

# **Evaluating the role(s) of the Butte sink and Sutter Bypass for Butte Creek spring-run Chinook Salmon and other Central Valley juvenile salmonid populations - 2020 study year**

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## **DISCLAIMER**

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## SUMMARY

California's Central Valley (CCV) Chinook Salmon stock has declined substantially since the mid-1800s with the spring, winter and late-fall runs listed as threatened or endangered, and the fall run heavily supplemented by hatcheries. Butte Creek is largest Central Valley spring-run Chinook Salmon population, and has been relatively successful and stable compared to other threatened spring-run Chinook Salmon populations (i.e. Mill, Deer and Battle Creek). The Butte Sink and Sutter Bypass have been suggested to play an important role in their success by providing juvenile salmon a rich floodplain rearing habitat before their out-migration to the Pacific Ocean.

This project had several purposes. The first one was to quantify the differences in growth between the Butte Sink, Sutter Bypass, and adjacent Sacramento and Feather River habitats, for Butte Creek juvenile Chinook Salmon and other CCV Chinook Salmon populations that could potentially access those habitats. The second goal was to better understand the complex hydrology of the lower Butte Creek watershed during baseline and flooding conditions, and to characterize the food web composition and its dynamics through time. The third goal was to identify which runs of Chinook Salmon were accessing the Butte Sink and Sutter Bypass, when the weirs overtopped and the Sacramento River mixed with Butte Creek.

2020 was the second year this project was implemented. In comparison to 2019, 2020 was a hydrologically dry year, with a lack of substantial precipitation in the winter leading to zero inundation of the Sutter Bypass from the Sacramento River via the passive weirs (i.e., Moulton, Colusa and Tisdale weirs). Dry conditions excluded all salmon spawned in the Sacramento River and upstream tributaries (i.e., Mill Creek, Battle Creek, Deer Creek) from accessing the Butte Sink and Sutter Bypass. Spring-run and fall-run Chinook Salmon spawning in Butte Creek were presumably the only fish with access to Bypass channels and wetlands, and were captured during seining events. Similar to 2019, off-channel wetland habitats were characterized by a higher zooplankton abundance and supported higher juvenile salmon growth rates than channel habitats. In 2020, channel habitats were separated into canal and river channel habitats, and except for one canal location in the upper Sutter Bypass region, Sacramento River growth rates were found to be higher than canal growth rates. Wetland cage fish diet was driven by amphipods and cladocera, while canal channel cages showed a copepod and small cladocera

dominated fish diet, and river channel fish diet was driven by insects, as well as copepoda and cladocera species in locations situated downstream of known off-channel effluent points.

## INTRODUCTION

The California Central Valley (CCV) supports four runs of Chinook Salmon that are named according to the season in which the adults return to freshwater: fall-, late-fall-, winter-, and spring-run. Prior to Euro-American settlement, an estimated 1-2 million wild Chinook Salmon would return to the CCV rivers each year (Yoshiyama et al. 1998), achieving this abundance in large part because they had access to vast and diverse natural freshwater habitats, from which this unique diversity of Chinook Salmon life history strategies emerged.

Central Valley rivers once carried runoff from large winter storms and spring snowmelt onto low-lying floodplains, slowing and spreading water into complex mosaics of riparian forest and wetlands. Large flood basins, floodplains, and tidal wetlands were often inundated for long periods in most years providing food rich rearing habitat that was essential to support the large salmon populations. Those highly productive floodplain waters provided ideal conditions for juvenile salmon to feed and grow before migrating to the ocean (Welcomme 1979, Ribiero et al. 2004). Over the last century and a half, however, floodplain habitats have been diminished by 95% since pre-settlement levels (Hanak et al. 2011). Valued for their rich soils, most of the Central Valley's floodplains have been converted to agriculture and have been disconnected from their rivers by levees and dykes (Speir et al. 2015). Flow alteration, especially the reduction of large flow events, from large upstream dams and water diversions, has also limited the inundation duration and extent of remnant floodplain habitats. The loss of floodplain habitat, along with other limiting factors such as the loss of spawning habitat and the degradation of remaining migratory corridors have taken a toll on CCV Chinook Salmon. Currently the fall- and late fall-run are listed as "Species of Concern", fall-run is also heavily supplemented by hatcheries, spring-run is listed as threatened, and winter-run is listed as endangered under the Endangered Species Act (Williams 2006).

