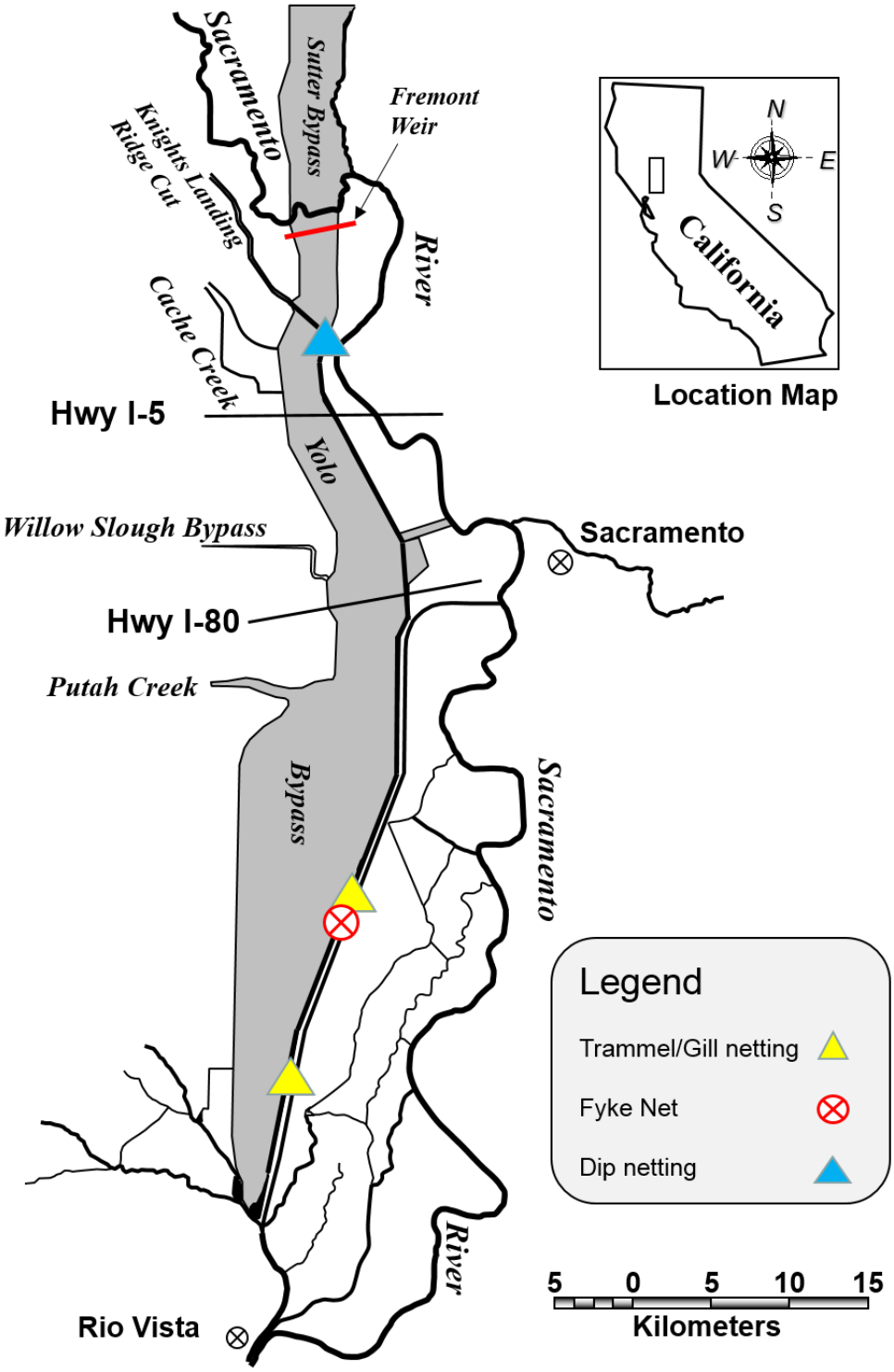


Figure 5.

Figure 5 depicts the locations of tagging activities between 2012 and 2014. The legend displays the type of tagging employed at each location. For a summary of individual fish tagged, please see Table 1 on the following page.

Tagging Summaries

Table 1: Complete summary of all fish tagged in the Yolo Bypass to date.

Year	Species	Life Stage	Tag Dates	Number Tagged	Estimated Tag Life
2012	White sturgeon	Spawning adult	March 16-23	68	2-5 years
2012	Chinook Salmon	Smolt	March 29	25	22 days
2012	Chinook Salmon	Spawning adult	October 24-November 27	12	90 days
2013	Chinook Salmon	Smolt	March 5	25	63 days
2013	Chinook Salmon	Spawning adult	September 26 – November 25	52	90 days
2014	White sturgeon	Spawning adult	February 13 – March 11	25	10 years
2014	Chinook Salmon	Spawning adult	September 30 – November 21	35	90 days

Table 2: Tag Summary of Juvenile Late-Fall Chinook Salmon

Year	Fork Length Range (mm)	Mean Fork Length (mm)	Weight Range (g)	Mean Weight (g)
2012	107-145	126.5	12.0-32.1	22.3
2013	107-125	116	12.6-23	17.1

Tagging Summary

Table 3: Tag Summary of Adult Fall Chinook Salmon

Year	Fork Length Range (cm)	Mean Fork Length (cm)	Males	Females	Unknown Sex
2012	59.5 - 84.0	74.9	3	8	1
2013	64.9 – 90.0	79.5	23	24	5
2014	61.8 - 96.0	75.2	14	15	4

Table 4: Tag Summary of Adult White Sturgeon

Year	Fork Length Range (cm)	Mean Fork Length (cm)	Males	Females	Unknown Sex
2012	92 – 190	146.2	42	4	21
2014	109 – 192	142.5	23	1	1

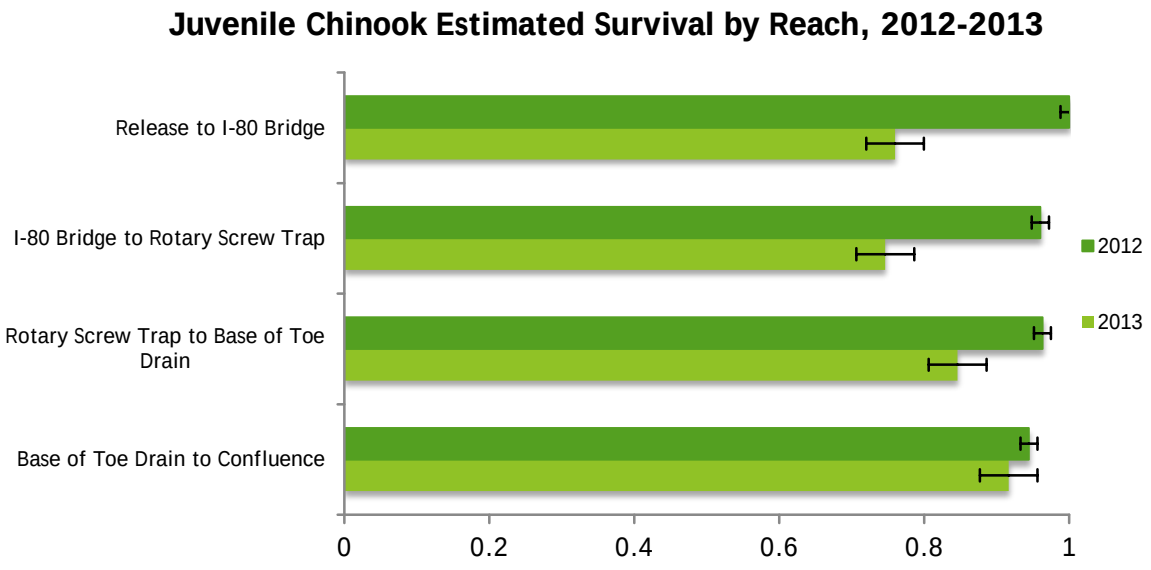
Juvenile Chinook Survival Analysis

Survival (Phi) was estimated by year using Program MARK (v.8.0). Reported estimates are for survival and detection probability from release site (river km 159) to the Base of the Confluence (river km 106), a reach of 53km.

The parameter estimates reported in the table below correspond to the fixed effects model Phi ~ year + p, where p refers to detection probability. This model had the second-lowest AIC score during model selection (Delta AICc = 0.02). Detection probabilities in the Yolo Bypass were excellent for both years, resulting in estimated parameter values of 1.0; both parameter estimates and reach-specific survival estimates may be revised after data from Chipps Island receiver are included in future analyses.

Parameter	Estimate	Standard Error	Lower 95% CI	Upper 95% CI
Phi 2012	0.8529412	0.0429488	0.7477680	0.9190101
Phi 2013	0.7500000	0.0578638	0.6209878	0.8459889
p	1.0000000	0.0000000	1.0000000	1.0000000

Figure 6: Survival estimates by reach in the Yolo Bypass for the model Phi ~ (year*reach) + p (Delta AICc = 0.07).



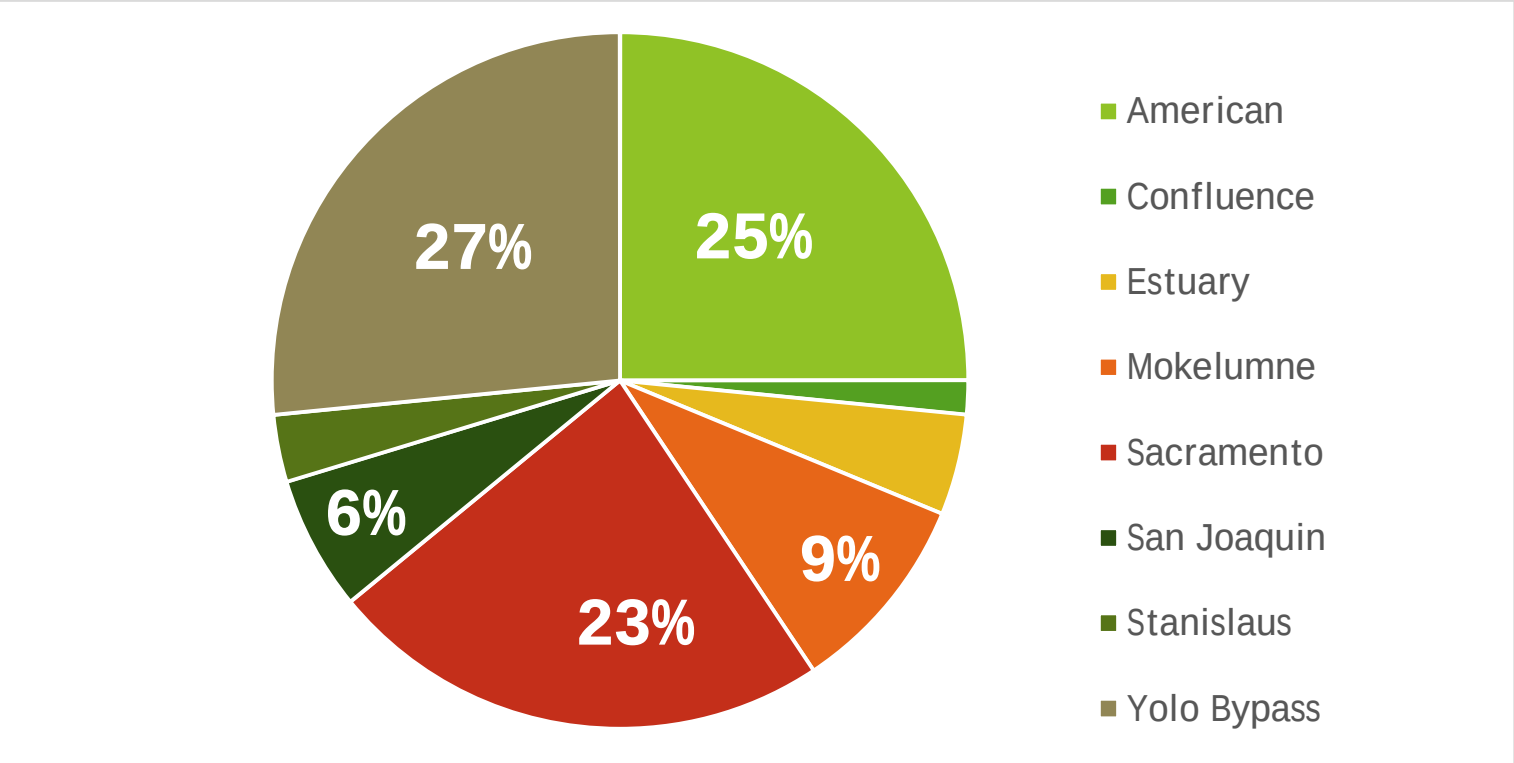
Standardized by river kilometer, estimated survival for 2012 was 0.997/km, or 0.97/10km. Estimated survival for 2013 was 0.994/km, or 0.947/10km.

Adult Chinook Salmon Route Selection and Final Detection Summary

Table 6: Final Detection Locations of Adult Chinook Salmon Migrants, 2012-2013

Location	Distinct Routes	Individuals
American River	6	16
Base of the Confluence	1	1
Mokelumne River	1	6
Sacramento River	8	15
San Joaquin River	1	4
Stanislaus River	1	2
Toe Drain (Yolo Bypass)	1	17
Totals	**20**	**64**

Figure 7: Final detection locations of adult Chinook migrants by proportion.



Adult Chinook Salmon Residence Time Summary

Table 7: Mean residence at receiver locations throughout the Yolo Bypass.

Site	River Kilometer	Number of Fish	Mean Residence (days)
Confluence	0	43	0.34
Base of Toe Drain	7.21	43	0.28
Rotary Screw Trap	14.44	42	0.51
Lisbon Weir	29	19*	0.67
Above Lisbon	30.5	11	0.52
I-80 Bridge	39.84	9	0.30
Cache Creek	52.83	1	0.03
Knagg's Ranch	54.59	1	1.61

*outlier removed

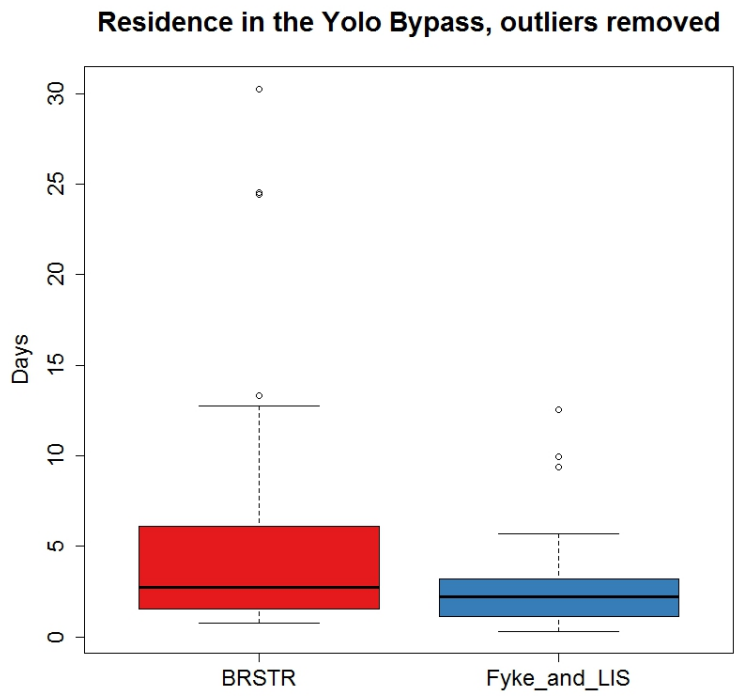


Figure 8: To see if residence time differed with tagging location, migrants tagged in the 'lower bypass' (below Lisbon Weir) and those tagged in the 'upper bypass' (above Lisbon Weir) were grouped and compared. The boxplot on the left shows these data with three possible shed tags removed from the analysis. The means for the groups are fairly similar – 5.86 days for the lower bypass, and 3.75 days for those tagged in the upper bypass. Total mean residence was 4.86 days.

Adult Migrant Movement Summary

The two migrant species tagged in this study (white sturgeon and Chinook Salmon) differ in their respective migratory ranges. This can be observed in the maps of detection locations and migrant tracks below.

Figure 9: Ranges of detection locations for white sturgeon (gray dots), Chinook Salmon (red dots) and both (black dots).

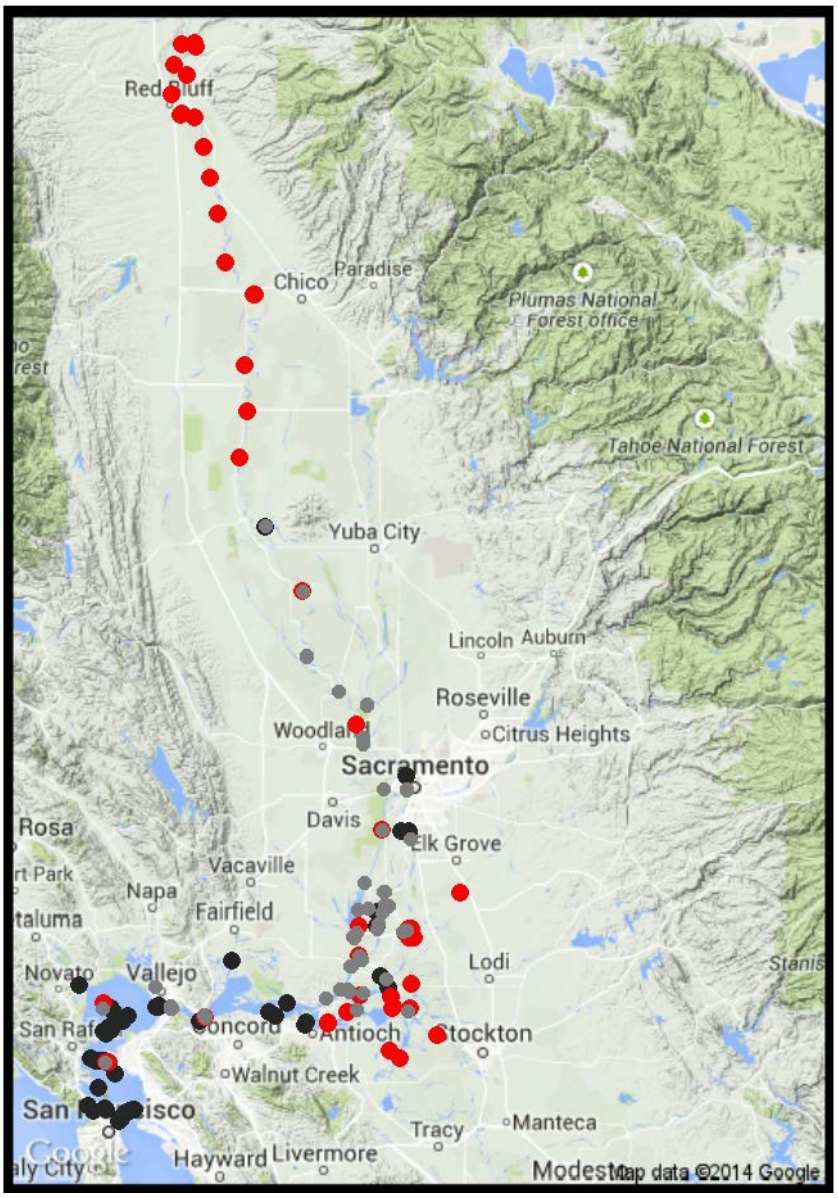
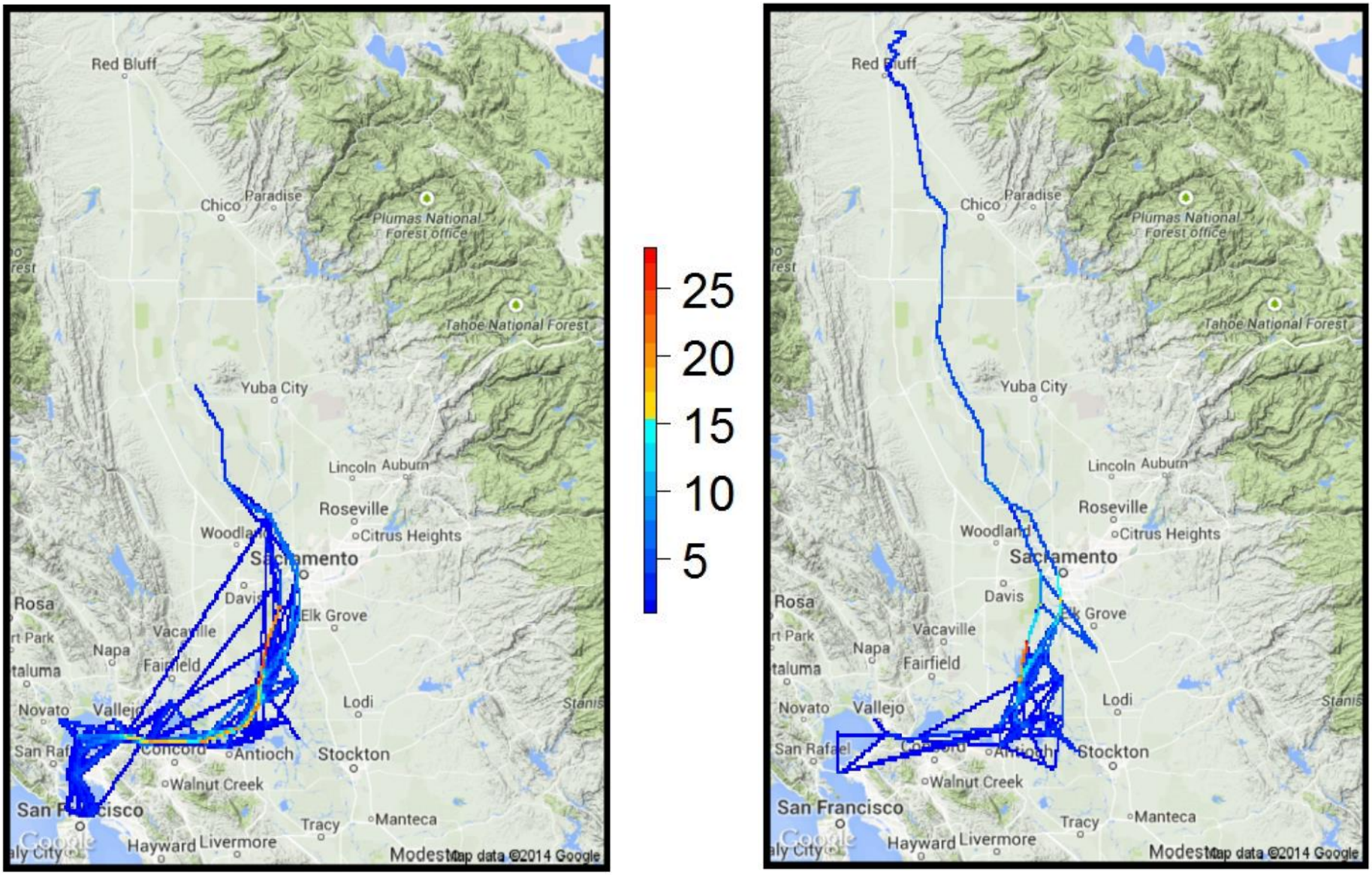


Figure 10: Individual migrant track density plots for white sturgeon (left) and Chinook Salmon (right) migration tracks. Lines across land indicate a false detection in the chronology of a single migrant track. False detections were discarded prior to residence time calculations.