In order to control high flows that would otherwise inundate farmland and cities, the Sacramento Flood Control Project was created in 1911 and adopted by Congress in the Flood Control Act of 1917 (Kelley 1989). The Project was designed to passively spill water from the

Sacramento River and tributaries through a system of weirs into a series of flood bypasses. The system of bypasses was designed to divert floodwaters from the main river channels and eventually convey the floodwaters into the Sacramento-San Joaquin Delta. The Sutter Basin is the uppermost flood bypass in the Sacramento Valley, encompassing approximately 14,000 hectares from the Butte Sink in the north to the confluence of the Sutter Bypass with the Feather and Sacramento Rivers near Verona in the south. In late winter and spring, Sacramento River water can flow into the Butte Sink and the Sutter Bypass via Moulton, Colusa, and/or Tisdale weirs. In addition, the upper Butte Creek watershed connects to the Butte Sink just north of the Sutter Buttes. The low lying topography of the Butte Sink and Sutter Bypass and the design of the weir infrastructure connected to the Sacramento River means that the Sutter Bypass floods nearly every year and is a crucial piece of the Central Valley Project relieving pressure on the levees of the Sacramento and Feather Rivers (CVFMPP 2010). The frequent inundation allows for off-channel ecosystem processes to persist in the current altered hydrologic landscape. These processes provide ecosystem services such as groundwater recharge, food web production, and off-channel habitat for aquatic species (Sommer et al. 2001, Grozholtz and Gallo 2006, Opperman et al. 2009).

Butte Sink and Sutter Bypass provide important rearing habitat for Butte Creek spring-run Chinook Salmon population, especially in years of extensive winter and spring flooding (Ward and Mc Reynolds 2004, Johnson and Lindley 2016). This ESA listed population has been a relatively successful and stable population compared to other threatened spring-run Chinook Salmon populations (i.e. Mill, Deer and Battle Creek; Azat et al. 2017). Recapture data of coded wire tagged (CWT) Butte Creek fry suggest that large numbers of spring-run juveniles reside for extended periods in the Butte Sink and Sutter Bypass before continuing their migration to the ocean (Ward and McReynolds 2004).

This project presents a unique opportunity to investigate and quantify the potential ecosystem benefits of one of the last ephemeral floodplain habitats found in the Sacramento Valley for the remaining populations of Chinook Salmon from the Sacramento River and its tributaries. This project focused on measuring the water quality, food web, and resulting performance of juvenile Chinook Salmon in the Sutter Basin and adjacent locations in the Sacramento and Feather Rivers. These findings will help inform water managers and habitat restoration and reconciliation efforts for Chinook Salmon in CCV.



## OBJECTIVES

The purpose of this study was to quantify, for the second year in a row, the benefits of the Butte Sink and Sutter Bypass for juvenile Chinook Salmon compared to adjacent river channel habitats. We aimed at answering the following questions:

- 1) How does the hydrology of the Butte Sink and the Sutter Bypass (see Figure 1 for region's delineation) affect juvenile Chinook Salmon?
- 2) What are the growth benefits to juvenile Chinook Salmon rearing in Butte Sink and Sutter Bypass in comparison to adjacent channelized river habitats?
- 3) What runs of Chinook Salmon utilize the Butte Sink and Sutter Bypass?

## MATERIALS AND METHODS

### Site locations

15 locations were selected for the 2020 study across the 5 regions of interest: 1) Butte Sink: North of Colusa weir, 2) Upper Bypass: Colusa weir to Tisdale weir, 3) Lower Bypass: Tisdale weir south to Sacramento River, 4) Sacramento River, and 5) Feather River (Table 1, Figure 1). Three different habitat types were identified; River channel, Canal channel, and Wetland (Table 1). Due to lack of flooding in 2020, no off-channel agriculture habitat was available. River channel and wetland sites from 2019 were replicated in 2020, with the exception of SRC1 which was moved downstream approximately 1km. Canal channel sites were added in anticipation of flooding which did not occur during the water year. They were opportunistically left in the canals as a comparison of productivity.

Table 1. Cage site locations across the different regions, and associated data collection.

Region	Location	Habitat type	Growth cage number	Gut content cage	Dissolved oxygen	Water quality	Lower trophic
Butte Sink	BSW1	Wetland	3	1	YES	YES	YES
	BSW2	Wetland	3	1	YES	YES	YES

	BSC1	Canal channel	2	1	YES	YES	YES
<b>Upper Bypass</b>	UBC1	Canal channel	2	1	YES	YES	YES
	UBC2	Canal channel	2	1	YES	YES	YES
	UBW1	Wetland	3	1	YES	YES	YES
	UBC3	Canal channel	1	0	YES	YES	YES
<b>Lower Bypass</b>	LBW1	Wetland	3	1	YES	YES	YES
	LBC1	Canal channel	1	0	Partial	YES	YES
	LBC2	Canal channel	4	1	YES	YES	YES
<b>Sacramento River</b>	SRC1	River channel	2	1	YES	YES	YES
	SRC2	River channel	2	1	YES	YES	YES
	SRC3	River channel	2	1	YES	YES	YES
	SRC4	River channel	2	1	YES	YES	YES
<b>Feather River</b>	FRC1	River channel	2	1	YES	YES	YES

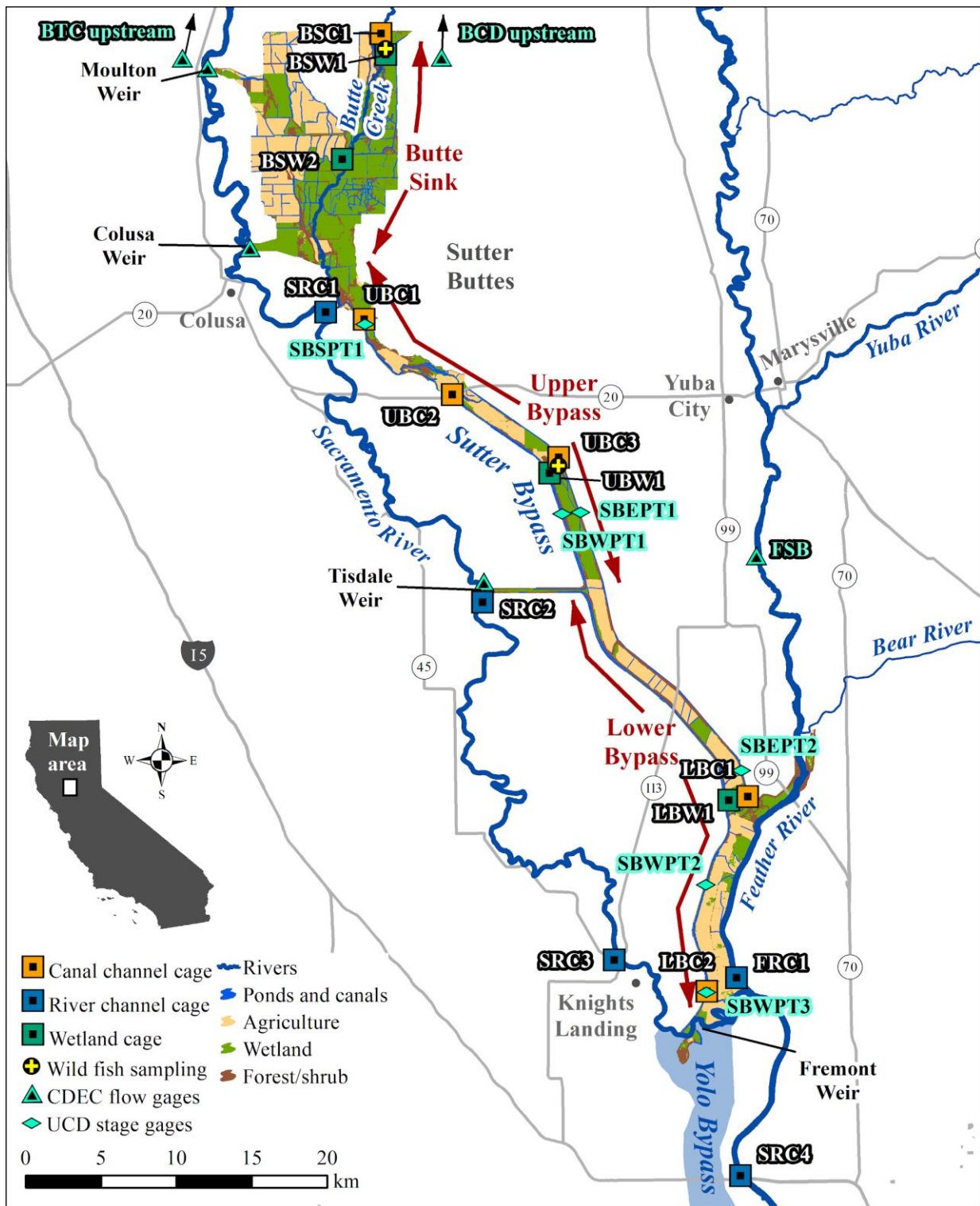


Figure 1. Study area map with the different Bypass regions (red) considered and the fish cage locations. The Butte Creek watershed is separated in three regions: 1) Butte Sink: North of Colusa weir, 2) Upper Bypass: Colusa weir to Tisdale weir, 3) Lower Bypass: Tisdale weir south to Sacramento River.

## Hydrology

River flow data for the three main inputs; Sacramento River, Feather River, and Butte Creek, including the Butte Sink and Sutter Bypass was downloaded from the California Data Exchange Center (CDEC, <http://cdec.water.ca.gov/>). Sacramento River flow data came from the Sacramento River at Butte City (BTC) gaging station. Feather River flow came from the Feather River at Boyd's Landing above Star Bend (FSB) station. Butte Creek flow data was obtained from the Butte Creek at Durham (BCD) station. Input to the Sutter Bypass from the Sacramento River at the three passive weirs was obtained from Sacramento River at Moulton Weir (MLW), Sacramento River at Colusa Weir (CLW), and Sacramento River at Tisdale Weir (TIS). Sutter Bypass flow was obtained from the Butte Slough near Meridian (BSL) gage.

An array of six pressure transducers (Solinst Leveloggers) was deployed in the Sutter Bypass channels to monitor stage fluctuations along the bypass (see Figure 1 for spatial distribution of the array). The transducers were installed in vertical stilling wells on the downstream side of bridge pilings in the borrow channels. Water surface elevation was surveyed using RTK GPS in the NAVD88 vertical datum and allowed conversion of logged stage to real world elevation. Discharge measurements surveyed with a Sontek M9 Acoustic Doppler Current Profiler (ADCP) in the spring of 2019 were used for rating curve development.