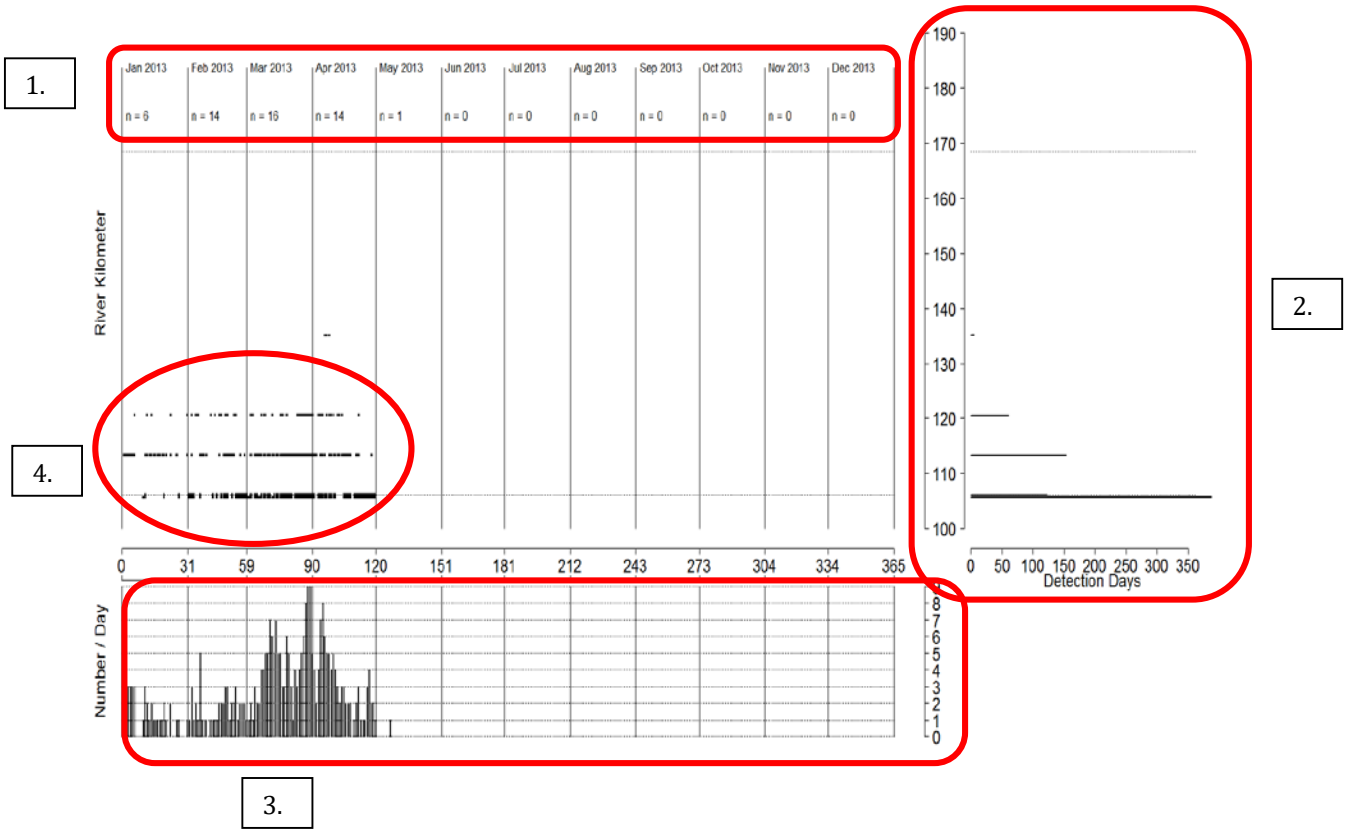


White Sturgeon Spatiotemporal Movement Summary

As iteroparous migrants, white sturgeon give us an opportunity to examine long-term trends in movement and behavior of individuals, and the chance to observe repeatability of those trends. The following section presents an overview of their presence in the Bypass via a few spatiotemporal plots.

Spatiotemporal plots allow us to see where individual white sturgeon in the Yolo Bypass are distributed in space (by river kilometer) and time (in these plots, by month of the year). The plots on the following pages show a clear pattern of residence by white sturgeon beginning in early October, and continuing through early May each year.

Figure 11: Anatomy of a spatiotemporal plot.



Clockwise from top:

1. Months of the year and number of individuals detected within each month (n).
2. Number of detections (x axis) by River kilometer (y axis)
3. Number of individuals (y axis) by Julian day (x axis, top)
4. Detections by river kilometer (y axis, right), Julian Day (x axis), and month (top axis).

Figure 12: Spatiotemporal patterns of white sturgeon (n=67) tagged in 2012.

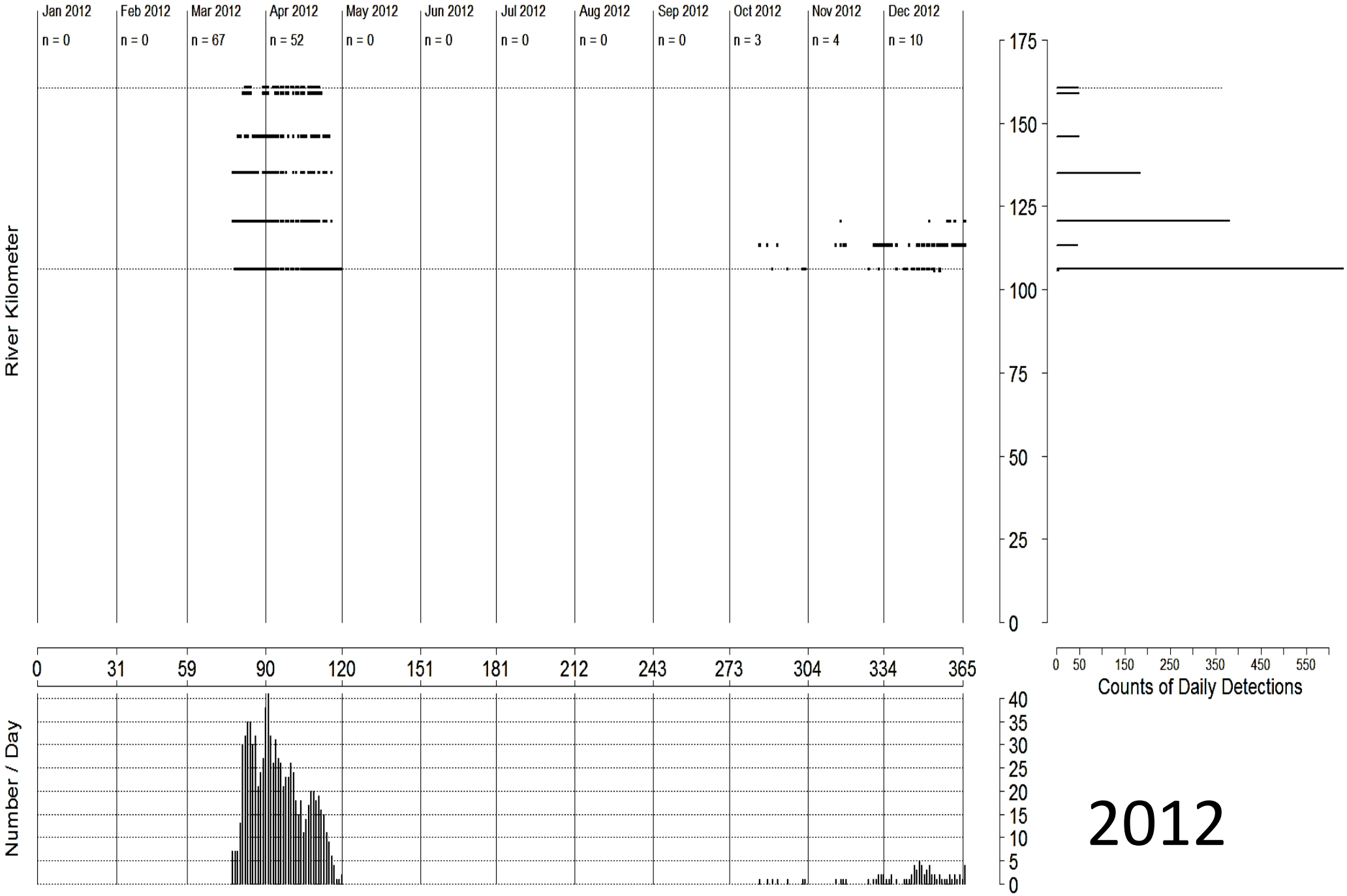


Figure 13: Spatiotemporal patterns of white sturgeon tagged in 2012 that returned in 2013 (n=19).

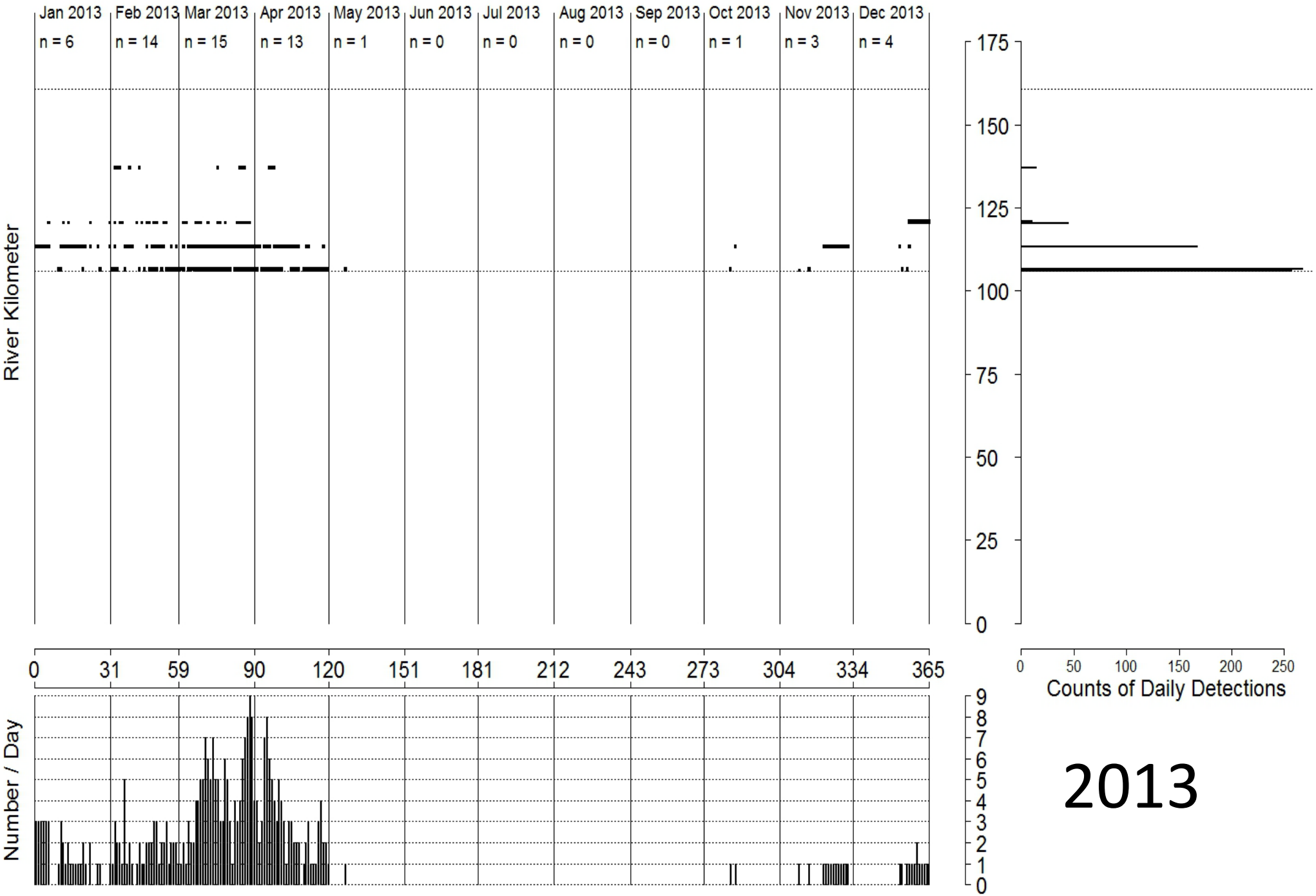
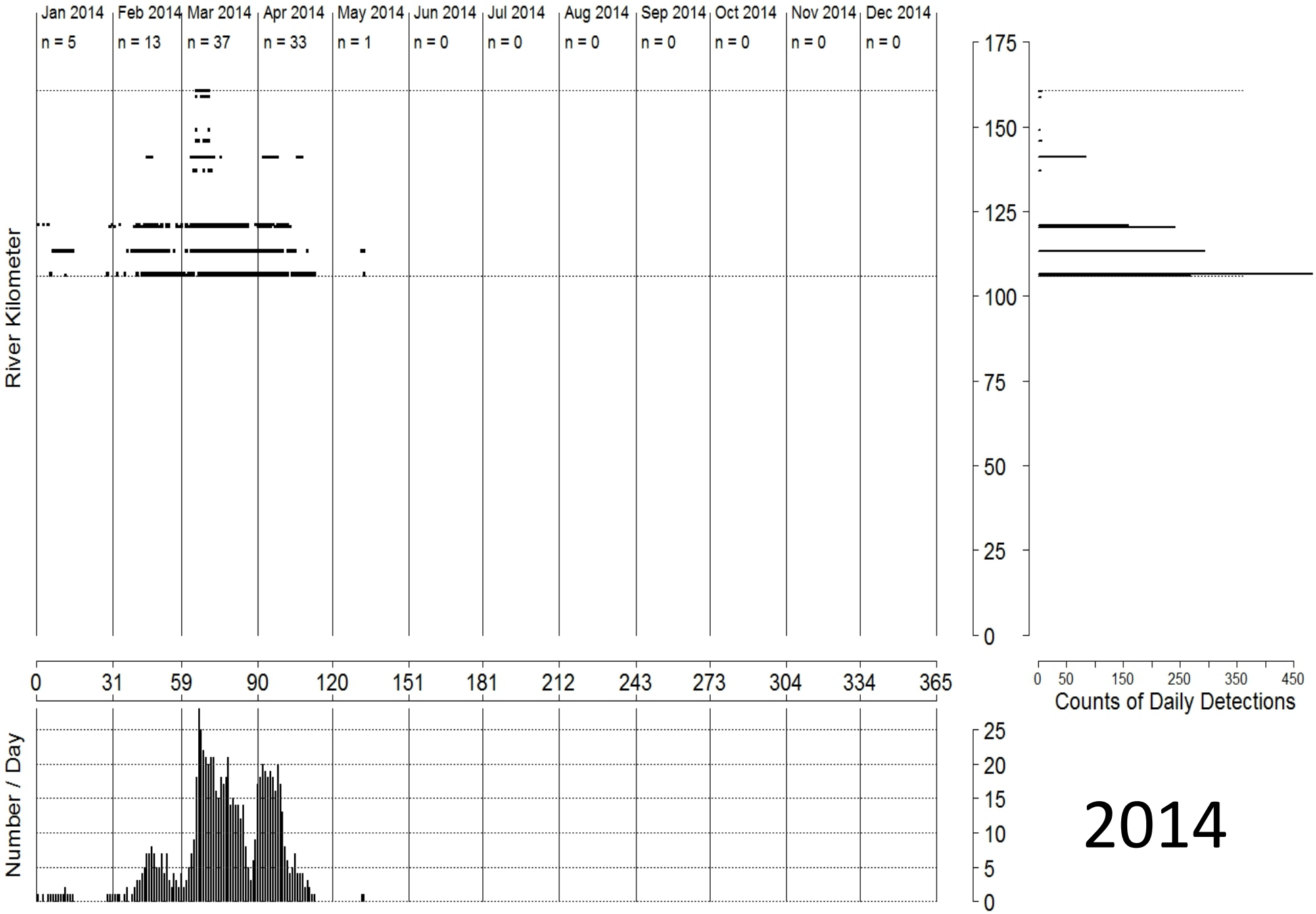


Figure 14: Spatiotemporal patterns of white sturgeon tagged in 2014 (n=25) and those tagged in 2012 that returned (n=14).



Planned Analyses

Environmental Covariates

We would like to begin examining the role of environmental covariates on movements within the adult migrants. Cross-correlation analysis with flow and Julian Day will be conducted on movements within the iteroparous (white sturgeon) and semelparous (Chinook Salmon) groups. A cluster analysis will be used to determine whether any clear behavioral variances exist between seasonally "early" or "late" semelparous migrants, as has been observed in other studies (Vincik *et al.*, 2013; Groot *et al.*, 1976; Olson and Quinn, 1993). Entries and exits from the Bypass will be recorded by the gated array of four receivers at the confluence just above Rio Vista (see Figure 1). Discharge (flow) is measured in cubic feet per second, and is recorded for the Yolo Bypass and the Sacramento River by the California Department of Water Resources (cdec.water.ca.gov/).

Analysis of full migratory tracks will be conducted using the larger array of ~250 monitors in the Sacramento-San Joaquin Delta (see Figure 4). Alteration of a migratory path will be defined as an exit from the Yolo Bypass, followed by subsequent migration up the Sacramento River. Abandonment of migratory path will be defined as an exit from the Yolo Bypass and no subsequent movements up the Sacramento River. The likelihood of migrants to abandon their trajectories will be analyzed with a Classification and Regression Tree (CART). The tree will explain the variation in alteration or abandonment of spawning migration (as evidenced by telemetry) by repeatedly dividing the data into parsimonious groups, using combinations of all the predictor variables that can be used to describe a fish's migratory path. Predictor variables may be categorical (e.g., semelparous or iteroparous) or numeric (total number of river kilometers traveled, Julian Day, turning rate, etc.) (De'ath and Fabricius, 2000). The CART will be analyzed using the rpart package in R (cran-r.org).

Movement Behavior and Barriers to Passage

Listening stations placed immediately downstream and upstream of all weirs in the Yolo Bypass allow us to determine whether a tagged fish has successfully passed upstream of a weir, as well as the residence time of that fish above and below the weir. Range tests will ensure that a fish below the weir cannot be detected by the monitor above the weir. Communication with the owners and operators of both Swanston and Wallace Weir allows us prior knowledge of their opening and closing. Water temperature and dissolved oxygen levels, which may represent physiological barriers to passage, will be measured continuously below each weir by YSI Sonde water quality units. A classification tree will be used to look iteratively for a predictor (e.g., species) and a cutoff point germane to fish movement and passage (e.g., residence time at a weir before or after it opens, specific temperature and/or dissolved oxygen thresholds) that separates the observations for salmon and sturgeon.

Conclusions

We have demonstrated the efficacy of acoustic telemetry for investigating migratory behavior in the Yolo Bypass. Preliminary results suggest:

- The Yolo Bypass may serve as a sink for a large proportion (~25%) of the adult Chinook Salmon that enter the Bypass during their spawning migration.
- White sturgeon are present in the Yolo Bypass throughout much of the year, and demonstrate the capability to exit the Bypass successfully under dry conditions.
- Survival in the Toe Drain from the I-5 Bridge to the Mouth of the Sacramento River is relatively high for outmigrating late-fall Chinook smolts under dry conditions.
- There does not seem to be any obvious areas of the Yolo Bypass that represent high mortality for juvenile Chinook, but in-depth survival modeling will examine this further.

From a broad perspective, results from these field studies will contribute to our understanding of how reproductive strategy reflects on the movement behavior of vastly different migratory species, and may provide a starting point upon which further comparative studies may be based.

By investigating behavior that is critical to the ecological well-being of migratory species in a human-dominated system, this study can inform actions that take an adaptive, reconciliation approach to management. The Yolo Bypass has vast potential as a system capable of supporting human demands without eliminating the processes needed to sustain desirable aquatic species.

References

De'ath, G., & Fabricius, K. E. 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. *Ecology*, *81*(11), 3178-3192.

Groot C, Simpson K, Todd I, Murray PD, Buxton GA. 1975. Movements of sockeye salmon (Oncorhynchus nerka) in the Skeena Estuary as revealed by ultrasonic tracking. J. Fish Res Board Can 32:233–242

Olson, A, Quinn, T.P. 1993. Vertical and horizontal movements of adult Chinook Salmon, Oncorhynchus tshawytscha, in the Columbia River estuary. Fishery Bull. Fish Wildl. Serv. U.S. 91, 171–178

Vincik, R. F. 2013. Multi-year monitoring to facilitate adult salmon passage through a temperate tidal marsh. *Environmental biology of fishes*, *96*(2-3), 203-214.

Acknowledgements

We thank the Ecological Restoration Program for funding for this project. We would also like to thank everyone at the Department of Water Resources and in the Biotelemetry Lab who has helped with fieldwork, experimental design, and analysis so far. Special thanks to the landowners and managers in the Yolo Bypass (especially John Brennan and Mike Leary) who have graciously kept us in the loop with their day-to-day weir operations.

Appendix B: Yolo Bypass Historical Salmon Data Analyses

Project Leads: Lynn Takata, Ted Sommer, Louise Conrad (CDWR)

INTRODUCTION

The Department of Water Resources (under the guidance of IEP) has conducted fish monitoring in the Yolo Bypass (Bypass) since 1998. Much of the emphasis of this monitoring has been juvenile Chinook Salmon. Important issues such as growth and feeding ecology in specific years have been examined (Sommer *et al.*, 2001a, b; 2005; Henery *et al.*, 2010), but questions remain about long-term patterns of residency, growth, emigration and survival. Our previous studies based on much smaller data sets indicate that at least some dependent variables (total catch/day) has a strong flow response (Sommer et al., unpublished data; Del Rosario et al. 2013). Moreover, the work of Sykes et al. (2009) suggests that additional environmental variables are likely to be important. Utilizing data streams from several components of CDWR's Yolo Bypass monitoring program, this task aims to evaluate between-year (inter-annual) and within-year (intra-annual) demographic patterns of juvenile CChinook Salmon that utilize the bypass as rearing habitat. Data from groups of tagged hatchery CChinook Salmon and untagged wild CChinook Salmon, the general questions addressed here are:

- What environmental factors influence juvenile Chinook Salmon growth, residence time, size at emigration, and emigration timing in the Yolo Bypass?
- What factors influence relative catch of wild (unmarked) juvenile Chinook Salmon in the Yolo Bypass?
- Are there differences in comparative long-term survival between CChinook Salmon that utilized the Yolo Bypass versus those that utilized the adjacent Sacramento River as juveniles?

METHODS AND DATA SOURCES

Data for this analysis originates from three components of CDWR's Yolo Bypass fisheries monitoring program. First, catch of juvenile salmonids has been measured each winter and spring using a rotary screw trap near the base of the floodplain (Sommer *et al.*, 2005; Figure 1). The trap has been operated 5-7 days a week since 1998, weather and safety conditions permitting. It is strategically located near the downstream end of the Toe Drain, the eastern channel which empties the Yolo Bypass following inundation events. The second component is a beach seining monitoring program that has sampled 5-9 sites along the Toe Drain twice monthly since 1998. During flooding events, 4 additional sites are sampled weekly. The third component consists of paired releases of 50,000-100,000 coded-wire tagged (CWT) juvenile hatchery fish at the north end of Yolo Bypass and in the adjacent Sacramento River from 1999-2009 (Sommer *et al.*, 2001b, 2005). One or two paired releases events were conducted in each of these years, during February and/or early March. A

sub-sample of tagged fish were subsequently recovered by the Yolo Bypass rotary screw trap, and by the ocean fishery until 2007, after which the fishery was closed because of low stocks.

During the same time period, environmental data was collected including flow, duration of flooding, photoperiod, and temperature. Daily flow data was obtained from the Yolo Bypass component of CDWR's Dayflow Program, which an estimates total daily Delta outflow (http://www.water.ca.gov/dayflow/). The Yolo Bypass component consists of combined flows at the Yolo Bypass at Woodland, spill over the Sacramento Weir (rare), and flows in the South Fork Putah Creek. Duration of flooding was calculated as the number of days the Bypass experienced widespread flooding, which occurs when flows meet or exceed 4000 cfs. Photoperiod data was obtained from the United States Naval Observatory (http://www.usno.navy.mil/USNO/). Continuous (15 minute) water temperature data was collected by a logger installed at the rotary screw trap starting in 1999. Discreet temperature data was also collected during daily screw trap checks and biweekly/weekly beach seine events. Accumulated thermal units (ATUs) were calculated as the sum of daily mean temperatures.

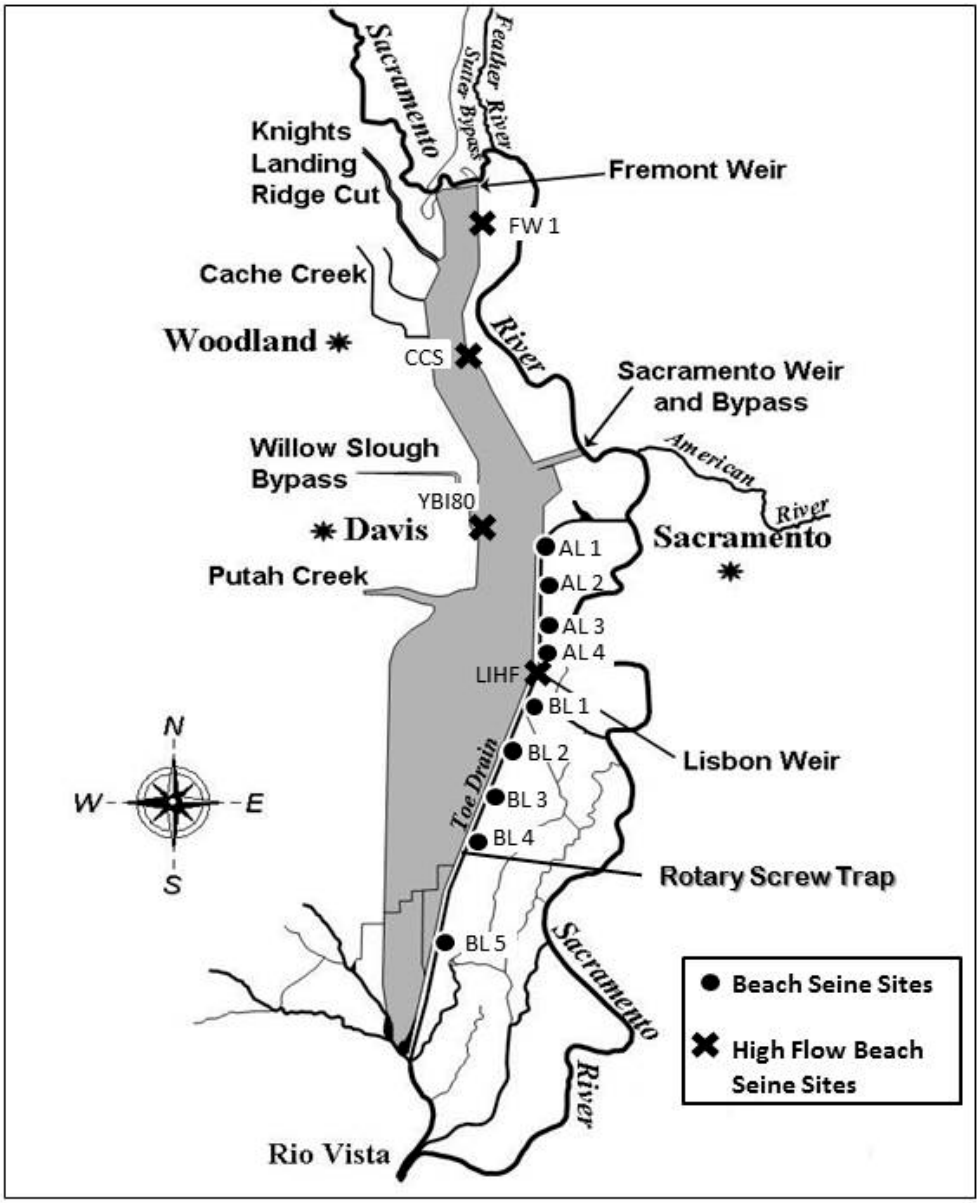


Figure 1. Map of the Yolo Bypass study area and sampling sites.

For analyses involving catch of wild (unmarked) Chinook juveniles, escapement estimates of the fall+spring Sacramento River spawning cohort were also included as an independent variable. Data was obtained from the GrandTab report: a compilation of Chinook Salmon escapement estimates assembled annually by CDFW, Fisheries Branch Anadromous Resource Assessment Unit (http://www.calfish.org/ProgramsData/Species/CDFWAnadromousResourceAssessment.aspx). Estimates are based on carcass surveys, live fish count, hatchery returns, and redd count data collected by an array of agencies, including CDFW, USFWS, DWR and USBR.

DATA ANALYSIS

The environmental variables affecting residence time, emigration timing, and growth were addressed by analyzing the dependent (fisheries) and independent (environmental, population data) variables (Table 1). The variables included both inter-annual and intra-annual to address different study questions. Multiple regression methods (e.g., Grimaldo *et al.*, 2009) were used to identify the major relationships. For example, one of the dependent variables (e.g. growth) was applied in a multiple regression model to evaluate whether there were significant relationships with the independent predictor environmental variables (flow, flooding duration, photoperiod, water temperature, ATU) (Table 1).

Environmental metrics used in inter-annual analyses were averaged over time periods when CWT or unmarked juvenile salmon were likely rearing in the Yolo Bypass system ("rearing periods"). For analyses involving CWT salmon, calculations were constrained from the date of release to the date of median cumulative catch at the RSTR (date when 50th percentile of the seasonal catch was captured). For unmarked salmon, calculations began from the first date after January 1 when Fremont Weir overtopped, as this would be when substantial numbers of wild juveniles could gain access to inundated Bypass habitat. Mean calculations ended on date of median cumulative catch. All dependent environmental were tested for colinearity before inclusion into respective regression models, and variables with correlation coefficients greater than 0.7 were eliminated from analysis (Dormann et al. 2012). Data used in linear regressions that displayed non-normality (Anderson-Darling test, $p<0.05$) were log transformed to meet assumptions.

For analyses involving wild juveniles, only salmon with clearly intact adipose fins were included. Fish categorized as winter-run via the "Fisher criteria" currently used for OCAP Biological Opinion (NMFS 2009) were excluded. For analyses involving CWT salmon, a small percentage recaptured at the rotary screw trap within 24 hours of release (~2%) were also excluded, because these individuals would not reflect demographics representative of juveniles that spent time rearing in the Bypass floodplain habitat.

Question	Dependent Variable(s)	Independent Variable (s)	Study years	Juvenile type	Statistics
What environmental factors influence ***INTER-annual*** **Chinook Salmon** growth, residence time, size at emigration, and emigration timing in the Yolo Bypass?	Apparent growth Residence time (days) Apparent growth rate Emigration timing (median catch date at RSTR)	Temperature ATU* Flow* Duration of flooding (days) Photoperiod* Temperature ATU Flow* Duration of flooding (days) Photoperiod	CWT: Release years 1999-2005, 2007-2011) Unmarked: Fremont Weir overtopping years 1999, 2000, 2002-2006, 2010 and 2011.	CWT Unmarked	Multiple linear regression
What factors influence ***INTER-annual*** relative abundance of wild (unmarked) juvenile Chinook in the Yolo Bypass?	CPUE per season at the RSTR	Temperature ATU Flow* Duration of flooding (days) Photoperiod* Spawner escapement	Fremont Weir overtopping years 1999, 2000, 2002-2006, 2010 and 2011.	Unmarked	Multiple linear regression
What environmental factors affect the ***INTER-annual*** comparative survival of juveniles that utilized the Yolo Bypass vs. the Sacramento River as rearing habitat?	Yolo Bypass to Sacramento River CWT estimated survival ratios in the ocean fisheries	Temperature ATU* Flow Duration of flooding (days) Photoperiod* Ocean upwelling index	1998-2005 (ocean fishery was closed in 2008 precluding use of recoveries after the 2005 release group)	CWT	Multiple linear regression Linear regression
What environmental factors affect ***INTRA-annual*** emigration timing and catch in the Yolo Bypass?	None Biweekly RSTR CPUE	Temperature Temperature ATU* Flow Photoperiod*	CWT: Release years 1999-2005, 2007-2011) Unmarked: Fremont Weir overtopping years 1999, 2000, 2002-2004, 2006, 2010 and 2011.	CWT & Unmarked Unmarked	Graphical examination Generalized linear modelling

Table 1. Summary of dependent and independent variables, study years, and statistics used in analyses of study questions for this task. Variables in gray text marked with an asterisk (*) were excluded from multiple regression models due to high colinearity (Pearson's correlation coefficient >0.7).

Inter-Annual Patterns

Inter-annual patterns of residence time and apparent growth were examined via CWT juveniles at the rotary screw trap. Releases included were conducted from 1999-2009. Data from 2006 was excluded due to low recaptures. Residence time (days) was calculated as the date of recapture minus date of release. Apparent growth rate (mm/day) was calculated as size at recapture (mm) minus mean size at release, divided by the number of days at large. Multiple linear regression models tested response variables against independent environmental variables (water temperature, ATU, photoperiod, flow, and duration of flooding) averaged by the calculated rearing period.

Environmental influences on emigration timing were examined via wild (unmarked) juvenile salmon captured at the RSTR during Fremont Weir overtopping years. Emigration date was calculated identically to CWT fish. Environmental data was restricted to years when the Sacramento River overtopped Fremont Weir during the winter and early spring, as these were periods when substantial numbers of wild juveniles would have access to inundated floodplain habitat. Overtopping years examined were 1999, 2000, 2002-2006, 2010 and 2011. 2005 was excluded from this analysis, because overtopping that year did not occur until late May after most wild juveniles have typically moved downstream. In addition, the relationship of total seasonal catch with environmental variables and the spawning population were examined. Catches at the rotary screw trap were adjusted for effort (hours of operation) and CPUE values were used as the response variable. In addition to environmental variables, escapement estimates of the fall and spring spawning cohort was also included in the regression model as an independent variable. Apparent growth rate of wild juveniles was also estimated to evaluate if patterns with environmental variables were evident, and if these were similar to patterns observed for CWT juveniles. Fork lengths from unmarked salmon captured in beach seine and rotary screw trap sampling from January-June in the Yolo Bypass were regressed on date. A robust iteratively re-weighted least squares regression procedure was utilized due to the presence of outliers in the dataset (Venables and Ripley 1997).

Inter-Annual Survival

Long-term survival of CWT releases was evaluated through catches in the commercial and sport ocean fisheries. Because fishing effort was assumed to vary from year to year but should be similar for release groups in any single year, survival analyses were based on the paired nature of the CWT releases and estimated catches in the commercial and sport ocean fisheries (Newman and Brandes 2010). Estimated catches were obtained from the Regional Mark Information System (RMIS) administered by the Pacific States Marine Fisheries Commission, and are based on the total number of fish that were tagged and expansion factor based on the total proportion of catch sampled. These values are then summed across all port and time strata for a total estimated catch (Nandor et al 2010). A "recovery fraction" was calculated for each release group in each system (Yolo Bypass or Sacramento River) as:

$$\frac{\text{\# Released}}{\text{Estimated \# Captured in Ocean Fishery}}$$

A paired t-test of recovery fractions was used to evaluate if there was a significant overall difference in long-term survival between CWT juveniles that reared in the Yolo Bypass in comparison to the Sacramento River. Patterns of comparative survival between Yolo Bypass and Sacramento River releases were also evaluated against independent environmental variables that reflected Yolo Bypass environmental conditions, as well as Yolo Bypass growth rate, residence time, and size at emigration, in regression models using a "survival ratio" as the dependent variable. The survival ratio was calculated for each paired release as follows (Figure 2):

$$\frac{\text{(\# Released in YB)/(Estimated \# of YB Release Captured in Ocean Fishery)}}{\text{(\# Released in Sacramento River)/(Estimated \# of Sac. R. Release Captured in Ocean Fishery)}}$$

Only data from releases during 1998-2005 could be used for these analyses because the fishery was closed 2008 due to low stocks.

In addition to environmental variables reflecting Yolo Bypass conditions, survival ratios were also compared against the late spring-early summer ocean upwelling index to evaluate if early juvenile habitat use translated to differential survival patterns at ocean entry. Upwelling indices were obtained from NOAA's Pacific Fisheries Environmental Laboratory (Bakun 1973) for a station located off of Point Arena, CA approximately 250 km northeast of San Francisco Bay (http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/). The index was averaged from March-June to coincide with the time span during which CWT released juveniles would exit the estuary.

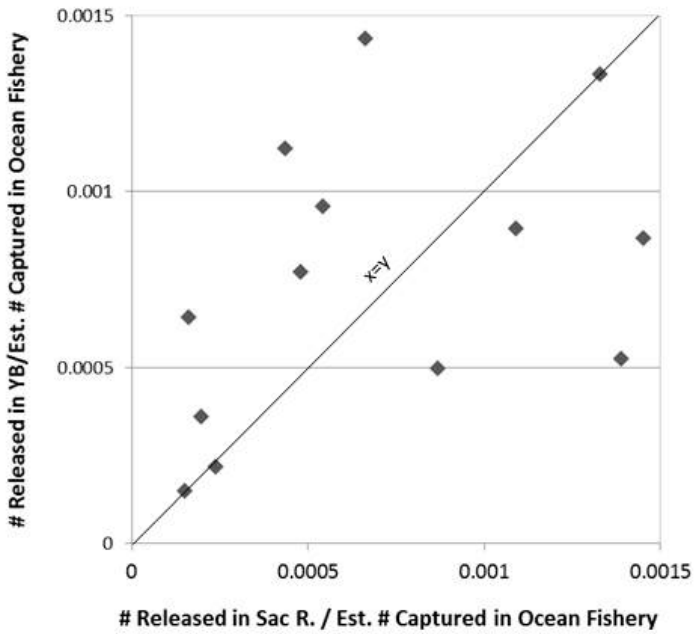


Figure 2. Recovery fractions from paired release groups captured in the ocean fishery. Each point depicts a release pair and the diagonal depicts the 1:1 recovery fraction line, where Yolo Bypass and Sacramento River recoveries were equivalent. Points below the diagonal are release pairs for which the survival of the Sacramento River release was comparatively higher. Points above the diagonal are release pairs for which the survival of the Yolo Bypass release was higher.

Intra-Annual Emigration

Intra-annual emigration patterns and relationships with environmental variables were examined for both unmarked and coded wire tagged juveniles catches at the rotary screw trap (RSTR) as they moved out of the Bypass. Relationships with water quality parameters were examined graphically through superimposition of cumulative catch curves against daily averaged flow. Environmental predictors for intra-annual emigration of unmarked juveniles were also evaluated quantitatively via generalized linear modeling. Variables were averaged over biweekly (2 week) periods in order to address temporal autocorrelation (Grimaldo et al. 2009). Because daily catches at the rotary screw trap exhibited a high frequency of zero and low counts, a Poisson error distribution was specified in the model with an offset term based on fishing effort (number of hours the rotary screw trap was fished). Dependent variables included were temperature, ATU, flow, and photoperiod. Models were compared using Akaike's information criterial adjusted for small sample datasets (AICc). Only data from years when the Sacramento River overtopped Fremont Weir were included in this analysis, as these were periods where substantial numbers of wild juveniles would have access to inundated floodplain habitat.

Overtopping years examined were 1999, 2000, 2002-2006, 2010 and 2011, and as with the inter-annual analyses of unmarked juveniles, 2005 was excluded because overtopping occurred very late in the season (late May).

RESULTS

For both inter- and intra-annual analyses, several environmental variables exhibited strong colinearity. For inter-annual rearing periods, flow was highly correlated with inundation duration for both wild and CWT juveniles (Pearson's correlation coefficient r=0.82 and 0.75). Because a flooding variable was considered biologically important for the evaluation of floodplain habitat use, flooding duration was retained in both sets of analyses. For analyses involving CWT fish, flooding duration was also strongly correlated with photoperiod (r=0.84) and ATU (r=0.80), and the later variables were dropped from inter-annual analyses. For the inter-annual analysis of wild Chinook seasonal catch, spawner escapement was highly correlated with photoperiod (r=-0.71). Since the quantity of the parent cohort was considered to be more relevant for catch, photoperiod was excluded. At the biweekly time scale of the intra-annual analysis of wild salmon emigration and catch, photoperiod was highly correlated with temperature (r=0.93) and ATU (r=0.88), so temperature and flow were the only variables retained for analysis (Figures 3-5).

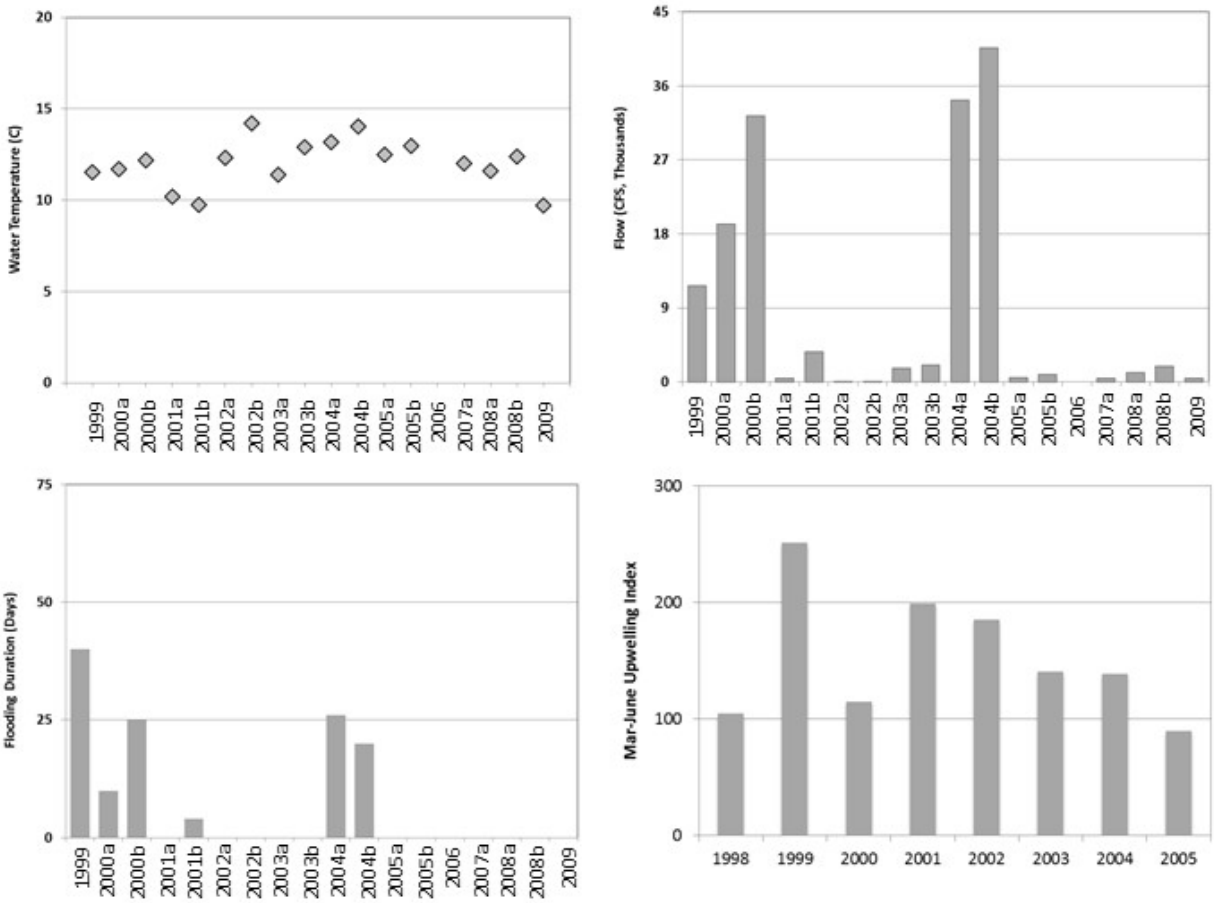


Figure 3. (Left panels) Environmental independent variables of water temperature and duration of flooding included in the analysis of ***inter-annual*** relationships with salmon growth and residence time in the Yolo Bypass conducted on ***CWT releases***. Variables were averaged over the rearing period from date of each CWT release to date of median cumulative catch at the RSTR. Flow and upwelling index **(right panels)** were additionally included for the evaluation of inter-annual comparative survival between Yolo Bypass and

Sacramento River CWT releases.

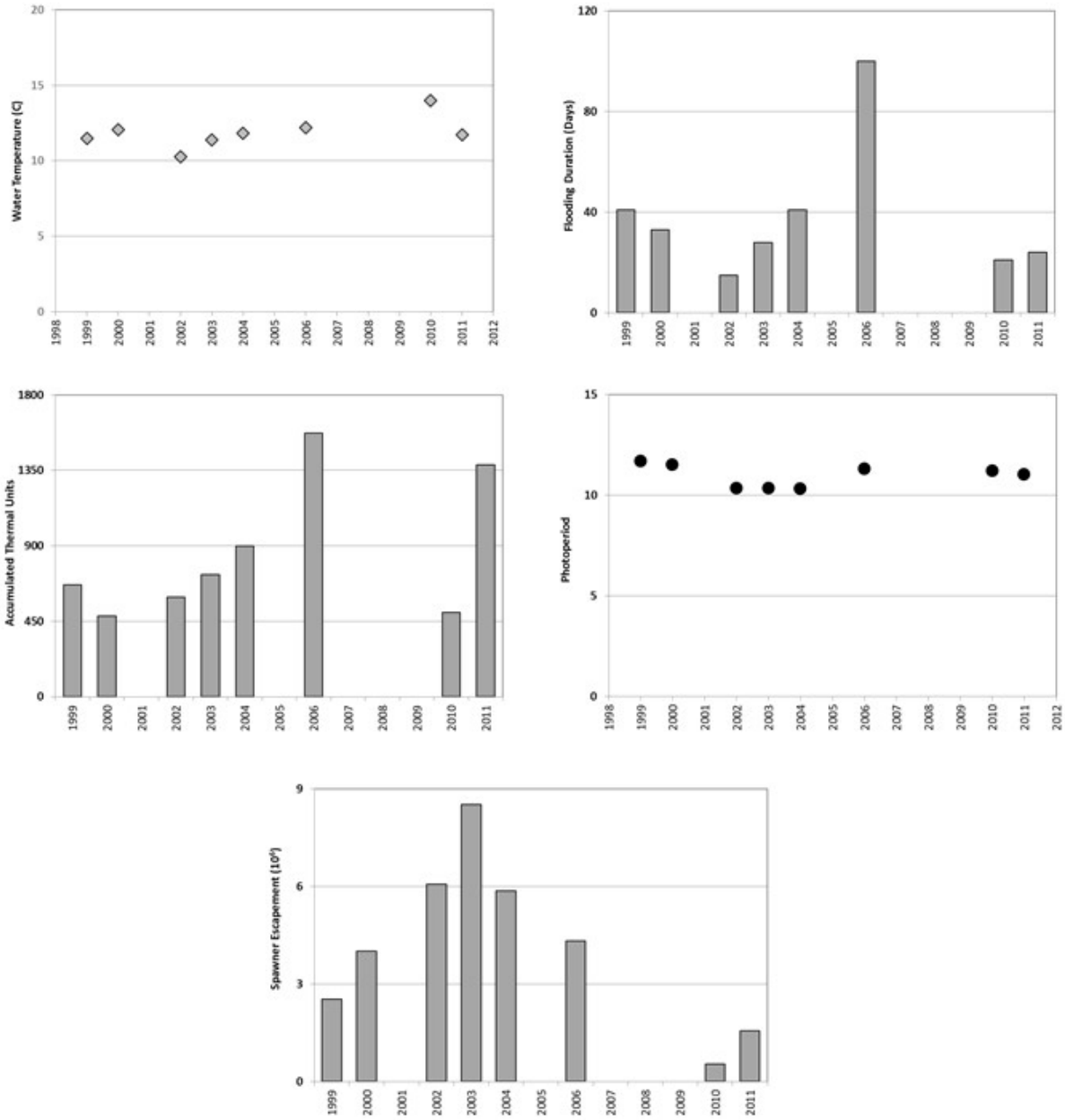


Figure 4. Environmental independent variables included in analysis of ***inter-annual relationships*** with growth, residence time, emigration demographics, and seasonal total catch of ***wild (unmarked) juvenile Chinook*** in the Yolo Bypass. Only years when Fremont Weir overtopped in the winter/early spring were included for analyses of wild juveniles (excluded 2001, 2005, 2007-2009). Variables were averaged over the rearing period each year which was the date of first overtopping at Fremont Weir to date of median cumulative catch at the RSTR. Escapement **(bottom panel)** was additionally included the analysis of total seasonal catch.