For the historical context of hydrologic conditions observed in water year 2020, we used a flood classification method modified from Whipple et al. (2017) to identify historical flooding patterns and recurrence intervals in the Sacramento River. Daily flow data from Sacramento River at Bend Bridge (USGS gage: 11377100) for the period 1893 to 2020 was used to identify individual flood events where mean daily discharge exceeded 20,000 cfs for a period of two or more days. The flood events were classified using unsupervised K-means cluster analysis (*kmeans* function from *stats* R package version 4.0.3., R Development Core Team 2015) based on explanatory variables including centroid day (*centday*), maximum flow (*maxflow*), duration in days (*duration*), and recession rate (*fallrate*). A principal component analysis biplot was used to visualize and interpret the contribution of explanatory variables to the flood clusters. Identified flood clusters were included in a flood recurrence interval calculation using Equation 1. To study changes in hydrological patterns the center of mass of annual water year flow (CT) was also

calculated on the daily flow data from the Sacramento River at Bend Bridge gage using Equation 2 (after Stewart et. al. 2005).

$$\text{Recurrence interval} = (n + 1)/m$$

where:  $n$  = number of years on record Eq. 1  
 $m$  = number of occurrences

$$CT = \sum(t_i q_i) / \sum q_i$$

where:  $t_i$  = days from beginning of water year (Oct 1<sup>st</sup>) Eq. 2  
 $q_i$  = stream flow at water-year-day,  $i$

## **Water quality sampling**

Water quality sampling was performed weekly at all cage locations from 1/13/2020 to 3/14/2020. Continuous water temperature (°C) and dissolved oxygen (mg/L) were collected at all cage locations using submersible Onset U26 loggers continuously recording at a 15-minute interval and suspended approximately 0.5 meters below the water surface.