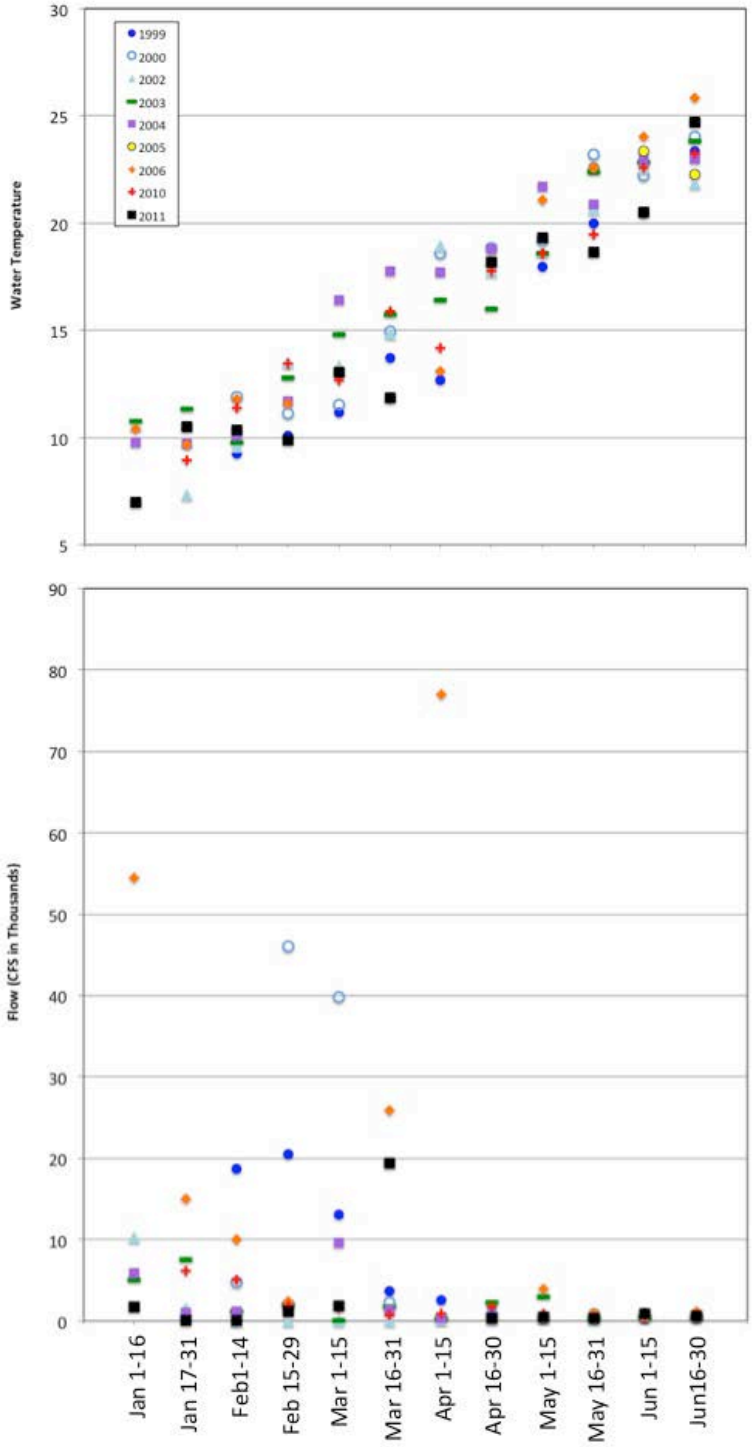


Figure 5. Independent variables used in ***intra-annual*** analysis of emigration and catch of wild (unmarked) juvenile Chinook, averaged over 2 week intervals.

Inter-Annual Patterns

Several inter-annual dependent variables were significantly related to the duration of flooding in the Yolo

Bypass. Apparent total growth (CWT), residence time (CWT) and annual CPUE (wild fish) were positively correlated with duration of flooding (p=0.002, 0.005 and 0.027 respectively) (Figure 6). The addition of other independent variables did not significantly improve model fits. In contrast, apparent growth rate (mm/day) for both CWT and wild fish were not significantly related to any of the evaluated environmental variables. The multiple regression model for inter-annual emigration timing (wild fish) included both ATU and photoperiod in the final model (p<0.001 and p=0.001) (Figure 7).

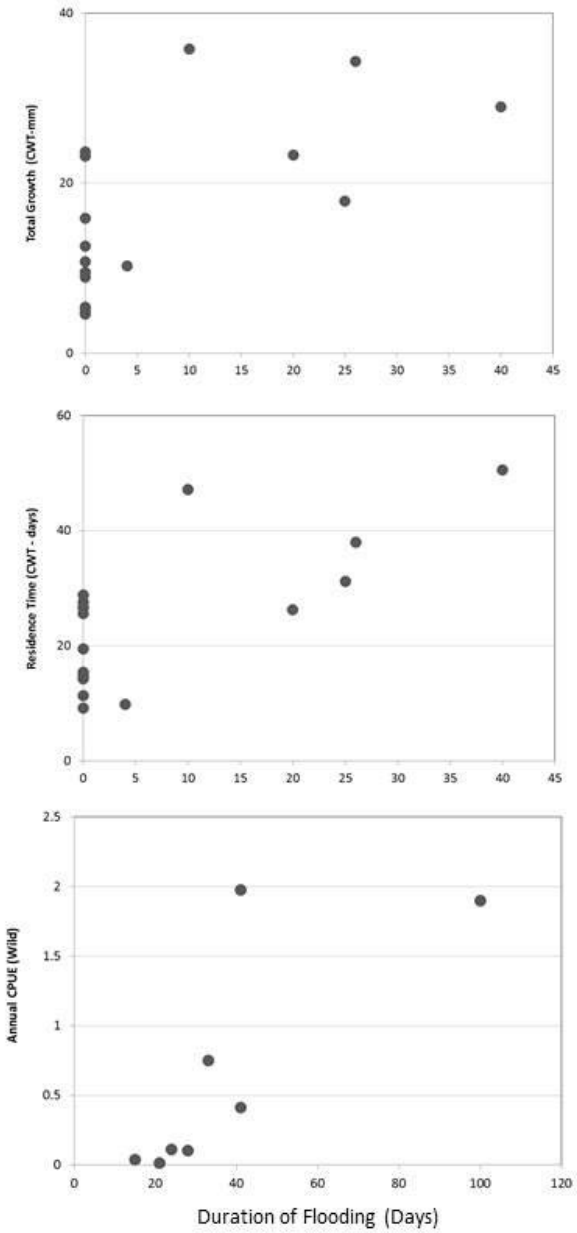


Figure 6. Significant inter-annual relationships between duration of flooding with total growth (top), residence time (middle), and annual catch (bottom).

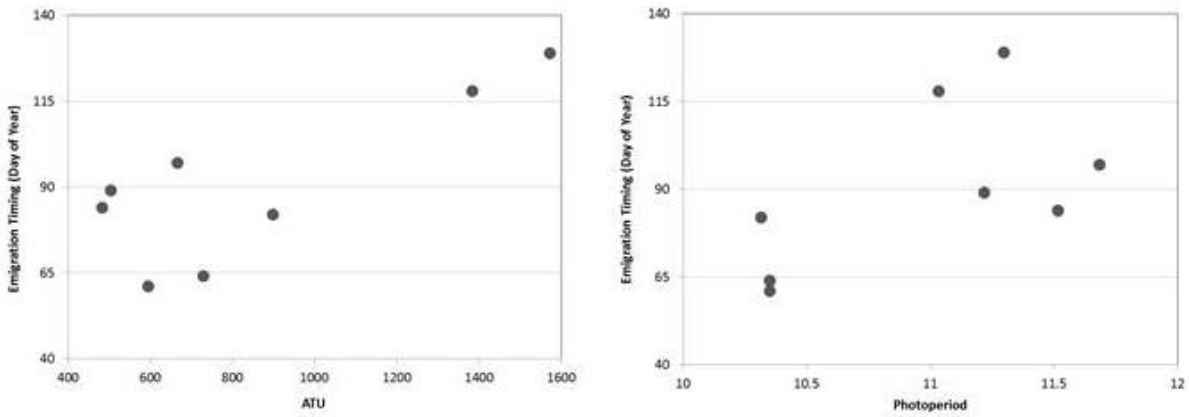


Figure 7. Inter-annual relationships between emigration timing and ATU (left) and photoperiod (right).

Comparative survival did not exhibit obvious patterns between rearing systems or with environmental conditions in the Yolo Bypass. Overall survival was not statistically different between systems (p=0.34), and Yolo Bypass:Sacramento River release survival ratios were not significantly explained by the independent variables. There were also not notable patterns between the survival ratio and the spring-summer upwelling index.

Intra-Annual Emigration Timing

The hydrographs of the 13 years examined crossed a wide range of overtopping timing, duration, and flow magnitudes. Flooding during the winter or early spring occurred in 8 (62%) years. Of these years, 5 years (63%) had extended flooding lasting longer than a week, with the longest continuous event extending over 65 days in March-May of 2006 (Figure 8). Flooding periods were comparatively early and brief in 2002, 2003 and 2010 with 7 day or shorter events occurring in January. There was no flooding in four of the examined years (31%), and in one year (2005) a 4-5 day flooding event occurred very late in the season after the majority of wild juvenile salmon moved downstream of Fremont Weir (Figure 9).

During years with extended flooding (1999, 2000, 2004, 2006 and 2011), both wild and CWT juvenile salmon appear to delay emigration until flooding subsides, and then move out of the Yolo Bypass in a pulse as reflected by the steep portion of cumulative catch curves (Figure 8). During CWT release years where flooding was very brief and early (2002, 2003), very brief and late (2005), or non-existent (2001, 2007, 2008, 2009), emigration appears to begin almost immediately after release (Figure 9). Residence time is significantly longer for CWT releases during years with extended flooding in comparison to CWT releases during non-flooding years (Man-Whitney U Test, p=0.005)

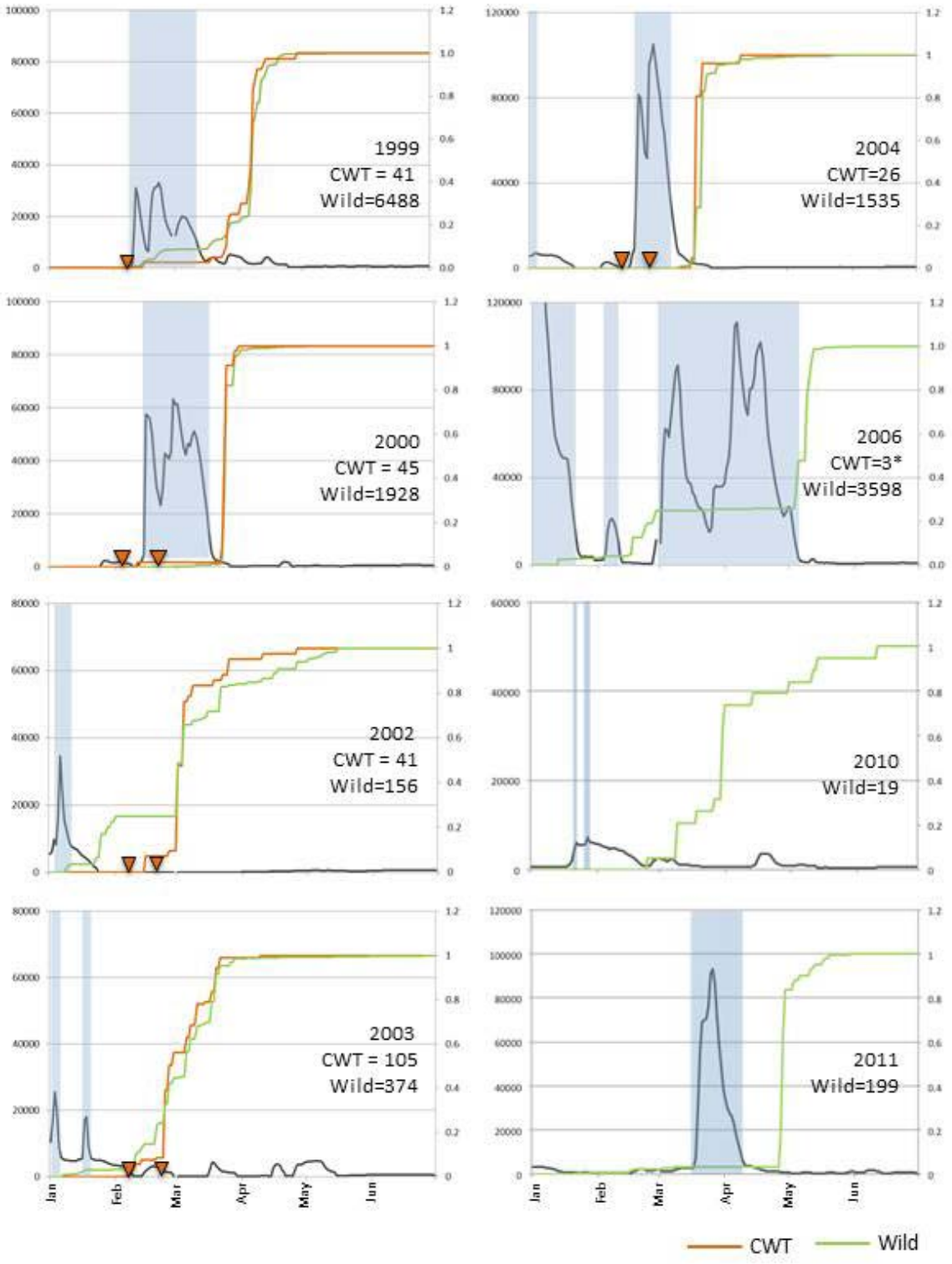


Figure 8. Cumulative daily catch curves of CWT (orange) and wild (green) juvenile salmonids at the RSTR overlaid on daily average flow during years when Fremont Weir overtopped. Blue shading depicts periods of flooding in the Yolo Bypass.

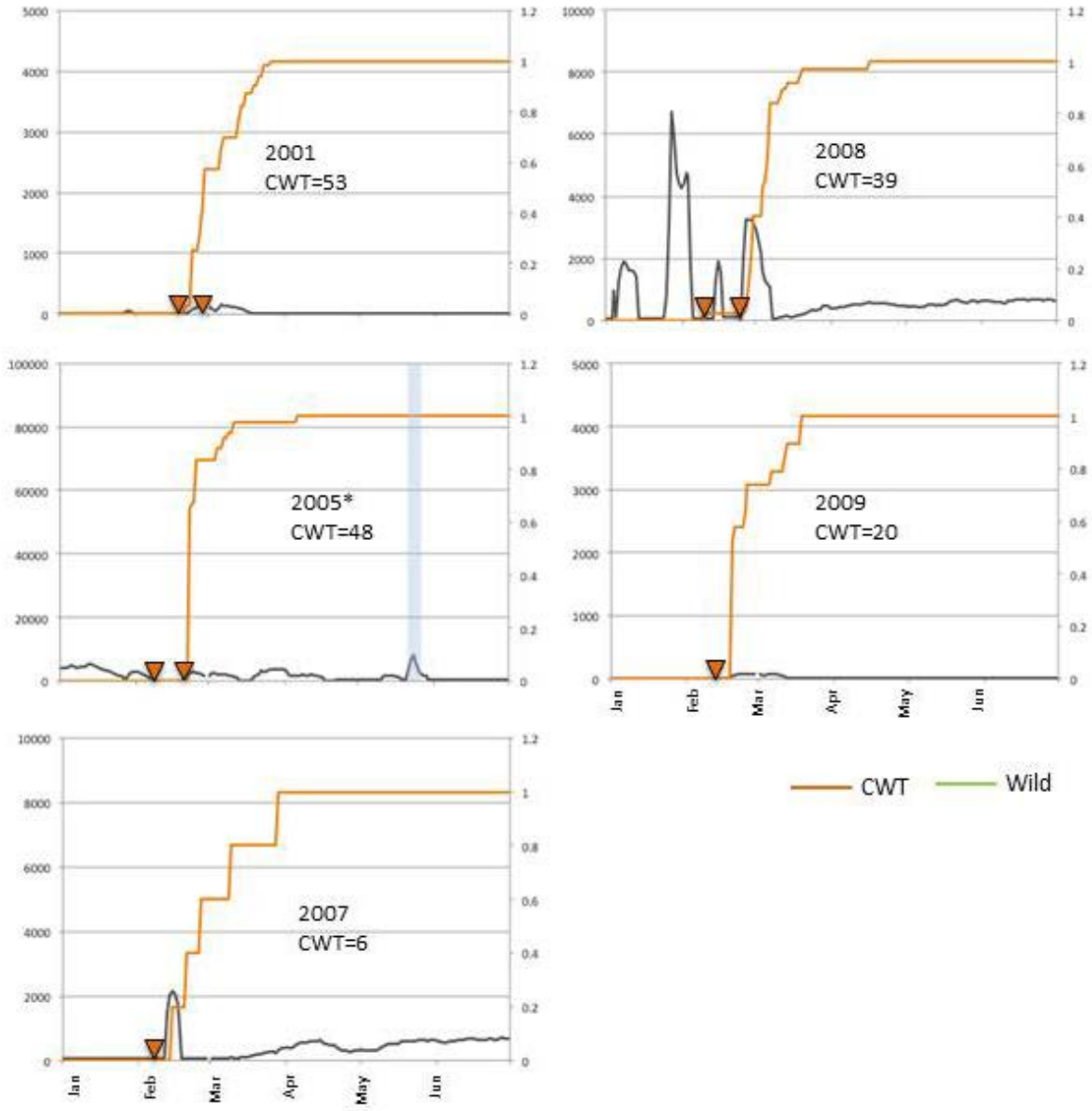


Figure 9. Cumulative daily catch curves of CWT (orange) and wild (green) juvenile salmonids at the RSTR overlaid on daily average flow during years when flooding did not occur in the Yolo Bypass. *2005 was included in this group because flooding occurred very late in the season when most wild juveniles had moved downstream of the Fremont Weir and would not access flooded bypass rearing habitat.

Neither temperature nor flow emerged as strong predictors of bi-weekly CPUE at the rotary screw trap in generalized linear modeling. According to AICc scores, the model that included temperature provided a marginally poorer fit than the null model containing the intercept only. The model that included temperature was more than 2 AICc points poorer than the null model (Table 2).

Temperature	Flow	Intercept	AICc	p
---	---	-0.48	1432.38	<0.001
-0.077	---	0.77	1434.28	<0.001
---	1.74×10^{-5}	-0.533	1434.45	<0.001
-0.075	2.55×10^{-6}	0.74	1435.87	<0.001

Table 2. Generalized linear model comparisons for environmental predictors of biweekly CPUE at the RSTR.

CONCLUSION AND DISCUSSION

Perhaps due to the expansive nature of the Yolo Bypass off-channel floodplain habitat, the extent of flooding is significantly associated with several inter-annual demographic elements of juvenile Chinook habitat use. With increased levels of flooding, resident juveniles spend extended periods in the Bypass, benefiting from significantly higher growth. Graphical evaluations of intra-annual residency and emigration also appeared to be driven by flooding during very wet years, with pulses moving out of the system only after waters began to recede. Larger body size is well known to confer enhanced survival in many fish species (Miller et al 1988) and as such, extended flooding periods in the Yolo Bypass may function to enhance survival for juvenile salmonids that can gain access to it.

Several limitations of our dataset likely limited our ability to detect significant statistical differences in comparative survival for Yolo Bypass CWT fish in comparison to those released in the Sacramento River. First, our dataset was limited by the closure of the 2008 fishery, consisting of only 8 years and 14 release groups (14 data points). Second, environmental variability was high during that short timeframe, and variables influencing the quality and quantity of floodplain habitat for juvenile salmon likely also varied widely. Four years exhibited extended flooding, 2 years exhibited very short, early flooding, one year had no flooding, and one year exhibited very brief, very late flooding. Third, survival at time scales before salmon reach market size cannot be quantified. For example, differences in smolt survival through the Delta to the Golden Gate, or differences in survival during the first year at sea are missed.

Interestingly, total seasonal catch of wild juveniles was significantly related to flooding duration, but not with spawning population. This suggests that the temporal window during which juveniles are able to gain access to the Bypass (e.g. how long Fremont Weir overtops), rather than the overall quantity of juveniles present in the Sacramento River system, may drive how many juveniles rear in the Bypass.

REFERENCES

Bakun, A. 1973. Coastal upwelling indices, west coast of North America, 1946–71. U.S. Department of Commerce, NOAA Technical Report NMFS–SSRF–671.

del Rosario, R.B., Y.J. Redler, K. Newman, P.L. Brandes, T. Sommer, K Reece, R. Vincik. Migration patterns of juvenile winter-run sized Chinook Salmon *(Oncorhychus tshawytcha)* through the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science* 11(1): 1-21

Dormann, C.F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carre, J. R. Garcia Marquez, B. Gruber, B. Lafourcade, P.J. Letao, T. Munkemuller, C. McClean, P.E. Osborne, B. Reineking, B. Schroder, A.K. Skidmore, D. Zurell, and S. Lautenbach. 2013. Collinearity; a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36:027-046.

Grimaldo, LF., T. Sommer, N. Van Ark, G. Jones, E. Holland, P. Moyle, B. Herbold, and P. Smith. 2009. Factors affecting fish entrainment into massive water diversions in a freshwater tidal estuary: Can fish losses be managed? *North American Journal of Fisheries Management* 29:1253-1270.

Henery, Rene E., T. R. Sommer, and C. R. Goldman. 2010. Growth and methylmercury accumulation in juvenile Chinook Salmon in the Sacramento River and its Floodplain, the Yolo Bypass. *Transactions of the American Fisheries Society* 139: 550-563.

Miller T.J., L.B. Crowder, J.A. Rice, and E.A. Marshall. 1988. Larval size and recruitment mechanisms in fishes; toward a conceptual framework. *Canadian Journal of Fish and Aquatic Science* 45: 1657-1670.

Nandor, G.F., Longwill, J.R., Webb, D.L., 2010. Overview of the coded wire tag program in the Greater Pacific Region of North America, in Wolf, K.S. and O'Neal, J.S., eds., PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations—A compendium of new and recent science for use in informing technique and decision modalities: Pacific Northwest Aquatic Monitoring Partnership Special Publication 2010-002, chap. 2, p. 5 - 46.

National Marine Fisheries Service 2009. NMFS Final 2009 Biological Opinion on the Long-Term Central Valley Project and State Water Project Operation, Criteria, and Plan. June 4, 2009. http://swr.nmfs.noaa.gov/sac/myweb8/BiOpFiles/2009/Draft_OCAP_Opinion.pdf

Newman, K.B. and P.L. Brandes. 2010. Hierarchical modelling of juvenile Chinook Salmon survival as a function of Sacramento-San Joaquin Delta water exports. *North American Journal of Fisheries Management.* 10(1): 157-169.

Sommer, T.R., W.C. Harrell, M.L. Nobriga, R. Brown, P.B. Moyle, W.J. Kimmerer, L. Schemel. 2001a. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. *Fisheries* 26: 6-16.

Sommer T.R., M.L. Nobriga, W.C. Harrell, W. Batham, W.J. Kimmerer. 2001b. Floodplain rearing of juvenile Chinook Salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 325-333.

Sommer, T, W. Harrell, and M. Nobriga. 2005. Habitat use and stranding risk of juvenile Chinook Salmon on a seasonal floodplain. *North American Journal of Fisheries Management* 25:1493-1504.

Sykes, G.E., C.J. Johnson, and J.M. Shrimpton. 2009. Temperature and flow effects on migration timing of Chinook Salmon smolts. *Transactions of the American Fisheries Society* 138: 1252-1265.

Venables, W.N., and Ripley, B.D. 1997. Modern applied statistics with S-Plus. 2nd ed. Springer-Verlag, New York.

Appendix C: Yolo Bypass Food Web Patterns During Low Flow Months

Jared Frantzich, DWR

Introduction:

Since 1998, the California Department of Water Resources (DWR) along with support from the Interagency Ecological Program (IEP) has carried out a comprehensive monitoring effort to investigate the importance of the engineered Yolo Bypass floodplain on lower trophic levels and those implications for Delta fishes. These baseline data are critical for evaluating success of future restoration projects, as the Yolo Bypass has been identified as a high restoration priority by the National Marine Fisheries Service Biological Opinions for Delta Smelt (*Hypomesus transpacificus)*, winter and spring-run Chinook Salmon (*Oncorhynchus tshawytscha*), and by the Bay Delta Conservation Plan (BDCP). Key findings include: (1) Yolo Bypass has a much higher dipteran drift density (specifically chironomids) of a preferred diet item of juvenile Chinook Salmon than the adjacent Sacramento River (Sommer et al., 2001a); (2) Juvenile Chinook Salmon within the floodplain of the Yolo Bypass have improved growth rates due to improved food availability in the floodplain compared to the Sacramento River (Sommer et al., 2001a, 2001b); (3) During winter and spring drainage events, the Yolo Bypass floodplain is a source of increased phytoplankton to the food web of the San Francisco Estuary (Jassby and Cloern, 2000; Schemel et al., 2004; Sommer et al., 2004, Lehman et al., 2007); (4) Yolo Bypass phytoplankton species composition is comprised of quality wide diameter cell diatom and green algae biomass (Lehman et al., 2007); (5) Yolo Bypass floodplain studies discovered a new species: *Hydrobaenus saetheri Cranston*, an estivating, winter-emerging chironomid (Cranston et al., 2007). Much of this past research has been focused on the importance of the Yolo Bypass during the winter and spring during periods of floodplain inundation, but less is known about the role the Bypass may play during the drier months of summer and fall. Therefore, beginning in 2011 as part of an Ecosystem Restoration Project (ERP) study element, the DWR began monitoring lower trophic levels year-round, to determine the contributions of future restoration efforts to the estuarine food web during other months.

Lower trophic productivity in the San Francisco Estuary is limited by several factors that include: contaminants (e.g., ammonium, Dugdale et al., 2007), hydrologic manipulation and channelization, loss of shallow water aquatic habitat, changes in nutrient ratios, and light conditions (Lucas and Thompson, 2012), but one of the most significant is the regime shift in the benthic clam community in the Estuary. The invasion of *Corbicula fluminea*, the most dominant freshwater benthic organism within the Delta (Peterson and Vayssieres, 2010), and later *Potamocorbula amurensis*, have been linked to greatly reduced phytoplankton biomass (Lucas et al., 2002; Alpine and Cloern, 1992; Jassby et al., 2002; Jassby, 2008). This has all led to a decadal decline in pelagic phytoplankton biomass and primary productivity in much of the Estuary and subsequently entire bottom-up changes in the overall food web structure and function (Cloern and Jassby, 2008; POD Workplan, 2010). The Cache Slough Complex (comprised predominately by: Cache Slough, Lindsey Slough, Liberty Island, Sacramento Deepwater Ship Channel, and Yolo Bypass) is one such region of the upper Estuary that through a high diversity of habitat types (i.e., multiple channel sizes, broad shoals, tidal marsh and dead-end sloughs) has been identified as generating higher levels of both phytoplankton and zooplankton as compared to other areas of the Estuary (Lehman et al., 2010; Nelson et al., 2011; Sommer et al., 2013). More importantly, this region of the upper Estuary has been identified as an important habitat for many native fishes year-round, including the endangered and endemic Delta Smelt (Sommer et al., 2013). Therefore, the focus of this study is to understand the process through which the Yolo Bypass may serve as a year-round source of primary and secondary productivity for the Cache Slough Complex and the lower Estuary.

This report describes the year-round sampling effort for the 2011-2013 water years, as well as the significance of phytoplankton bloom that was observed in fall 2011 and 2012 south of the Yolo Bypass at the Rio Vista Bridge in the Sacramento River as a result of increased rice discharge flows through the Toe Drain. In addition, the DWR, through a multi-agency collaboration with United States Bureau of Reclamation (USBR), University of California at Davis (UCD), and State Water Resources Control Board (SWRCB) initiated a comprehensive study in 2013 to further investigate the mechanisms and drivers in the development and transport of fall phytoplankton blooms from the Yolo Bypass to the lower Estuary.

Materials and Methods:

Study Area

The Yolo Bypass is the primary floodplain of the San Francisco Estuary (approx. 61 km long, and 24,000 ha), and when fully inundated in the winter and spring can double the wetted area of the Delta (Sommer et al., 2001a, 2001b, 2004; Schemel et al., 2004). Floodwaters from the Sacramento and Feather rivers are conveyed through the spilling of Fremont Weir to the north and the Sacramento Weir on the northeastern side of the Bypass. In addition, there are contributing flows from three side tributaries: Cache Creek, Putah Creek, and Willow Bypass Slough (Figure 1). During the drier months of summer and early fall, connectivity of the

Bypass to the Delta is maintained through the perennial riparian channel called the Toe Drain, which flows along the east side of the leveed floodplain. During the summer and fall, the floodplain of the Yolo Bypass is used heavily for agriculture with a large percentage used for rice production. The downstream flow within the Toe Drain during this time period is maintained mostly by upstream inputs from agricultural diversion from the upper Colusa Basin Drain, and those flows are controlled by elevation at the DWR-operated Knights Landing Outfall Gates, and further downstream through the local landowner-operated Wallace Weir in Ridge Cut Slough (Figure 1). The Lisbon Weir is a permanent rock barrier that mutes tidal influence upstream. It assists with maintaining water levels for water diversion upstream for both agriculture and the Yolo Bypass Wildlife Area, during varying tidal cycles.

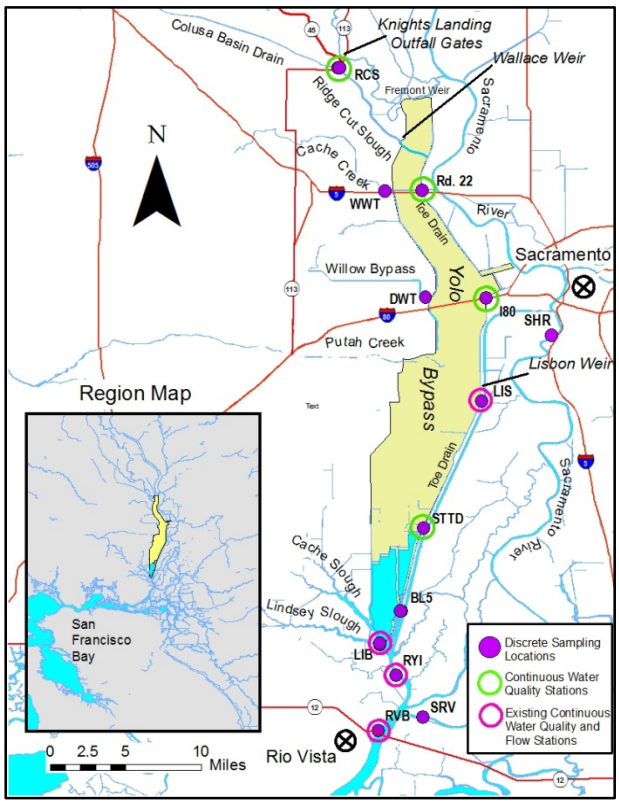


Figure 1. Location of the Yolo Bypass in relation to the San Francisco Estuary and its major tributaries. The core sampling locations are shown with solid pink circles. The continuous water quality monitoring stations are shown with open circles.

During late August and early September every year, the northern Central Valley's estimated 500,000 acres of irrigated and flooded rice fields are drained for harvest. This drainage water has two fates: 1) to enter the Sacramento River at Knight's Landing through the Outfall Gates or 2) to flow through Ridge Cut Slough and down into the Toe Drain of the Yolo Bypass and eventually into the North Delta. Local rice fields within the leveed Yolo Bypass also begin draining fields in September and October, adding to the overall discharge volume. During these drainage events we see substantial increases in flow throughout the Toe Drain of the Yolo Bypass, as observed at the Lisbon Weir flow gage (LIS – Figure 1) each September since 2005.

Physical Conditions

During 2011-2013, flow, velocity, and stage measurements in the Yolo Bypass were obtained from gauges operated by DWR below Lisbon Weir (Station: LIS; http://cdec.water.ca.gov/). Continuous water temperature data for the sites in the Yolo Bypass (STTD) and Sacramento River (SHR) were collected using installed temperature recorders (Onset Corp.). Additional discrete measurements using YSI 556 MPS (Yellow Springs Instruments, Yellow Springs, OH, USA) were collected at all study sites for conductivity, pH, and dissolved oxygen. In 2012, the collection of turbidity in nephelometric turbidity units (NTU) was measured using HACH 2100q turbidimeter. The collection of turbidity was added as a year-round physical water quality measurement for water clarity, complementing the long-term discrete collection of secchi depth. During the study period, discrete measurements were taken at the same locations and typically during the mid or late morning. The photosynthetically active surface irradiance (PAR) was measured in the water column by vertical profiles of a LICOR 193SA spherical quantum sensor (LICOR, Inc., Lincoln, NE, USA) and total irradiance in the euphotic zone was computed by integration over depth.

In March 2012, DWR installed and telemetered a YSI 6600 multi-parameter water quality sonde at the LIS flow gauge. This water quality sonde provides the addition of real-time continuously measured: water temperature, specific conductance, pH, dissolved oxygen, turbidity, and chlorophyll data for the Yolo Bypass. In 2013, the addition of three YSI 6600 water quality sondes

continuously measuring water temperature, specific conductance, and chlorophyll, were temporarily installed during the study period at site locations: 1) Toe Drain at Road 22 (RD22), 2) Toe Drain at I80 (I80), and 3) Screw Trap at Toe Drain (STTD). In addition, continuous water quality data from both the DWR-operated Sacramento River at Hood (SRH) and Sacramento River at Rio Vista Bridge (RVB) stations were used to determine changes in ambient water conditions downstream.

In 2013, water samples were collected from late July through October at eight sites in a north to south transect along the eastern edge of the Yolo Bypass to the Sacramento River at Rio Vista: Ridge Cut Slough at Hwy. 113 (RCS), Toe Drain at Knaggs Ranch (KNA), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), Screw Trap at Toe Drain, Prospect Slough (BL5), Cache Slough at Ryer Island (RYI), and Sacramento River at Rio Vista (RVB). Water samples for water quality analysis at all sites were collected near-surface (≤ 1m) and stored at 4°C and prepared for laboratory analyses within 24 hours of collection. Water samples for dissolved ammonia, phosphorus, and nitrate were filtered through 0.45 µm pore size Millipore HATF04700 filters (Millipore Corporation, Billercia, MA, USA) and additional unfiltered water samples for total phosphorus and nitrogen were all analyzed for nutrient concentration using EPA colorimetric methods. Water samples were also analyzed for total and volatile suspended solids using recommended EPA methods 160.2 and 160.4.

Biological Data

To investigate the inter-annual responses of two trophic levels: primary producers (phytoplankton) and primary consumers (zooplankton) to changing physical conditions, samples were compared between the Yolo Bypass and the Sacramento River. In 2013, there was further collection of water samples for chlorophyll *a* and phytoplankton enumeration and identification along much of the extent of the Toe Drain to obtain data on spatial and temporal variation during periods of increased agricultural drainage flows.

Chlorophyll a and Phytoplankton

The collection of bi-weekly water samples for the spectrophotometric determination (Standard Method 10200 H – APHA et al., 2012) of chlorophyll *a* concentration was used as an indicator of phytoplankton biomass at two long-term sampling locations: 1) Screw Trap at Toe Drain (STTD) and 2) Sacramento River at Sherwood Harbor (SHR). Water samples collected for chlorophyll *a* and phaeophytin concentration were filtered through APFF glass fiber filters (Millipore Corporation, Billerica, MA, USA). The filters were preserved with 1% magnesium carbonate and all samples were frozen until analysis. In summer and fall of 2013, the addition of nine stations [Ridge Cut Slough (RCS), Toe Drain at Road 22 (RD22), Toe Drain at I80 (I80), Toe Drain below Lisbon Weir (LIS), Prospect Slough (BL5), Liberty Island (LIB), Cache Slough at Ryer Island (RYI), Sacramento River at Vieira's Marina (SRV), and Sacramento River at Rio Vista Bridge (RVB)] were also sampled weekly for chlorophyll *a* and water samples were preserved in Lugol's for phytoplankton species identification and enumeration.

Zooplankton

The collection of biweekly zooplankton samples at STTD and SHR was achieved through the use of a conical plankton nets (0.50 m mouth, 2 m length and 153 µm mesh) sampled for approximately five (5) minutes during the mid to late morning during ebb tide. Sample volume was estimated from flow measurements using General Oceanic's Model 2030R flow meters. The plankton net tapers to a 0.076 m at the cod-end where a polyethylene jar screened with 153 micron mesh collects the organisms. All samples are preserved in the field with a buffered 10% formalin preservative. Samples were sorted, identified to the lowest taxon and enumerated by the contractor: EcoAnalysts, Inc.

Statistical Analyses

For all years, a Mann Whitney sign test was used to compare the concentrations of chlorophyll *a* and zooplankton in the Yolo Bypass (STTD) and Sacramento River (SHR). The effect of flow in the Yolo Bypass and Sacramento River on biological data (chlorophyll *a* concentration and zooplankton densities) was evaluated by calculating Pearson correlation coefficients for log-transformed data.

For 2013, a multiple linear regression was used to determine which physical and chemical parameters were driving the chlorophyll *a* concentrations during increased rice-field drainage flows in the Yolo Bypass. All data was log-transformed and independent variables included: water temperature, specific conductance, dissolved oxygen, turbidity, and flow. A 2-sample t-test was used to characterize the significance between any differences in the mean concentration in above Lisbon Weir (I80) and below Lisbon Weir (LIS) between measured constituents (n approximately 96 for each category). A Mann Whitney sign test was also used to compare the concentrations of nutrients at the I80 and LIS site locations.

Results:

Physical habitat

Water Temperature and Flow

The water temperature in all years for the Sacramento River and Yolo Bypass followed typical seasonal trends and closely tracked one another throughout the summer and fall, although the Yolo Bypass consistently maintained a higher daily mean (Figure 2(b)). The flow conditions within the Sacramento River during the summer and fall, followed typical trends of many temperate rivers, with flow conditions varying considerably among the years (Figure 2 (a)). In 2011, the Sacramento Valley observed a wet water year classification for the Sacramento Valley (based on: Unimpaired Runoff (MAF)), there was a significant winter pulse and sufficient flows to inundate the floodplain and charge many of the local tributaries (i.e. Cache Creek and Putah Creek) (Figure 1) within the Yolo Bypass for the months of March and April (SWRCB 1999). In 2012 and 2013, the water year classifications were below normal and dry respectively, resulting in insufficient flows to provide considerable floodplain inundation and recharge to local tributaries (Figure 2 (a)). The Yolo Bypass observed a greater standard deviation and maximum water temperature in the high flow year (2011) as compared to the dryer 2012 and 2013 water years (Figure 2 (b)). Flow pulses were observed in all years during the late summer and fall in the Toe Drain of the Yolo Bypass. These flow pulses were closely tied with the timing of rice-field drainage for fall harvest practices throughout the Central Valley. In the month of August in all years the Toe Drain below Lisbon Weir observed net negative flows and a subsequent switch to net positive flows in late August and early September, with increased rice-field drainage flows.

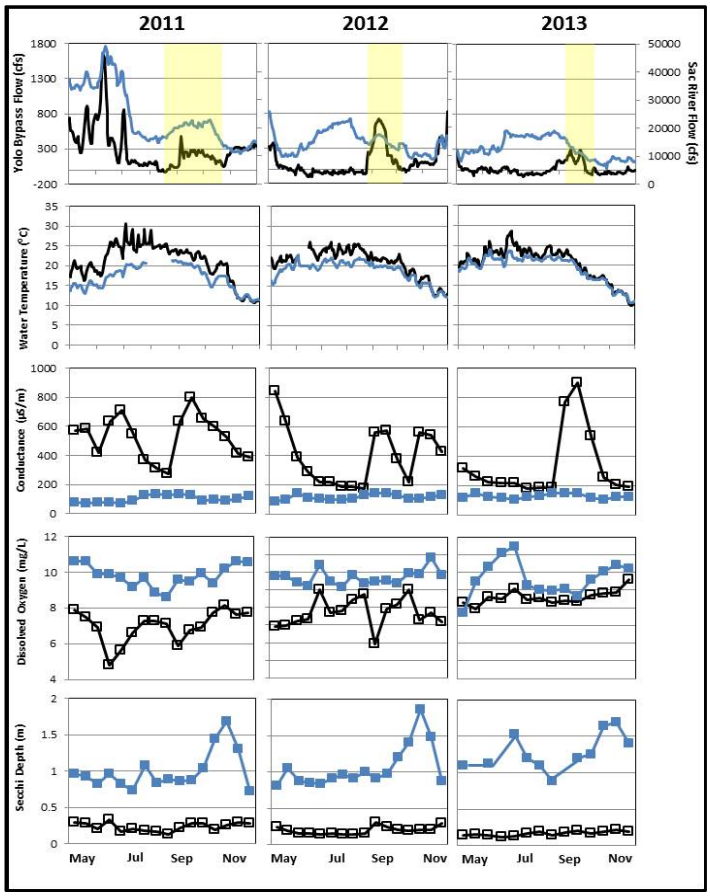


*Figure 2. Physical conditions of Yolo Bypass (black line) and Sacramento River (blue line) during the months of May-Nov of 2011, 2012, and 2013. The variables from top to bottom: (a) mean daily flow (cfs); (b) water temperature (°C); (c) conductance (µS/cm); (d) dissolved oxygen (mg/L); (e) secchi depth (m)*Shaded area indicates increased flows in Yolo Bypass due to rice-field drainage*

Table 1. Max flow (cfs) at Lisbon ADCP and calculated rice-field discharge volume through the Toe Drain of the Yolo Bypass in 2008-2011

Year	Max Flow at Lisbon (cfs)	Discharge Volume at Lisbon (ac-ft)
2013	284	10,800
2012	724	27,000
2011	400	21,400
2010	423	9,000
2009	183	3,000
2008	111	3,500

The volume of fall-rice-field discharge in the Toe Drain of the Yolo Bypass was calculated for each year using the equation: *discharge = area x velocity*. The channel area was calculated using cross-sectional depth data from an acoustic doppler current profiler (ADCP) attached to a boat operated by DWR. The velocity data was obtained from the LIS gauging station. The total discharge volume in 2011 and 2012 was substantially greater (2-3 fold) than any of the previous years on record (Table 1). In particular, 2012 discharge flow intensity and volume through the Toe Drain was unprecedented considering that it was a below normal water year in the Sacramento Valley. In 2012, DWR had to restrict discharge of rice-field water at the Knights Landing Outfall Gates, due to gate repairs and this forced more water through Ridge Cut Slough into the Toe Drain.

Discrete Water Quality Monitoring

In all years, the conductance was considerably higher in the Yolo Bypass throughout the summer and fall as compared to the Sacramento River. In the Yolo Bypass, the conductance closely followed the changes in the flow intensity (Figure 2 (a) and (c)). The major sources of salinity into the Toe Drain of the Yolo Bypass include: side tributary inputs (i.e. Putah Creek and Cache Creek), agricultural drainage (local and Colusa Drain inputs), and wastewater treatment drainage (i.e. Woodland and Davis) (Figure 1). The dissolved oxygen concentrations decreased in both regions during the summer and rose in the late fall. The Sacramento River and Yolo Bypass dissolved oxygen concentrations coincided closely with the warming of water temperatures in the summer, but the Yolo Bypass in 2011 and 2012 also had dissolved oxygen concentration levels tied closely to the increases in flow and chlorophyll *a*; this suggests influence from respiration and primary production (Figure 2 (a) and (d) and Figure 5 (b)). The mean secchi depth of the Yolo Bypass was considerably lower than the Sacramento River in all years (Figure 2 (e)).

Table 2. Monthly average, minimum, maximum, and standard deviation of 2013 discrete water quality measurements at site locations (RD22, I80, LIS, STTD, and BL5)

	Water Temperature (ºC)											
Site	**Ave.**			**Min.**			**Max.**			**Std. Dev.**		
	Aug.	**Sept.**	**Oct.**	**Aug.**	**Sept.**	**Oct.**	**Aug.**	**Sept.**	**Oct.**	**Aug.**	**Sept.**	**Oct.**
RD22	23.5	21.1	16.6	21.7	17.5	13.9	25.2	23.9	20.1	0.8	1.5	1.2
I80	24.2	21.4	16.7	22.0	17.5	13.8	27.2	24.8	21.2	1.2	1.7	1.3
LIS	22.9	21.3	16.8	20.2	17.8	14.6	26.8	24.4	20.7	1.2	1.7	1.0
STTD	23.4	21.6	16.8	21.0	17.4	13.9	25.8	25.0	19.6	0.9	1.6	1.2
BL5	20.6	19.5	17.3	19.0	18.7	16.1	21.8	20.6	18.3	1.4	0.9	0.9
	Specific Conductance (µS/cm)											
RD22	688	712	734	615	585	593	810	863	947	40	66	82
I80	858	862	782	721	635	628	990	1307	984	66	114	111
LIS	437	912	454	231	682	308	935	1066	754	182	96	142
STTD	260	782	339	194	323	238	446	1010	778	38	140	125
BL5	162	228	228	154	186	161	168	328	358	7	57	88
	pH											
RD22	7.71	7.87	8.14	7.63	7.77	7.98	7.78	7.98	8.21	0.11	0.08	0.09
I80	7.84	7.93	8.34	7.83	7.91	8.12	7.84	7.97	8.55	0.01	0.02	0.20
LIS	8.24	8.07	8.29	8.03	8.00	8.09	8.64	8.19	8.44	0.28	0.08	0.14
STTD	7.85	8.04	7.72	7.67	7.88	7.58	8.03	8.35	7.80	0.25	0.19	0.10
BL5	7.74	7.70	7.67	7.50	7.44	7.36	8.05	7.99	7.93	0.28	0.23	0.30

	Turbidity (NTU)											
RD22	38.9	35.8	47.9	38.6	27.9	41.2	39.1	50.6	54.1	0.4	9.2	6.5
I80	54.5	52.1	49.9	50.2	49.1	43.8	58.7	56.5	54.7	6.0	3.0	4.5
LIS	57.4	34.4	39.4	50.1	34.1	38.3	110.3	49.3	63.2	21.1	5.0	4.9
STTD	75.1	54.1	54.5	64.4	42.2	41.2	85.7	64.2	59.8	15.1	9.6	8.9
BL5	30.8	32.1	21.7	23.4	16.6	9.6	44.5	50.5	35.5	11.9	15.2	10.9

In 2013, discrete water quality measurements (water temperature (°C), specific conductance (µS/cm), pH and turbidity (NTU)) were also collected at the nine special study site locations (Figure 1) paired with the collection of water samples for organic and inorganic analyses. The mean water temperature at all sites (RD22, I80, LIS, and STTD) within the boundaries of the Toe Drain during the study period followed similar trends, but sites at and above Lisbon Weir experience higher max temperatures (Table 2). The mean specific conductance was higher above Lisbon Weir, but specific conductance increased notably in September at all downstream sites. The mean turbidity within the extent of the Toe Drain remained high throughout the study period (>35 NTU). The mean pH was higher at the upper Lisbon Weir sites (I80 and RD22) (Figure 1); both these sites are below wastewater treatments plant discharge points. The mean turbidities increased at STTD and BL5 during the month of September coinciding with increased rice field drainage flows (Table 2 and Figure 2 (a)).