Point water quality data was also collected weekly at all locations with a YSI Exo2 multiparameter sonde. The parameters collected were: temperature (°C), dissolved oxygen percent saturation (%), dissolved oxygen concentration (mg/L), turbidity (NTU), chlorophyll-a concentration (µg/L), blue-green algae concentration (µg/L), electrical conductivity (µS/cm), salinity (PSU), and pH. Due to sonde malfunction and overlapping project use on a few occasions, sonde measurements were not taken in some weeks.

Additionally, water grab samples with 125mL bottles were used for laboratory water chemistry analysis. The parameters analyzed included total nitrogen (ppm), ammonium (NH<sub>4</sub>; ppm), nitrate (NO<sub>3</sub>; ppm), total phosphorus (TP; ppm), phosphate (PO<sub>4</sub>; ppm), and dissolved organic carbon (DOC; ppm). Chlorophyll-a (ppb) and pheophytin α (ppb) was sampled with water grab samples in 1L bottles, filtered and analyzed at UC Davis. Due to COVID19, the lab responsible for processing water samples was closed and our samples from the majority of the

project expired and were disposed of. However, we were able to measure electrical conductivity from the samples, before disposal, with the use of a handheld conductivity probe.

### **Zooplankton sampling and community analysis**



Zooplankton was sampled weekly, at all cage locations, from 1/13/2020 to 3/18/2020, using a 30 cm diameter 150  $\mu\text{m}$  mesh zooplankton net thrown five meters and retrieved through the water column four times from the stream bank. To account for differences in sampled volume due to variable water velocities, a flow meter attached to the zooplankton net was used to quantify the volume of water sampled. All samples were preserved in a solution of 95% ethanol until being processed for zooplankton species identification at the UC Davis Center for Watershed Sciences lab. Zooplankton densities were estimated for all cage locations.

Zooplankton subsampling was necessary due to the high density of invertebrates within the samples. Samples were rinsed through a 150  $\mu\text{m}$  mesh and then emptied into a beaker. The beaker was filled to a known volume to dilute the sample, depending on the density of individuals within the sample, and then sub-sampled with a 1mL large bore pipette. If densities

were still too great for enumeration the sample was split using a Folsom splitter before sub-sampling with the bore pipette. The dilution volume, number of splits, and number of aliquots removed was recorded and used to obtain total estimates of invertebrates which were divided by the total volume sampled to estimate density. Zooplankton samples were sorted into two groups of one hundred. One group was for the taxonomic group with the highest amount of individuals counted. A second group was for the total individual counts of each of the other taxonomic groups added up such that they met or exceeded a hundred in their total numerical count. If a hundred counts of the single highest taxonomic group was reached, but not a hundred of the remaining total individuals, then in the following aliquots the highest taxonomic group was not counted. Invertebrates were identified with the aid of a dissecting microscope at 4x magnification to the lowest taxonomic level possible using keys from “Ecology and Classification of North American Freshwater Invertebrates” (Thorp and Covich 2009), “Recent Freshwater Ostracods of the World” (Karanovic 2012), and “An Introduction to the Aquatic Insects of North America” (Merritt et al. 1996). Copepods were only identified to family.

Ambient zooplankton taxa were grouped into operational taxonomic units (OTUs) for plotting and analysis components (Table 2). A zooplankton community analysis was performed on the OTUs using a non-metric multidimensional scaling (NMDS) approach (using the *vegan* package in R). We used bi-weekly OTU’s total densities (organisms m<sup>-3</sup>), to correspond with the growth measurement periods. Bi-weekly densities were standardized using a Hellinger transformation prior to analysis (Legendre and Gallagher 2000).

Table 2. Operational taxonomic units (OTUs) defined for ambient and gut zooplankton taxa.