Continuous Water Quality Monitoring

In 2011 and 2012, chlorophyll in relative fluorescence units (FU) recorded at station RVB (Figure 1), provided substantial evidence of a fall phytoplankton bloom occurring in the lower Sacramento River in both years (Figure 3). After, reviewing low (≥3 FU) continuous chlorophyll data from the upper reaches of the Sacramento River at the SRH station, it seemed apparent the source of this increased phytoplankton biomass was from the Cache Slough Complex. Moreover, isotopic studies indicate that the bloom came largely from contributions from the Cache Slough corridor of which Yolo Bypass is a part (C. Kendall, USGS, 2012 Interagency Ecological Program [IEP] Workshop oral presentation).

In 2013, DWR deployed YSI sondes at two above Lisbon Weir sites in the Toe Drain (RD22 and I80) and one more in addition to LIS further downstream at STTD (Figure 1). The high resolution (15 minute) continuous data from these sites were used to compare the differences in means above and below Lisbon Weir before and after the observed increased rice-field drainage flows. The mean chlorophyll *a*, specific conductance and water temperature above Lisbon Weir were all significantly higher than below Lisbon Weir until net positive flows on August 23 were observed at LIS (Table 3). The mean chlorophyll *a* below Lisbon Weir (LIS) continued to increase and maintain significantly higher levels then above Lisbon Weir (I80) as the flow increased; reaching a maximum concentration on September 12. Further results, from a multiple regression model shows evidence that increased flow and specific conductance were good predictors of increased chlorophyll *a* at LIS and as far downstream as STTD (Table 4).

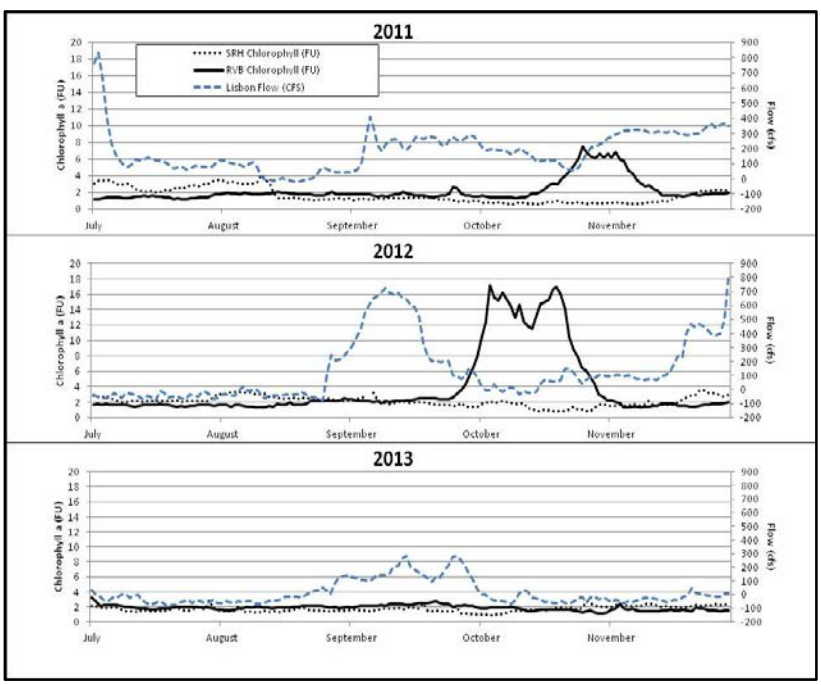


Figure 3. Daily average continuous chlorophyll (FU) and Lisbon gauge flow (cfs) 2011-2013 data from Sacramento River at Hood (SRH) and Sacramento River at Rio Vista Bridge (RVB)

Table 3. Comparisons between mean values for three constituents from above Lisbon Weir (I80) and below Lisbon Weir (LIS) sites of the Yolo Bypass (average n = 96) for 15 days during 2013

Date	Net Flow at LIS (cfs)	Mean Chl-a (µg/L)		Mean EC (µS/cm)		Mean Temp. (°C)	
		I80	LIS	I80	LIS	I80	LIS
15-Aug-13	(-36)	17.0*	13.8	758*	329	25.5*	23.6
19-Aug-13	(-17)	20.5*	11.5	789*	362	25.5*	24.5
23-Aug-13	(+24)	15.7*	11.6	914*	558	23.3	22.6
27-Aug-13	(+7)	13.9*	10.8	883*	592	23.8	22.9
31-Aug-13	(+140)	16.8	27.3*	913	929	24.2	24.0
4-Sep-13	(+110)	12.8	29.8*	856	967*	22.6	22.5
5-Sep-13	(+100)	12.7	30.8*	908	926	22.6	22.1
12-Sep-13	(+212)	17.4	31.5*	949*	927	22.3	22.4
13-Sep-13	(+263)	15.0	28.7*	964	957	22.5	22.3
14-Sep-13	(+285)	12.8	26.1*	920	994*	22.4	22.1
18-Sep-13	(+143)	11.2	21.8*	936	924	21.0	21.0
22-Sep-13	(+126)	15.4	17.2	1017	1030	19.2	19.8
26-Sep-13	(+283)	12.6	16.9*	676	746*	19.3	19.2
30-Sep-13	(+106)	12.5	14.6*	658	685*	19.6	18.9
4-Oct-13	(-25)	10.4	15.5*	683	690	16.5	16.5

** Indicates that the mean constituent concentration at I80 and LIS sites are significantly different as determined by a 2-sample t-test (P>0.05)*

Table 4. Results from a multiple linear regression analysis of mean log -transformed estimated Chl a (dependent variable) with a suite of physical (EC, temperature, DO, turbidity, and flow) independent variables.

Station	Dates	*N*	r^2	SE	Independent Variables	β	*P*-level
LIS	Aug 15 - Oct 31 2013	71	0.69	0.652	Intercept	-2.23	0.001
					EC (µS/cm)	0.68	<0.001
					Temperature (°C)	0.07	0.728
					DO (mg/L)	0.81	0.005
					Turbidity (NTU)	0.30	0.072
					Flow (cfs)	0.05	0.006
STTD	Aug 15 - Oct 31 2013	77	0.91	0.218	Intercept	-3.20	<0.001
					EC (µS/cm)	0.05	<0.001
					Temperature (°C)	0.16	<0.001
					Flow (cfs)	0.02	0.057

Nutrients

In 2013, nutrient concentrations in the rice-field drainage water entering the Toe Drain of the Yolo Bypass was much lower than expected. Nutrient concentrations from sites RCS and KNA (Figure 1) for dissolved ammonia, dissolved nitrate, dissolved inorganic nitrogen, and dissolved orthophosphate were 0.01-0.06-N(mg/L), 0.01-0.32-N(mg/L), 0.02-0.34-N(mg/L), and 0.04-0.19 P(mg/L) (Figure 4). The orthophosphate levels maintained above limiting values of 0.03-P(mg/L), but dissolved inorganic nitrogen in these upper sites were sometimes below the limiting value of 0.07 mg N/l (Jassby 2005, Lehman et al. 2007). The dissolved inorganic nitrogen levels downstream at I80 were 0.45-1.8-N(mg/L) considerably higher than all the sites sampled during the study period (Figure 4). This can be attributed to the site location being below both the Woodland and Davis wastewater treatment discharge points into the Toe Drain (Figure 1). Further investigations by UCD scientists discovered significant amounts of nitrate (>40-N (mg/L)/l) in analyzed discharge water (unpublished data 2013, Randy Dahlgren). The dissolved nitrate and ammonia levels were both

significantly higher (P = 0.01) above Lisbon Weir (I80) than below, but the orthophosphate levels were not significantly different (P = 0.09) (Table 5). The N:P ratios for much of the Toe Drain were ≤ 8, indicating a nitrogen limitation during the study period (Figure 4). The sites from STTD south had much higher concentrations of ammonia, suggesting tidal movement landward is transporting Sacramento River wastewater treatment discharge into the Cache Slough Complex. The N:P ratios for the RYI and RVB stations were often between 10 and 17 indicating either phosphorus or nitrogen may be limiting (Figure 4).

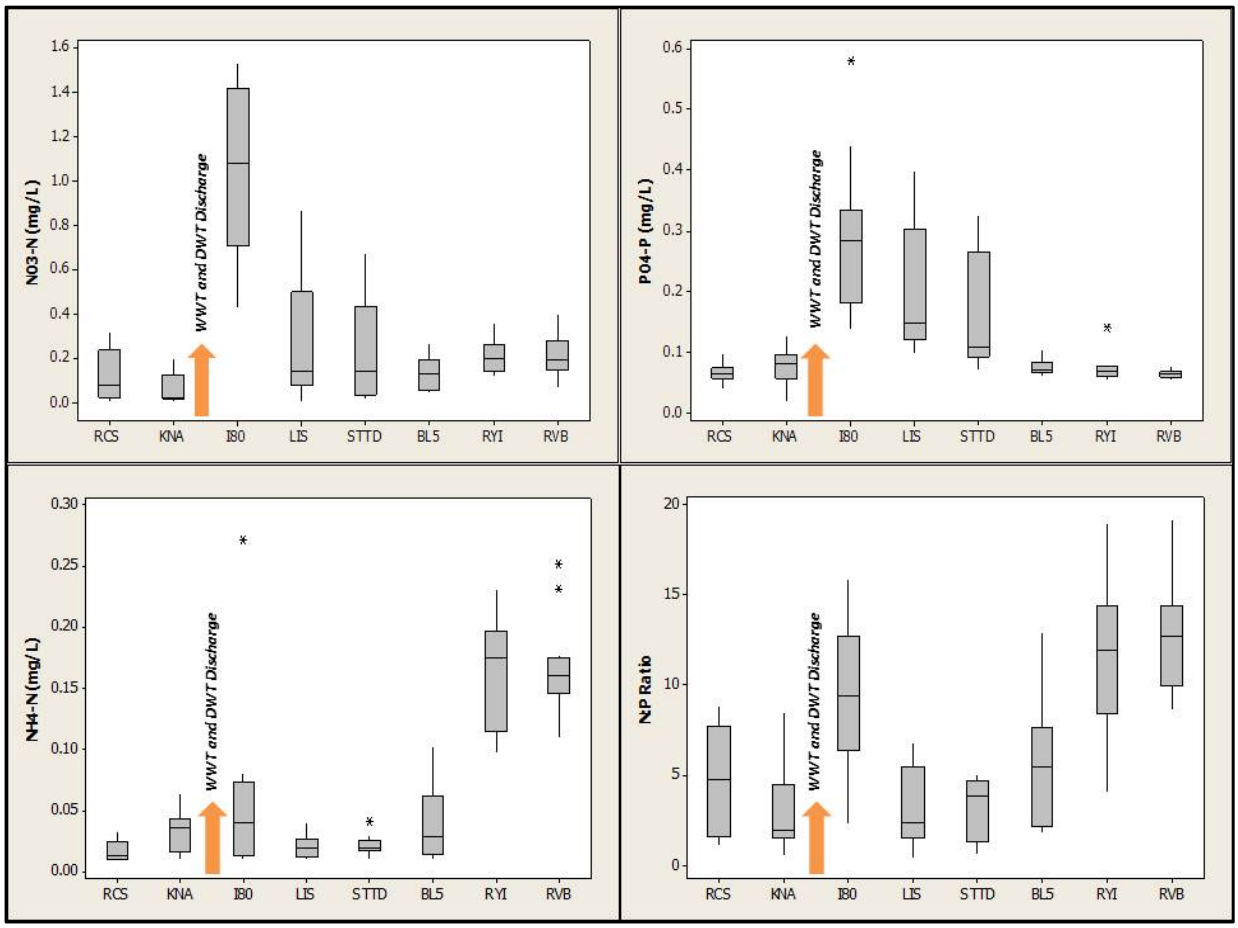


*Figure 4. Boxplots displaying the differences in median concentrations of: dissolved nitrate, dissolved ammonia, dissolved orthophosphate and the N:P ratios in Aug. – Oct 2013 (moving north to south in the Yolo Bypass) . *The orange arrow indicates the location of the wastewater treatment plants: Woodland (WWT) and Davis (DWT).*

Table 5. Results of Mann-Whitney sign test (P>0.05) comparing levels of nutrients above Lisbon Weir at I80 and below Lisbon Weir at LIS for 2013

Constituent	U		*n*		*P*
Dissolved Ammonia-N(mg/L)	12.5		9		0.0151
Nitrate-N(mg/L)	11.5		9		0.0127
DIN-N(mg/L)	13		9		0.0173
Orthophosphate-P(mg/L)	21		9		0.0929

Biological resources

Chlorophyll a and Phytoplankton

Chlorophyll *a* concentrations were significantly higher in the Yolo Bypass than in the Sacramento River (Figure 5 (b) and Table 6). The levels in the Sacramento River were highest during periods of low flow, while the Yolo Bypass experienced the highest levels during the highest flows in the late summer and fall (Figure 5 (a) and (b)). Flow was a significant predictor for adult calanoid copepod abundance in the Yolo Bypass, while flow did not seem to correlate well with Sacramento River zooplankton abundance during the summer and fall (Table 7).

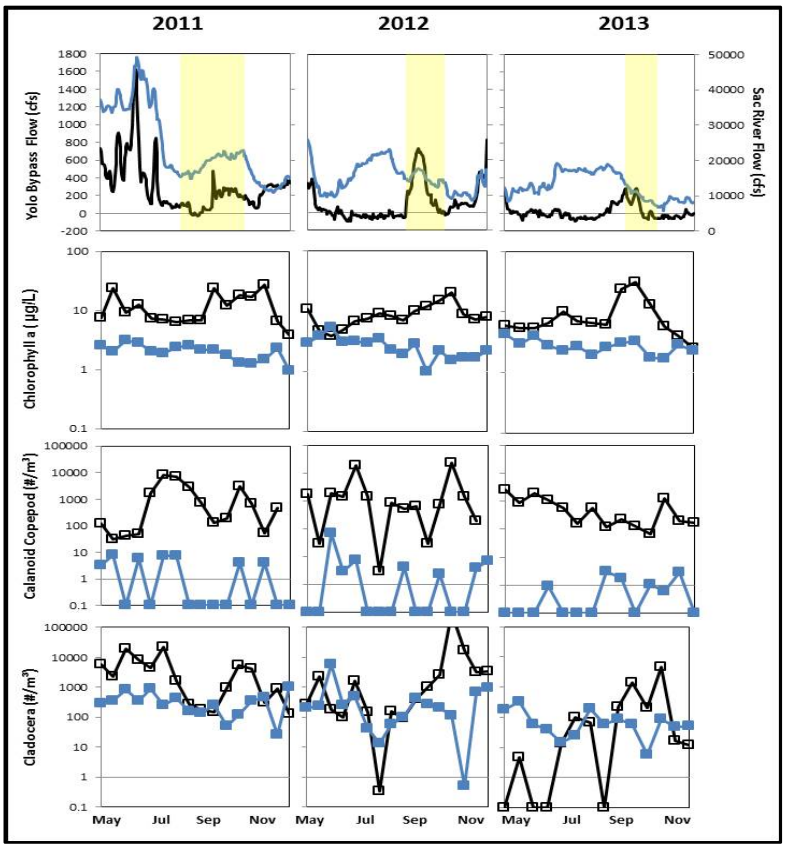


Figure 5. Trends in lower trophic levels in the Yolo Bypass (clear black symbols) and Sacramento River (solid blue symbols) during May – Nov. of 2011, 2012, and 2013. The variables from top to bottom are: (a) Mean daily flow (cfs); (b) chlorophyll a (µg/L); (c) density of calanoid copepod adults (m³); (d) density of cladocerans (number/m³). Note that 0.1 = 0 density for copepods and cladocerans. The highlighted portions of the flow graphs represent the summer/fall increased rice field drainage flows in the Yolo Bypass.

In 2013, continuous chlorophyll FU data along with lab analyzed chlorophyll *a* was used to develop a regression model and ultimately to create a continuous estimated chlorophyll *a* (µg/L) value for all sites. Continuous estimated mean chlorophyll *a* values at the above Lisbon Weir sites: RD22 and I80, were 10.5 µg/L and 14.9 µg/L respectively. In 2013, chlorophyll *a* reached a max of 29.66 µg/L at the I80 on September 8 and a max of 37.59 µg/L at LIS site locations on September 9, with a positive daily net flow at LIS of 143 cfs. It took approximately 5-days for chlorophyll *a* to reach a max of 46.44 µg/L, approximately 7 miles downstream at the STTD site, coinciding with a max net flow of 285 cfs at LIS (Figure 6).

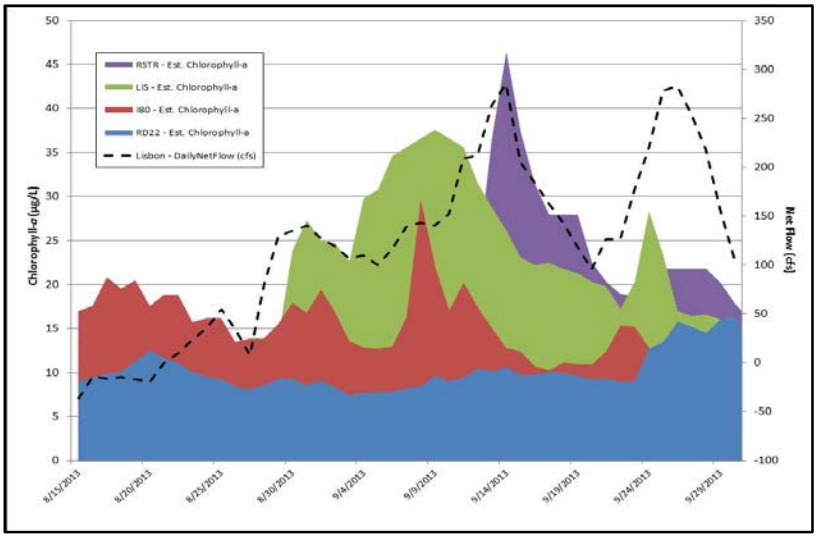


Figure 6. Daily average estimated continuous chlorophyll a (µg/L) and Lisbon gauge net flow (cfs) data at 2013 continuous water quality monitoring stations in the Yolo Bypass.

The phytoplankton biovolume (µm³/L) throughout the 2013 study period at the LIS station was 90% diatoms, 6% flagellates, 3% green, and the remaining 1% were cyanobacteria and golden-brown. About 54 % of the diatom biovolume was made up of the species: *Synedra ulna* (19%), *Thalassiosira sp.* (19%), and *Aulacoseira sp.* (10%) (Figure 7).

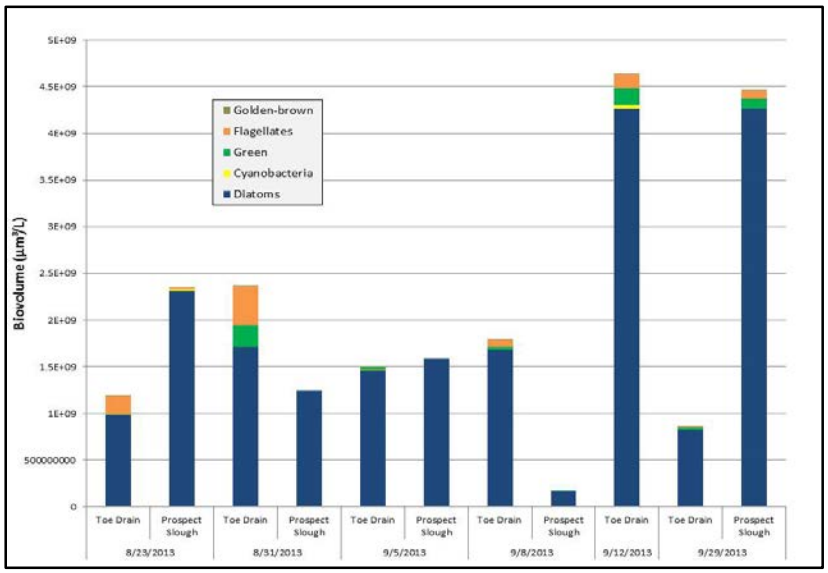


Figure 7. Phytoplankton biovolume (µm³/L) by group classification in Toe Drain (LIS) and Prospect Slough (BL5) in 2013

Zooplankton

The zooplankton community in the Yolo Bypass was dominated by *Bosmina* (95% of the cladoceran in number/m³), *Pseudodiamptomus forbesi* (53% of calanoid copepod adults), and *Sinocalanous doerri* (45% of calanoid copepod adults). In the Sacramento River, calanoid copepod adults were dominated by *Ilyocryptus* (83%), *Sinolcalonus doerri* (10%), and *Diaptomidae spp. (*4%). The Sacramento River cladoceran composition was more evenly dispersed than Yolo Bypass, with *Bosmina* (39%), *Ceriodaphnia* (25%), *Daphnia* (18%), and *Chydorus* (15%). There were significant differences in the densities of cladocerans and calanoid copepod adults between the Yolo Bypass and Sacramento River (Table 6). The Sacramento River had much lower volumes than the Yolo Bypass in all years (Figure 5). Flow was a significant predictor for adult calanoid copepod adult abundance in the Yolo Bypass, while flow did not seem to correlate well with Sacramento River zooplankton abundance during the summer and fall (Table 7). In all years, there were increases in the densities of both cladocerans and calanoid copepods adults in the Yolo Bypass at STTD during the month of October. The increased zooplankton densities were observed after increases in rice-field drainage flows and increased chlorophyll *a* concentrations (Figure 5). Specifically in 2012, we saw exceptional densities of both cladocerans and copepods adults in October with *Bosmina* (3.20E+05 /m³) and *Pseudodiaptomus forbesi* (1.79E+04) being the dominant taxa (Figure 5).

Table 6. Results of Mann-Whitney sign tests (P>0.05) comparing levels of different organisms in the Yolo Bypass (STTD) and Sacramento River (SHR) for the months of May-Nov for all years

Biological Data	**Z**		***n***		***P***
Chlorophyll *a*	7.99		47		<<0.0001
Calanoid copepod adults	7.47		47		<<0.0001
Cladocera	2.25		47		0.0244

Table 7. Correlations between flow and different organisms in the Yolo Bypass (STTD) and Sacramento River (SHR) for the months of May-Nov for all years combined (2011-2013). The Pearson correlation coefficients are shown, together with the number of observations and P-values in parentheses.

Biological Data	**Sacramento River (SHR)**		**Yolo Bypass (STTD)**
Chlorophyll a	0.0008(n=46, 0.853)		0.095(n=46, 0.037)
Calanoid Copepod Adults	0.0058(n=46, 0.614)		0.233(n=46, <<0.001)
Cladocera	0.0496(n=46, 0.137)		0.122(n=46, 0.017)

To obtain a perspective on how the densities of Yolo Bypass compare to other regions of the Estuary, available (2011 and 2012) zooplankton density data (IEP long-term monitoring data) was acquired for seasonal trend analysis of both caladocerans and calanoid copepod adults. The density data was grouped into regions and averaged: South/Central Delta Region (IEP sites: NZS42, NZ032,

NZ028, NZ048, and NZ054), Suisun Region (NZD16, NZD19, NZD28, NZM10, NZ086), and Yolo Bypass (STTD). In 2012, summer and fall densities of calanoid copepod adults were nearly 2 times greater in the Yolo Bypass than the South /Central Delta Region and 8 times greater than the Suisun Region. In addition, the average cladoceran densities in the Yolo Bypass were a factor of 7 greater than the Central/South Delta Region.

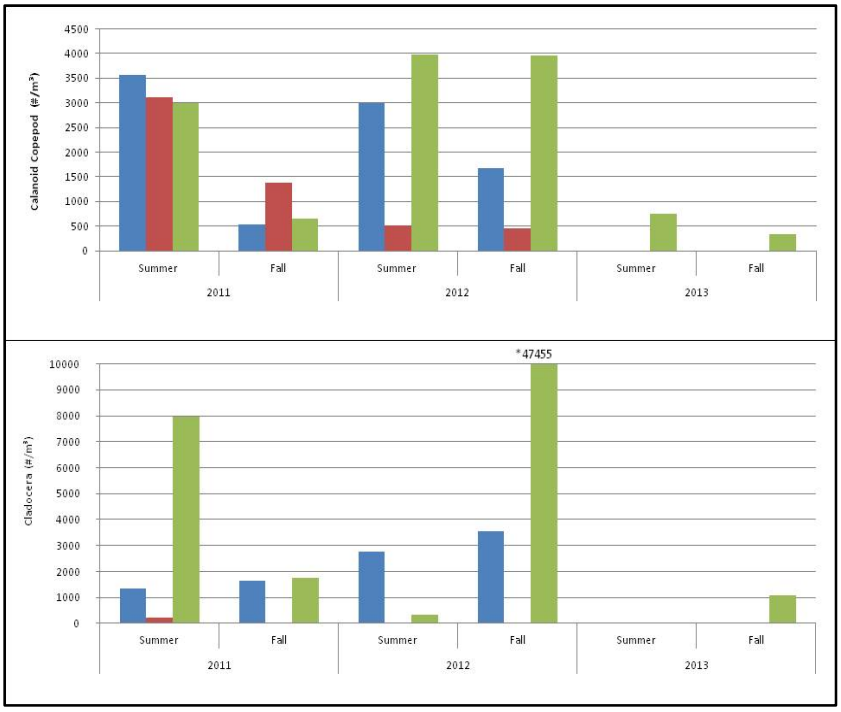


Figure 8. Average density (number/m³) of adult calanoid copepod and cladocera in summer and fall; green bars (Yolo Bypass Region - STTD), blue bars (South/Central Delta Region: NZS42, NZ032, NZ028, NZ048, and NZ054*), and red bars (Suisun Region:* NZD16, NZD19, NZD28, NZM10, NZ086*)*Indicates average (number/m³) of cladocera in Yolo Bypass in fall 2012*

Discussion:

The extension of the lower trophic monitoring in the Yolo Bypass and Sacramento River in the summer and fall of 2011-2013, has provided significant evidence that the Bypass can be an important food web subsidy to the lower Estuary even without floodplain inundation. The dynamic hydrologic and water quality conditions that occur in the Toe Drain of the Yolo Bypass from: agricultural practices (rice field harvest) and wastewater treatment discharge (Woodland and Davis), provide pathways for phytoplankton growth and transport; aiding in bottom-up benefits to higher trophic levels. The observed changes in DWR water operations at the Knights Landing Outfall Gates in 2012, unintentionally exposed the opportunity to consider future changes in water management strategies in the Yolo Bypass. The changes in 2012 have shown evidence of enhancing the Cache Slough Complex and lower Estuary food web during the fall. The Estuary's decadal decline in phytoplankton biomass has been linked to immense habitat changes and subsequent increases in invasive species. This plankton loss has been directly linked to declines in many of the Estuaries pelagic fishes including Delta Smelt, Longfin Smelt, Striped Bass, and Threadfin Shad. These declines have many negative implications related to ecosystem function, future restoration, and water supply reliability that affect the entire state. Based on this study's results, it seems as though the Yolo Bypass can serve as an alternate pathway for fall food web enhancement even during a time in which the Estuary is typically flow and food-limited.

Acknowledgements:

This research would not be possible without the funding support by the Ecosystem Restoration Program and the Inter Agency Ecological Program. I would like to acknowledge the Erwin VanNieuwenhuyse (USBR), Chris Foe (SWRCB), and Randy Dahlgren for all their expertise in study water quality and nutrient dynamics in the San Francisco Estuary. Addition thanks to colleagues: Ted Sommer, Louise Conrad and Brain Schreier for all their project support. I am especially grateful for all the staff that has helped collect all the data for this project over the past three years.

References:

Ahearn, D.S., J.H. Viers, J. F. Mount, and R.A. Dahlgren. 2006. Priming the productivity pump: flood pulse driven trends in a suspended algal biomass distribution across a restored floodplain. Freshwater Biology 51: 1417-1433.

Cloern J.E. and A.D. Jassby. 2008. Complex seasonal patterns of primary producers at the land-sea interface. Ecology Letters 11:1294-1303

Cranston, P.S., G.M. Benigno, and M.C. Domingeuz. 2007. *Hydrobaenus saetheri* Cranston, new species, an aestivating, winter-emerging chironomid (*Diptera: Chironomidae*) from California. Pages 73-79 in Contributions to the Systematics and Ecology of Aquatic Diptera-A tribute to Ole A. Saether. T. Andersen, editor. The Caddis Press

Dugdale, R.C., F.P. Wilkerson, V.E. Hogue and A. Marchi. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science 73: 17-29.

Frantzich, J., Ikemiyagi, N., and Conrad, L., 2013, 2010-2011 Yolo Bypass Fisheries Monitoring Status and Trends Report, IEP Newsletter 2013, Volume 26, Number 1:

Jassby A.D., Cloern J.E., and T.M. Powell.1993 Organic carbon sources and sinks San Francisco Bay: variability induced by river flow. Marine Ecology Progress Series 95:39-54

Jassby, A.D. and J.E. Cloern. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic Conservation: Marine and Freshwater Ecosystems 10: 323-352.

Jassby, A.D., J.E. Cloern, and B.E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnology and Oceanography 47: 698-712.

Jassby, AD. 2005. Phytoplankton regulation in a eutrophic tidal river (San Joaquin River, California). San Francisco Esturaies Watershed Sci 3:1-2

Jassby, A.D. 2008. Phytoplankton in the upper San Francisco Estuary: recent biomass trends, their causes and their trophic significance. San Francisco Estuary and Watershed Science. Vol. 6, Issue, Article 2.

Lehman, P. 2007. The influence of floodplain habitat on the quantity and quality of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary. Aquatic Ecology

Lucas, L. V., J. E. Cloern, J. K. Thompson, and N.E. Monsen. 2002. Functional variability of habitats within the Sacramento-San Joaquin Delta: Restoration implications. Ecol. Appl. 12: 1528-1547

Lucas, L. V., J. K. Thompson, and L. R. Brown. 2009. Why are diverse relationships observed between phytoplankton biomass and transport time? Limnol. Oceanography., 54(1), 2009, 381-390

Peterson, H. and M. Vayssieres. 2010. Benthic assemblage variability in the upper San Francisco Estuary: a 27-year retrospective. San Francisco Estuary and Watershed Science Volume 8, Issue 1 Article 2.

POD Workplan. 2010. Interagency Ecological Program. 2010 POD Workplan Synthesis and Results. Available at: http://www.water.ca.gov/iep/pod/synthesis_reports_workplans.cfm

Schemel, L.E., T.R. Sommer, A.B. Mueller-Solger, and W.C. Harrell. 2004. Hydrologic variability, water chemistry, and phytoplankton biomass in a large floodplain of the Sacramento River, CA, U.S.A. Hydrobiologia 513: 129-139.

Sommer, T., M. L. Nobriga, B. Harrell, W. Batham, & W. J. Kimmerer. 2001a. Floodplain rearing of juvenile Chinook Salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:325-333.

Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001b. California's Yolo Bypass: evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26:6-16.

Sommer, T.R., W.C. Harrell, A. Mueller Solger, B. Tom, and W. Kimmerer. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 14: 247-261.

Sommer, T. R., and F. Mejia, 2013, A place to Call Home: A Synthesis of Delta Smelt Habitat in the Upper San Francisco Estuary, San Francisco Estuary and Watershed Science 11(2), 27 p.

[SWRCB] State Water Resources Control Board. 1999. *Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh* (Adopted December 29, 1999, Revised in Accordance with order WR2000-02 March 15, 2000). Sacramento, CA.

Appendix D: Analyses of Historical Yolo Bypass Food Web Data

Project Lead: Kris Jones, Jared Frantzich, Louise Conrad, Ted Sommer, CDWR

Study Questions:

- Can specific flow thresholds be identified, which enhance phytoplankton abundance in the Yolo Bypass?
- Can bottom-up effects be detected between primary producers (phytoplankton) and primary consumers (drift species and zooplankton)?
- What are the general patterns of species composition for zooplankton and drift invertebrates in the Yolo Bypass and can these patterns be linked to environmental factors?

Methods

Biological Data

This study makes use of sampling data collected by the California Department of Water Resources as part of their food web studies conducted in the Yolo Bypass since 1998. The major components of the program include chlorophyll *a*, zooplankton, and drift sampling at the Toe Drain screw trap (Appendix B, Figure 1). Chlorophyll *a* was measured as a proxy for phytoplankton biomass in discrete water samples, and was collected weekly according to procedures described in Mueller-Solger et al. (2002). Drift samples were collected for approximately 30 minutes during mid-morning once or twice each week during flood events and every other week during lower flow periods (net size: 0.46 m x 0.3 m mouth, 0.91 m Length and 500 µm mesh). Sample volume was estimated from flow measurements with a flow meter (General Oceanics Model 2030 R) and net dimensions. Drift samples were stored in ethanol or formaldehyde, and then the invertebrates were identified to family or order using a dissection microscope. Zooplankton samples were taken concurrently with the drift samples using a Clarke-Bumpus net (0.13 m diameter, 0.76 m length, 153 µm mesh) placed into the surface flow in the Yolo Bypass. Sample volume was recorded as for the drift net. Samples were concentrated and stored in 5% formalin, after which the zooplankton were removed, and crustacean zooplankton were counted and identified to class or order. Catch per unit effort (CPUE) values were then calculated for both zooplankton and drift species according to standard methods[2].

Environmental Data

Discrete water quality measurements were collected concurrently with the biological sampling (see above); secchi depth was recorded and electrical conductivity was measured using a YSI 556 MPS (Yellow Springs Instruments, Yellow Springs, OH, USA). Continuous water temperature data were also collected at the Toe Drain screw trap using fixed temperature recorders at hourly intervals (Onset Corporation). Stage measurements were obtained at fifteen minute intervals from gauges operated by the California Department of Water Resources below Lisbon Weir (Appendix B, Figure 1) (Station: LIS http://cdec.water.ca.gov/). To reflect the environmental conditions leading up

[2] CPUE for drift species was calculated as the total count divided by sampling volume. Zooplankton CPUE was calculated as CPUE = ((C/S)L)/V; N = the number of taxon per cubic taxon per cubic meter of water filtered; C = the cumulative number of a taxon counted for the sample; L = the reconstituted sample volume (dilution volume) in milliliters; S = the number of Sedgewick-Rafter cells examined (1 ml ea); V = the volume of water filtered through the net (m^3) (where volume filtered is estimated by VolFiltered = (end meter - start meter) * calibration factor * mouth area).

to each sampling event, temperature and stage data were summarized for the maximum value for the week prior to each sampling event; only data for temperature and stage could be summarized on a weekly basis due to the frequency with which measurements were taken (secchi depth and electrical conductivity were only discretely measured).

Statistical Analyses

Flow Thresholds

All analyses were performed in the R environment (R Development Core Team 2014). In order to examine the relationship between flow and primary productivity, generalized additive models with negative binomial error structure were performed to study the relationship between stage and chlorophyll *a*. For the purposes of this study, we were also interested in characterizing the conditions that were associated with the first large spikes in chlorophyll *a* concentration in the spring. To get at this question, change point analyses were performed using binary segmentation (Edwards and Cavalli-Sforza 1965, Scott and Knott 1974, Sen and Srivastava 1975) to detect abrupt changes in mean chlorophyll *a* concentration over the time series. For this method, a single changepoint test is applied to the entire dataset. If a changepoint is identified the data is split into two at the changepoint location. The single changepoint procedure is repeated on the two new data sets, before and after the change. If changepoints are identified in either of the new data sets, they are split further. This process continues until no changepoints are found in any parts of the data. For the purpose of this study, the first changepoint in each year was used to identify the first spike in chlorophyll *a* concentration along with the environmental data associated with that particular sampling event.

Bottom-Up Effects

Due to the large number of taxa represented in the datasets for drift invertebrates (n=34; Appendix D.1) and zooplankton (n=17; Appendix D.2), data were restricted to those taxa that constituted >90% of the total catch. To test for bottom-up effects, monthly averages were calculated for all biological data so that monthly data for primary producers (chlorophyll *a* concentrations) could be paired appropriately with monthly data for primary consumers (zooplankton and drift invertebrates CPUE); data were summarized in this way, as sampling for chlorophyll *a*, zooplankton and drift invertebrates did not always occur concurrently. In order to examine whether bottom-up effects could be detected, negative binomial models were performed to evaluate whether chlorophyll *a* was a good predictor for zooplankton and drift invertebrate relative abundance (i.e., CPUE).

Assemblage Patterns for Drift Species and Zooplankton

Multivariate analyses were carried out on drift invertebrate and zooplankton assemblage data using the statistical package PRIMER (Clarke and Gorely 2006). Assemblage similarities were explored using non-metric multi-dimensional scaling (NMDS; Clarke and Green 1988; Clarke 1993) on Bray-Curtis dissimilarity indices computed from square-root transformed annual abundance data.

NMDS plots provide a visualization of the among-sample Bray-Curtis dissimilarity (dissimilarity equals 1– Bray-Curtis similarity) by placing samples that are more similar closer together than those that are less similar. The computation of Bray-Curtis dissimilarity takes into account the presence and abundance of all taxa in each sample (e.g., the square-root transformed mean abundance of each of the taxa observed during a given year). Ordinarily, the symbols in an NMDS plot do not convey the composition of the samples being compared. However, to visualize the assemblage data in the NMDS plots, pie-diagrams representing the assemblage composition were substituted for the symbols that were initially plotted. The X and Y coordinates of the symbols from NMDS plots were used to spatially organize the pie diagrams, which display untransformed annual average abundances of the numerically dominant taxa for each sample. The size of the pie diagrams are scaled to represent differences in relative annual abundance among the drift invertebrate and zooplankton taxa.

In order to examine which abiotic variables best matched the patterns of drift invertebrate and zooplankton

assemblage composition, we used the BEST function in PRIMER to rank correlations between the assemblage composition and environmental data. Environmental variables were normalized prior to constructing a dissimilarity matrix using Euclidean distance. The dissimilarity matrix based on environmental variables was compared to a Bray-Curtis dissimilarity matrix computed from square-root transformed annual average organism abundance data.

Results

Flow Thresholds

Chlorophyll *a* data were evaluated for the period of January to April between the years of 2001 and 2012. During our study period, chlorophyll *a* concentrations increased through the spring, with the highest concentrations observed in April (Appendix D.4). When examining the data for these first spikes in chlorophyll *a* concentrations, the majority of these first spikes occurred during the month of March and were associated with a broad range of stage values (Appendix D.5). When performing analyses on the entire data set, models investigating flow effects on primary production revealed that stage was a significant predictor of chlorophyll *a* concentrations ($P < 0.001$; Figure 2); chlorophyll *a* concentrations decreased with increasing stage, with the highest chlorophyll *a* concentrations observed for stage values between 6-7 feet (approximately 2000-2500 cfs).

Upon closer inspection, a significant interaction was observed between temperature and stage ($P < 0.001$). Separate analyses of the lowest and highest temperature data (Low: minimum temperature to the median; High: median temperature to the maximum) revealed that stage had a significant negative effect on chlorophyll *a*, but only at higher temperatures ($P = < 0.001$; 14.4-23.5^{o}C); no significant effect of stage were detected for chlorophyll *a* at lower temperatures ($P = 0.155$; 7.5-14.4^{o}C).

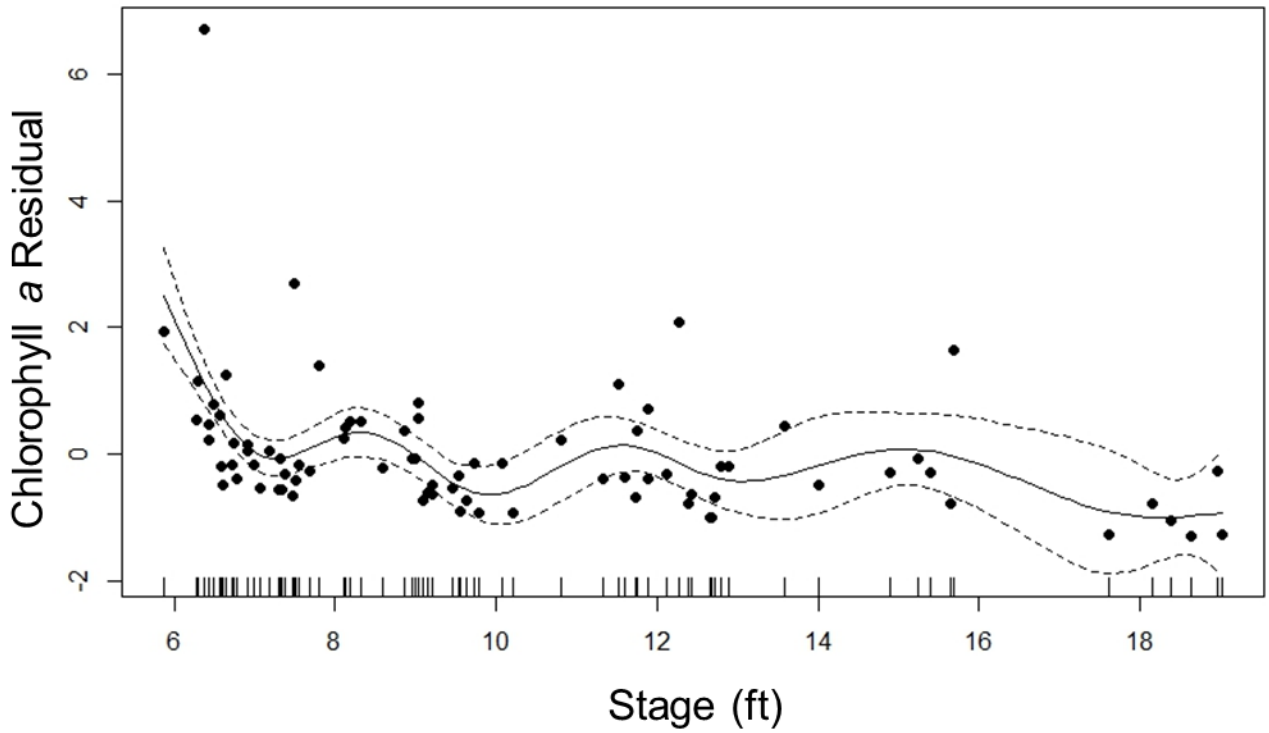


Figure 2. Relationship between stage and chlorophyll *a*. Data are displayed as residuals. The solid line represents the predicted means and dashed lines are the 95% confidence intervals.

Table 2. Results from generalized additive models evaluating the relationship between chlorophyll *a* concentration and A) drift invertebrate CPUE; B) zooplankton CPUE. DWR food web data were used for these analyses for the period of 2001-2012.

A)

Taxa	Effect/(SE)	*P*
Amphipoda	-0.19597/(0.08727)	0.025
Araneida	0.22352/(0.08707)	0.010
Coleoptera	0.06229/(0.05738)	0.278
Collembola	0.06084/(0.05630)	0.280
Diptera	0.10602/(0.03487)	0.002
Hemiptera	0.13330/(0.04978)	0.007
Homoptera	0.44259/(0.09064)	<0.001
Hymenoptera	0.26320/(0.08006)	<0.001

B)

Taxa	Effect/(SE)	*P*
Acanthocyclops	0.19792/(0.07407)	0.008
Bosmina	0.10265/(0.03049)	0.001
Ceriodaphnia	-0.005261/(0.0488)	0.914
Daphnia	0.05019/(0.03972)	0.206
Pseudodiaptomus	-0.02397/(0.12486)	0.848
Sinocalanus	0.20072/(0.09295)	0.031
Other_Calanoids	0.18333/(0.05346)	<0.001
Other_Cladocera	0.06526/(0.02924)	0.026

Bottom-Up Effects

The datasets used in analyses exploring the relationship between primary producers and primary consumers spanned the years of 2001-2012. For drift species, 26 taxa accounted for the lowest 3% of the total catch (Appendices D.1 & D.3a), whereas 9 taxa accounted for the lowest 1.5% of the total catch for zooplankton (Appendices D.2 & D.3b). To simplify analyses, these taxa were excluded from all analyses (see Appendices 1 & 2).

Analyses testing for bottom-up effects suggest that chlorophyll *a* was a good predictor for a majority of the represented taxa for drift species and zooplankton (Table 2 a & b, respectively). For a majority of represented drift invertebrates and zooplankton, we found that their abundances increased with increased chlorophyll *a* concentrations. In one instance we observed a significant negative effect of chlorophyll *a* on relative abundance (i.e., Amphipoda) (Table 2a); however, as Amphipoda was one of the least represented drift invertebrates in our analyses (Appendix D.1), it is possible that these patterns could simply be an artifact of a small sample size.

Assemblage Patterns for Drift Species and Zooplankton

The datasets used in analyses exploring assemblage patterns for primary consumers spanned the years of 1999-2012. Assemblage data for drift species indicated that Homopterans were the numerically dominant taxa during the study period, followed by Dipterans and Hemipterans (Table 4); these three taxa together accounted for 76% of the overall abundance over the study period. Dipterans were consistently the dominant taxa for the drift species

represented in our analyses (Table 4); however, Homopterans were the numerically dominant taxa across study years due to a particularly

Table 4. Total catch per unit effort for drift invertebrates between the years of 1999 and 2012.

Year	Amphipoda	Araneida	Coleoptera	Collembola	Diptera	Hemiptera	Homoptera	Hymenoptera
1999	0.4	0	0	0	2.2	0.9	0.1	0
2000	5.29	1.29	28.57	3.29	43.57	14.57	0.43	0.86
2001	2.83	0.17	2.5	4	6.83	6.33	0	1
2002	0.2	0.2	1.8	7.4	9.2	1.6	12.2	1
2003	0.7	0	6.7	0.5	20.5	3.7	0	0.3
2004	0.86	0.14	1.29	0	4.29	8.14	0.57	0
2005	2.44	2.38	17.44	3	27.94	33.75	0	1.38
2006	1.09	0.64	0.64	0	17.36	0.55	0.45	0
2007	0	6	9	15	52.2	12.4	128.6	21.8
2008	0.13	65.5	35.25	3	183.5	207.25	360	65.38
2009	1.63	3.38	9	40.13	31	4.75	2.75	4.75
2010	0.08	0.17	0.42	0.92	5.75	1.5	0.42	0.25
2011	0.44	0	0.11	0.78	7.56	4.33	0	0
2012	0	0.13	0.63	2.88	3.5	8.63	0	0.13

Table 5. Total catch per unit effort for zooplankton between the years of 1999 and 2012.

Year	*Acantho.*	*Bosmina*	*Ceriodaphnia*	*Daphnia*	*Pseudo.*	*Sinocalanus*	Other Calanoids	Other Cladocera
1999	13	22	0	24	0	0	0	55
2000	9	2	4	53	0	0	1	65
2001	268	189	0	1,050	0	8	16	1,395
2002	167	1,350	0	290	0	110	12	1,719
2003	93	207	168	448	0	2	6	1,088
2004	426	824	205	456	0	2	18	1,820
2005	1,594	1,386	2,444	6,177	9	0	271	8,370
2006	45	190	68	208	0	1	10	1,032
2007	0	1,144	602	761	0	115	29	3,623
2008	29,627	8,549	1,324	17,538	0	0	6,194	15,163
2009	206	341	183	965	5	2	8	1,684
2010	0	1,443	1,702	7,556	3	0	163	5,043
2011	242	238	328	699	0	3	21	3,099
2012	0	1,425	311	652	40	1	14	2,961

abundant year in 2008 (Table 4). Assemblage data for zooplankton revealed that Cladocerans were the dominant taxa represented in our analyses, followed by *Daphnia* and *Acanthocyclops* (Table 5); these three taxa together accounted for 79% of the overall abundance over the study period. Zooplankton abundance was highest in 2008, with *Acanthocyclops* consisting of the largest percentage of the taxa during that year (38%; Table 5).