Zooplankton OTU	Gut OTU
Cladocera large bodied adult	Cladocera
Cladocera large bodied juvenile	
Cladocera small bodied adult	
Cladocera small bodied juvenile	
Copepoda adult	Copepoda

Copepoda copepodite	
Ostracoda adult	Ostracoda
Rotifera adult	Rotifera
Insecta aquatic adult	Insect
Insecta aquatic larvae	
Insecta terrestrial adult	
Insecta terrestrial larvae	
N/A – excluded due to rareness in ambient zooplankton samples	Amphipoda

### Caged salmon experiment





The cage experiment was implemented from 2/10/2020 to 3/18/2020 (i.e., 33 to 35 days per cage location) to study site-specific juvenile Chinook Salmon growth rates in the winter months. A high flow contingency plan resulted in additional cages installed in the Sutter Bypass borrow channel (LBC2 site) which would have allowed for deployment at three locations along a lateral transect spanning the flooded bypass to test for lateral habitat differences under full bypass inundation conditions. Due to low flow and lack of inundation of adjacent agricultural fields, the extra cages at LBC2 remained in the channel (see Table 1 for site specific cage deployment numbers). Cages were utilized to maintain fish within a specific habitat for the duration of the study. Floating cage dimensions were 2’x2’x4’ and constructed with 1” pvc pipe frames enclosed with 1/4” plastic mesh material. The cages allowed for re-measurement of fish at a specific location as well as allowing for food resources to enter the cage that are of a suitable size for juvenile salmon.

Each cage was stocked with 5 individually PIT tagged juvenile fall-run Chinook Salmon sourced from the Coleman National Fish Hatchery. The caged salmon were measured for fork length (FL) to the nearest millimeter and weighed wet to the nearest 1/100th of a gram (g) with an Ohaus Scout Pro scale, at a two-week interval except for the last week of the experiment (i.e., week 0: 2/10/2020-2/13/2020, week 2: 2/24/2020-2/26/2020, week 4: 3/9/2020 - 3/10/2020, and week 5 (end): 3/14/2020 - 3/18/2020). All locations except two channel sites UBC3 and LBC1 had an additional cage with 10 untagged fish to be sampled at a two-week interval for gut content analysis. Three fish from each gut cage were randomly sampled and euthanized at weeks 2 and 4 (Table 3). Additionally, at the end of the experiment, all remaining caged fish were euthanized and were used for stomach contents identification.

Table 3. Number of salmon lethally sampled at each sampling date and for each site location.

<b>Region</b>	<b>Location</b>	<b>Week 2 (2/24 - 2/26)</b>	<b>Week 4 (3/9 - 3/10)</b>	<b>Week 5 (3/14 - 3/18)</b>	<b>Total</b>
<b>Butte Sink</b>	BSW1	3	3	16	22
	BSW2	3	3	16	22
	BSC1	3	3	14	20

<b>Upper Bypass</b>	UBC1	3	3	11	17
	UBC2	3	3	10	16
	UBW1	3	3	8	14
	UBC3	0	0	5	5
<b>Lower Bypass</b>	LBW1	2	2	15	19
	LBC1	0	0	5	5
	LBC2	3	3	22	28
<b>Sacramento River</b>	SRC1	2	2	10	14
	SRC2	3	3	11	17
	SRC3	3	3	11	17
	SRC4	3	3	12	18
<b>Feather River</b>	FRC1	3	3	13	19

### **Wild fish sampling**

Due to a lack of substantial precipitation there were no recorded weir overtopping events to transport water from the Sacramento River this winter. Therefore, the majority of the water flowing through the Butte Sink and Sutter Bypass came from the Butte Creek watershed. Although fish from the Sacramento River could not access the Butte Sink and Sutter Bypass, wild fish sampling, using fykes and beach seines, was performed approximately bi-weekly from 2/4/20 to 3/14/20 to characterize Butte Creek spring- and fall-run juvenile access to managed wetland areas in the Butte Sink and at the Wildlife Refuge in the Sutter Bypass. Chinook salmon were measured for fork length to the nearest millimeter, weighed to the nearest 0.01 g, and genetic fin clips were taken. A subsample of 32 fall-run sized salmon were lethally sampled following the guidelines of our scientific collecting permit (CDFW permit SC-13029). Length-

At-Date criteria (LAD; Greene 1992) was used as a proxy for Chinook Salmon run identification until submitted genetic fin clips are analyzed.

## **Salmon diet**

Stomach contents from euthanized caged salmon and collected fall-run Chinook Salmon (allowed under CDFW permit SC-13029) were identified to their lowest possible taxonomic group with the aid of a dissecting microscope at 4x magnification. Due to the partially decomposed nature of stomach contents, individuals were identified to their lowest taxonomic level, and were grouped into gut OTUs (Table 2). Cladocerans and amphipods were size classed into being smaller than or larger than 1.5 millimeters. Total prey wet weight in grams was measured by the difference between the full stomach weight and the reweighed stomach with the contents removed. The same taxonomic keys from the zooplankton identification were used to identify the stomach contents.