Results from the BEST analyses indicated that the abiotic variables which best matched the pattern of relative abundance and assemblage composition for drift species and zooplankton were stage and temperature; however, these patterns were only weakly correlated for drift invertebrates (correlation = 0.177) and zooplankton (correlation = 0.197). While there were no clear statistical trends in total organism abundance for either drift species or zooplankton (1999-2012), annual abundances for drift invertebrates (Figure 3) and zooplankton (Figure 4) tended to be least in wet years. Conversely, the highest annual abundances observed for both drift species and zooplankton were in 2008, which was a critically dry year (based on the Sacramento and San Joaquin Water Year Index). Clusters of annual assemblage data in NMDS plots also suggest that assemblage patterns in drier years were more similar than wetter years, although these patterns were less pronounced for the drift invertebrate data (Figures 3&4).

Conclusions

We analyzed the relationship between measures of environmental factors that are known to be important for the relative abundance of primary producers (phytoplankton) and primary consumers (drift species and zooplankton). Higher levels of phytoplankton biomass (measured as chlorophyll *a* in the floodplain) associated with lower flows and increased residence times are consistent with previous work in this system (e.g., Sommer et al. 2004). In our study, we observed an overall negative relationship between stage and chlorophyll *a*, with the highest chlorophyll *a* concentrations occurring between stage values of 6-7 feet (approximately 2000-2500 cfs). These data revealed that the first spikes in chlorophyll *a* concentrations most commonly occurred in March, and were associated with a broad range of stage values. Upon closer examination of the data, temperature appeared to be a key factor in explaining patterns of phytoplankton biomass across years; the effects of stage on phytoplankton biomass seemed to be most apparent at warmer temperatures.

Our investigations of bottom up effects suggest that the relative abundance of many zooplankton and drift species on the Yolo Bypass seem to be positively associated with phytoplankton biomass. Overall, differences in relative abundance and assemblage patterns for primary consumers appear to be only weakly linked to temperature and flows; however, our results do suggest some apparent divisions between wet and dry years in term of differences in relative abundance and species composition. While it is possible that the these weak patterns are simply due to the inherent limitations of a correlational study, they do suggest some interesting patterns which should be explored in future work.

While the results from this study provide further links between environmental factors and lower trophic productivity on the Yolo Bypass, there are several important points to consider. First, this study was only able to make associations between environmental drivers and chlorophyll *a* concentrations—we were unable to link environmental factors to the species composition of phytoplankton on the Yolo Bypass, as these data were unavailable. It is very likely that the observed interaction between stage and temperature on chlorophyll *a* will have species-specific effects for phytoplankton on the Yolo Bypass. Further work should be performed, which explore assemblage patterns for phytoplankton under different temperature and flow conditions, as increased residence times and warmer temperatures have been associated with less nutritious and potentially harmful phytoplankton such as *Microcystis* (e.g., Lehman et al. 2008), which can have adverse effects up the food chain. Second, this study only focused on the factors that were important for promoting primary and secondary consumers—it did not focus on factors important for fish. If the focus of future restoration is to promote conditions which have bottom up benefits for fishes, studies are needed that take a holistic approach in exploring the interplay between the environmental factors that are optimal for lower trophic levels and threatened species (e.g., Chinook Salmon, Delta Smelt etc.).

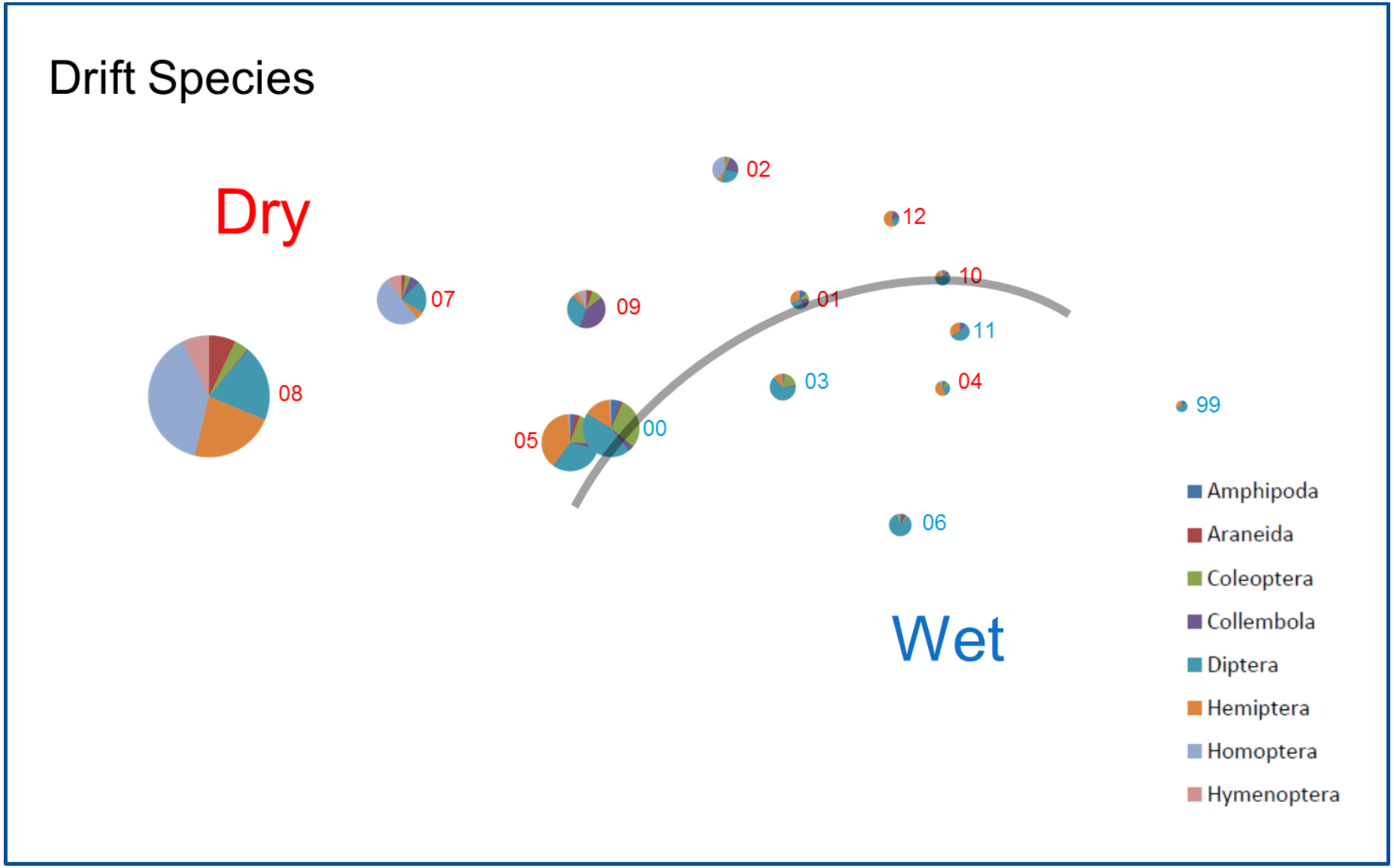


Figure 3. Assemblage structure for drift species from 1999-2012. Pie charts representing dominant taxa abundance and relative density (pie diameter) of drift invertebrate assemblage are arranged based on NMDS analysis of Bray-Curtis dissimilarities. The pie-charts show untransformed taxa abundances. Wet and dry years are labelled in blue and red, respectively; wet and above normal years were considered 'wet', whereas below normal, dry and critical were considered 'dry' (based on classifications from the Sacramento and San Joaquin Water Year Index).

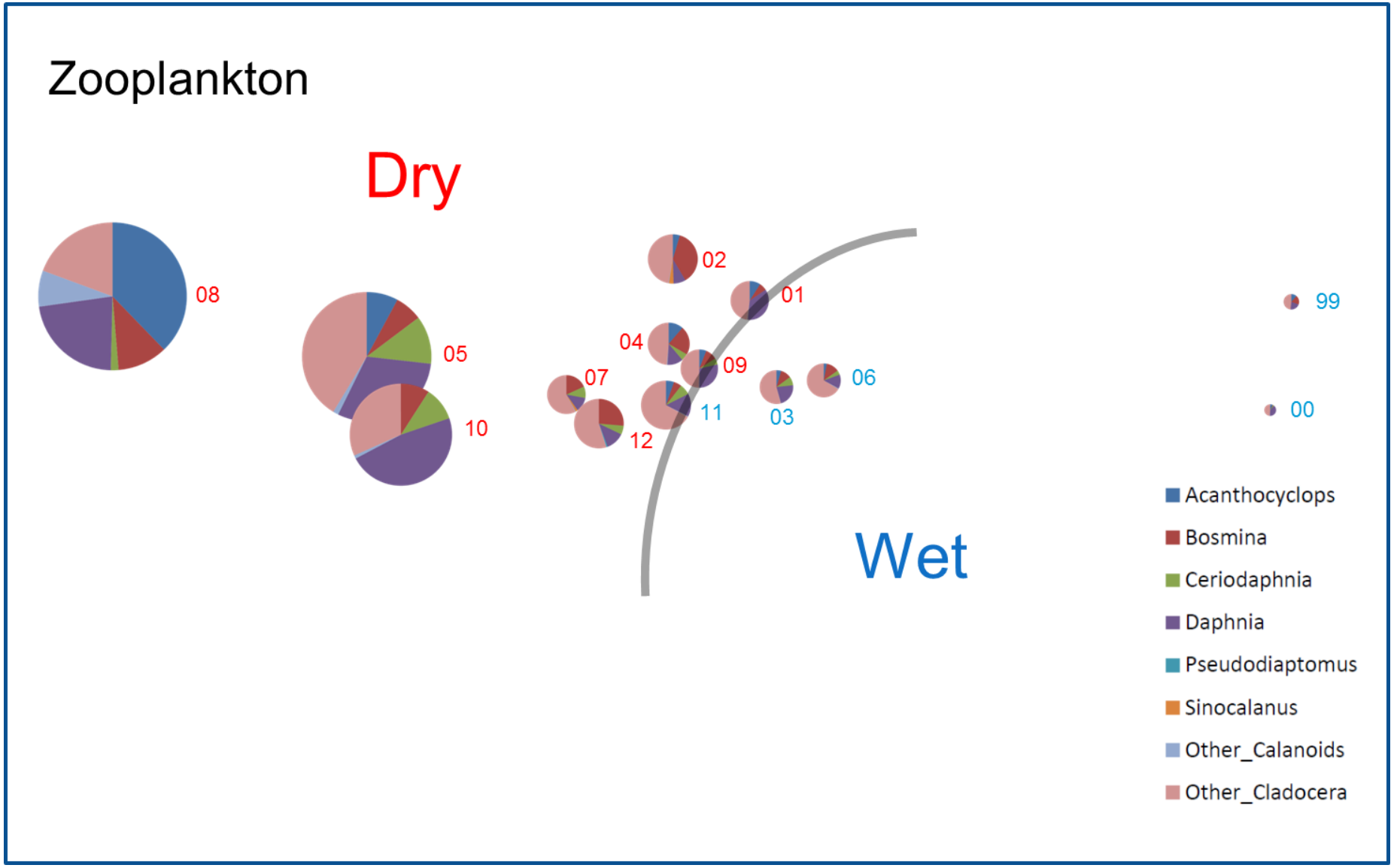


Figure 4. Assemblage structure for zooplankton from 1999-2012. Pie charts representing dominant taxa abundance and relative density (pie diameter) of zooplankton assemblage are arranged based on NMDS analysis of Bray-Curtis dissimilarities. The pie-charts show untransformed taxa abundances. Wet and dry years are labelled in blue and red, respectively; wet and above normal years were considered 'wet', whereas below normal, dry and critical were considered 'dry' (based on the classifications from the Sacramento and San Joaquin Water Year Index).

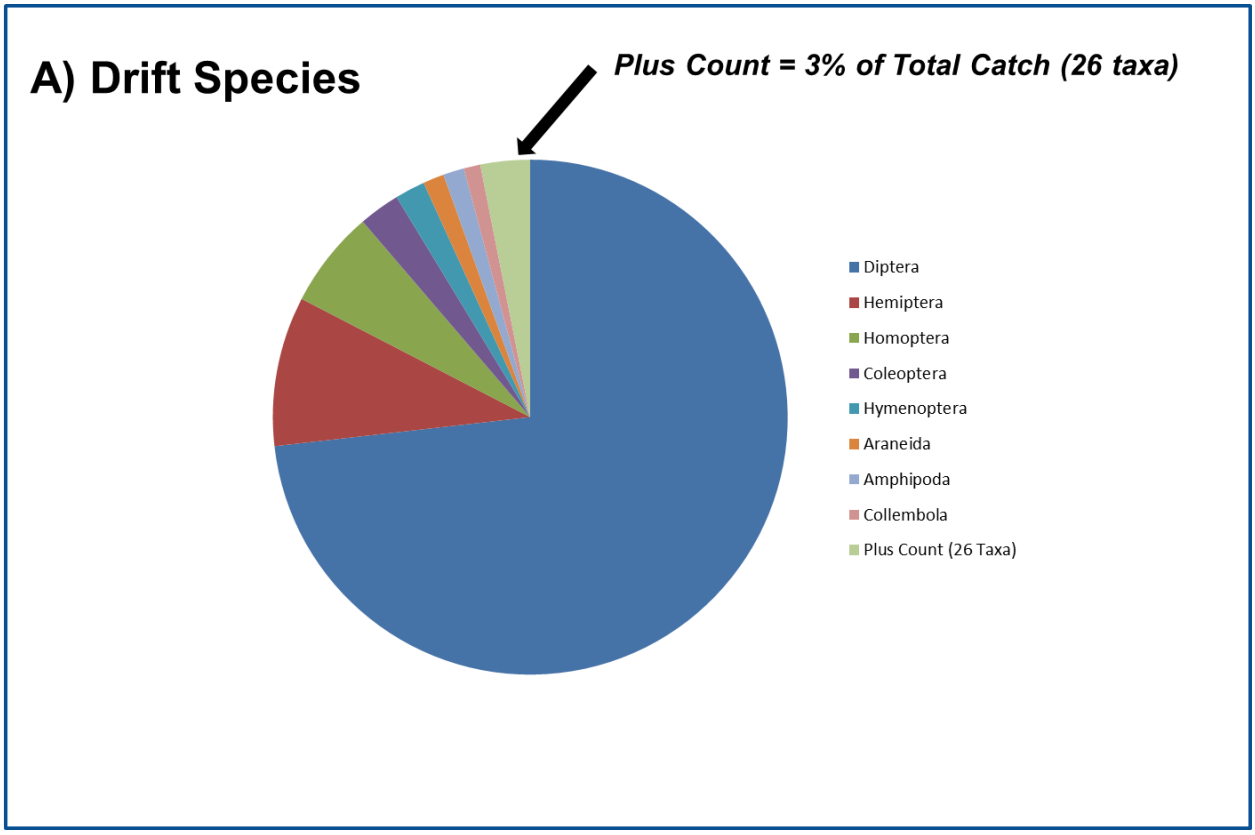
Appendix D.1. Summary of assemblage data for drift invertebrates, shown as the total CPUE across the study period (1999-2012) as well as the relative proportions of each group among the total sample. Taxa in bold were those taxa included in analyses (un-bolded taxa were removed from all datasets used in analyses).

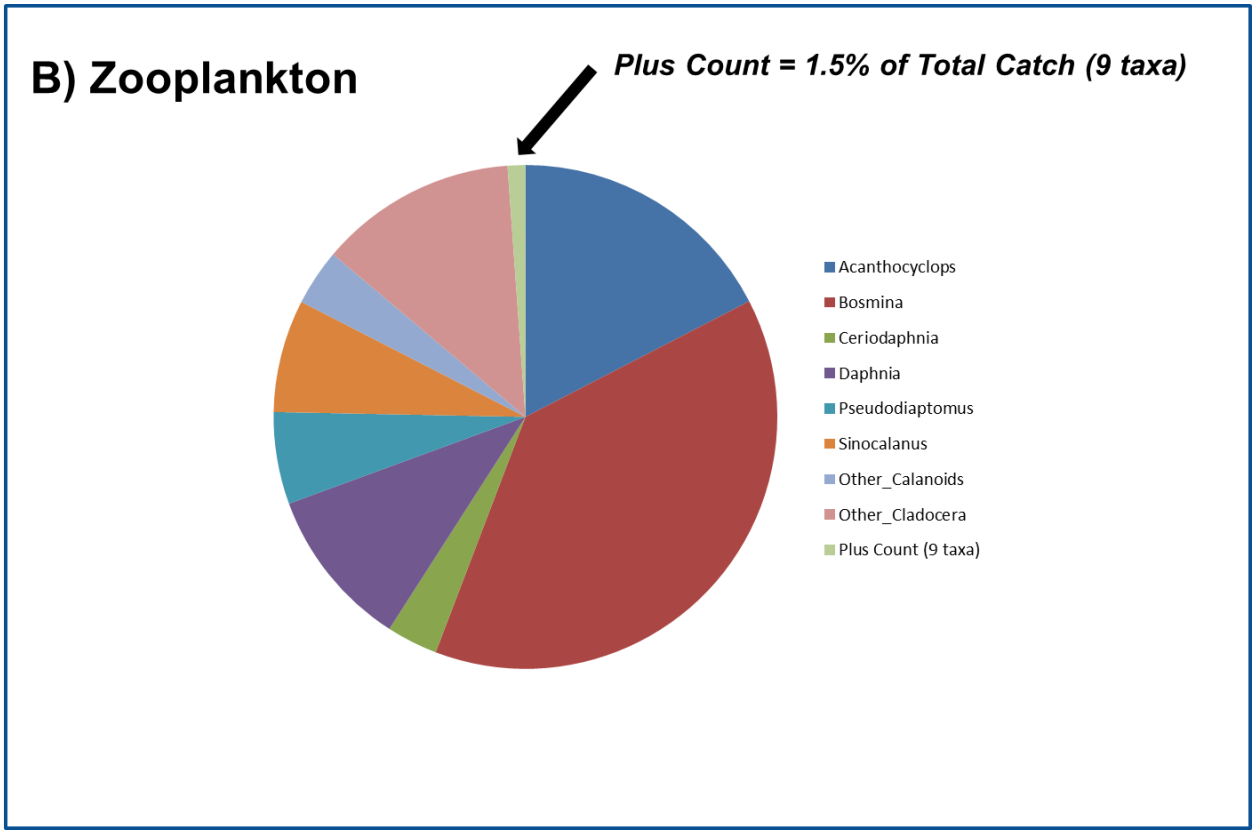
Drift species	Total CPUE	%Total
Diptera	**71,822**	**73.20%**
Hemiptera	**9,222**	**9.40%**
Homoptera	**6,012**	**6.13%**
Coleoptera	**2,538**	**2.59%**
Hymenoptera	**1,855**	**1.89%**
Araneida	**1,301**	**1.33%**
Amphipoda	**1,292**	**1.32%**
Collembola	**1,025**	**1.04%**
Ostracoda	587	0.60%
Thysanoptera	428	0.44%
Decapoda	396	0.40%
Psocoptera	358	0.37%
Plecoptera	326	0.33%
Geophilomorpha	189	0.19%
Acari	189	0.19%
Lepidoptera	170	0.17%
Odonata	122	0.12%
Ephemeroptera	97	0.10%
Hydracarina	94	0.10%
Mysidacea	82	0.08%
Trichoptera	3	0.00%
Phalangida	2	0.00%
Isopoda	2	0.00%
Trombidiformes	2	0.00%
Hydrachnida	2	0.00%
Neuroptera	1	0.00%
Diplura	1	0.00%
Julida	1	0.00%
Thysanura	1	0.00%
Orthoptera	1	0.00%
Dermaptera	0	0.00%
Neotaenioglossa	0	0.00%
Oribatei	0	0.00%
Lithobiomorpha	0	0.00%
Total	98,121	100.00%

Appendix D.2. Summary of assemblage data for zooplankton, shown as the total CPUE across the study period (1999-2012) as well as the relative proportions of each group among the total sample. Taxa in bold were those taxa included in analyses (un-bolded taxa were removed from all datasets used in analyses).

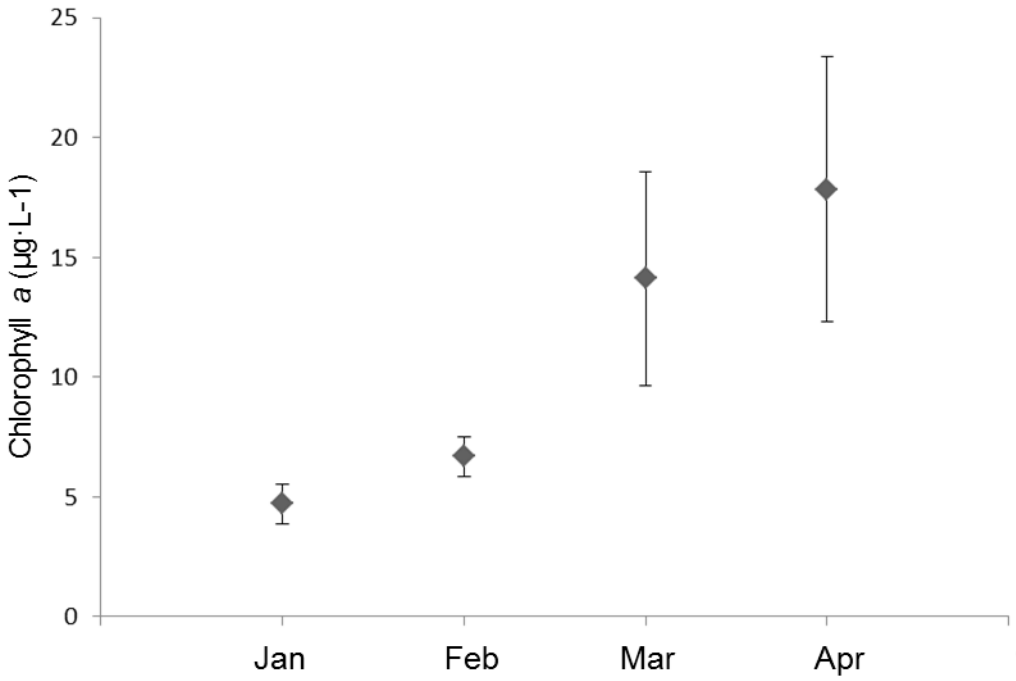
Zooplankton	Total CPUE	%Total
Bosmina	**1,293,596**	**38.39%**
Acanthocyclops	**586,517**	**17.41%**
Other_Cladocera	**427,728**	**12.69%**
Daphnia	**347,823**	**10.32%**
Sinocalanus	**243,940**	**7.24%**
Pseudodiaptomus	**198,867**	**5.90%**
Other_Calanoids	**121,983**	**3.62%**
Ceriodaphnia	**110,729**	**3.29%**
Ilyocryptus	15,131	0.45%
Ostracods	11,740	0.35%
Diaphanosoma	3,891	0.12%
Macrothrix	3,850	0.11%
Camptocercus	1,858	0.06%
Eurytemora	1,204	0.04%
Osphranticum	498	0.01%
Oithona_Spp	131	0.00%
Tortanus_spp	1	0.00%
Total	3,369,487	100%

Appendix D.3. Visual summary of assemblage data for A) drift species; and B) zooplankton. Data show the relative proportions of each group across the study period (1999-2012). Plus counts represent the taxa excluded from datasets (as detailed in Appendices 1 and 2).





Appendix D.4. Mean monthly values and standard errors of chlorophyll *a* concentration are presented for January through April; monthly mean values were calculated across study years (2001-2012).



Appendix D.5. Summary data for the first spikes in chlorophyll *a* concentrations across the study period (2001-2012), which were identified using changepoint analyses.

Year	Date	Chlorophyll *a* (µg·L-1)	Stage (feet)
2001	3/16/2001	12.8	11.4
2002	3/21/2002	32.4	6.8
2003	3/5/2003	13.1	9.0
2004	3/19/2004	23.0	14.2
2005	3/29/2005	18.7	11.5
2006	1/26/2006	22.2	15.7
2007	3/12/2007	9.4	6.3
2008	3/26/2008	26.8	6.3
2009	4/23/2009	53.8	5.9
2010	3/30/2010	156.0	6.4
2011	4/6/2011	162.3	18.4
2012	3/7/2012	15.7	6.6