## **Growth estimation and modelling**

We used individual fork length and weight measurements collected at weeks 0, 2, 4 and 5 to estimate a site-specific mean daily growth rate during the intervals (expressed in millimeters per day (mm/day), and grams per day (g/day)), as well as a site-specific daily growth rate averaged for the entire length of the experiment (i.e., 33 to 35 days).

To explore the potential impact of cage location on fish growth rate we assessed whether there were statistically significant differences in the 5-weeks averaged mean daily FL growth rates among habitat types (using *aov* function in R).

Additionally, we developed various mixed effect growth models (Equation 3, Zuur et al. 2009, 2013) to investigate the influence of various biological and environmental factors on the site-specific mean daily fish FL growth rates. Particularly we looked at the influence of ambient zooplankton OTU densities (per m<sup>3</sup>; see Table 2), chlorophyll-a concentration (CHL), pH, turbidity (Turb), water temperature (Temp), water temperature range averaged over the period of interest (Temprange), dissolved oxygen (DO), dissolved oxygen range averaged over the period

of interest (DOrange), and electrical conductivity (EC). Based on preliminary data exploration we decided to use the logarithm of the zooplankton densities in this analysis. Additionally, in order to investigate non-linear effects of certain factors on fish growth we also included squared and interaction terms for factors that were initially found to have the highest influence on growth. We used growth estimated at weeks 2 and 4, and for each factor we used the mean value averaged over the week before and the week when fish sizes were collected (e.g., factor averaged over weeks 1 & 2 for growth estimated at week 2). Prior to fitting the models to the growth data, all the factors were also standardized. Habitat type was used as a random effect in the model. The coefficients of each model were estimated using the *lmer* function from the *lme4* R package. Finally, we used Akaike's Information Criterion corrected for small sample sizes (AICc) for model selection (Akaike 1973, Burnham and Anderson 2002).

$$\text{Growth Rate} = \text{Fixed effect} + \text{Random effect} \quad \text{Eq. 3}$$

$$\text{Fixed effect} = B_0 + B_i X_i$$

$$\text{Random effect} = \text{loc} + a + \text{eps}$$

where  $X_i$  = *i*th fixed effect factor

$a$  = random effect intercept

$\text{eps}$  = random effect error

$\text{loc}$  = habitat type factor

## RESULTS

### Hydrology

2020 was classified as a dry water year, with a lack of substantial precipitation in the winter leading to zero inundation of the Sutter Bypass from the Sacramento River via the passive weirs (i.e., Moulton, Colusa and Tisdale weirs). This effectively excluded all salmon spawned in the Sacramento River and upstream tributaries (i.e., Mill Creek, Battle Creek, Deer Creek) from accessing the Sutter Bypass during water year 2020. Spring-run and fall-run Chinook Salmon spawning in Butte Creek were presumably the only fish with access to Bypass channels and wetlands. Juvenile Salmon from the Sacramento and Feather Rivers could potentially enter the

southern Sutter Bypass channels from the confluence with the Sacramento River, but this behavior has not been observed.

Gage data upstream of the Sutter Bypass from Sacramento River at Butte City (CDEC station: BTC), Butte Creek at Durham (CDEC station: BCD), and Feather River at Star Bend (CDEC station: FSB) show very low flow in these three tributaries to the Sutter Bypass, especially during the cage experiment period (Figure 2). Besides Butte Creek which runs through the borrow canals of the Sutter Bypass, no water from the salmon-bearing water bodies of the Sacramento or Feather Rivers entered the Bypass this season.

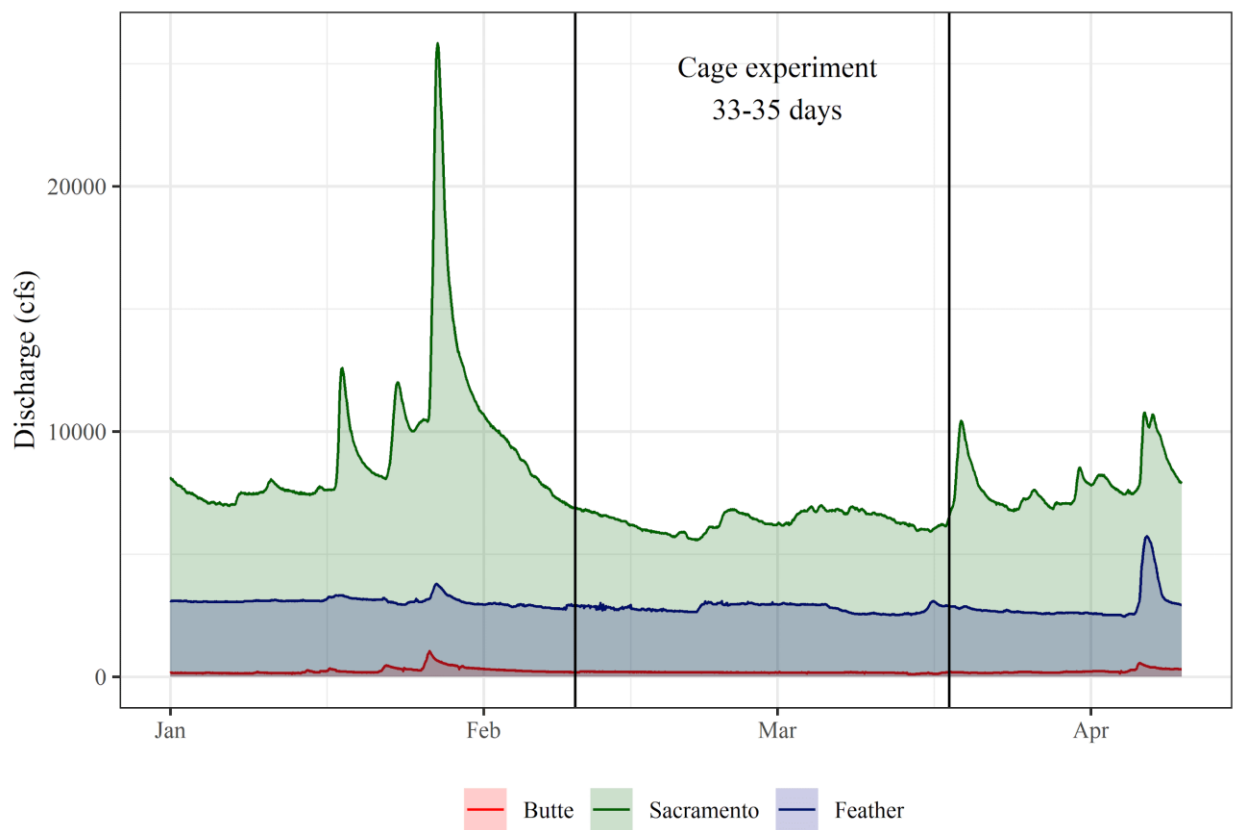


Figure 2. Flow (cfs) measured at Butte City (BTC), Butte Creek at Durham (BCD), and Feather River at Star Bend (FSB) gages from January to April 2020.

Our network of stage loggers in the Sutter Bypass channels showed some small flow pulses (<1,500 cfs) emanating from Butte Creek (Figure 3), but these pulses resulted in limited inundation of off-channel habitat. Off-channel wetland habitat in the Sutter Bypass was confined

to the managed wetlands at the Sutter National Wildlife Refuge (NWR), Willow Slough wetland in the lower Bypass, and near-channel lowlands in the bean field adjacent to the west-borrow canal immediately south of Highway 20.

Historical trend analysis revealed that extremely dry water years like 2020 with zero qualifying flood events were observed in 2 out of 60 years (3.3%) before Shasta dam construction and 15 out of 77 years (19.5%) after Shasta dam was built. K-means cluster analysis on individual qualifying flood events in the Sacramento River at Bend Bridge ( $n = 649$ ) resulted in five distinct flood clusters identified as: 1) early small, 2) late small, 3) intermediate, 4) long duration, and 5) ravaging (Figure 4A). A series of changes in flood duration and intensity were observed post dam construction (Figures 4B and 4C). For example, there was a complete elimination of ravaging floods post dam construction, which was to be expected given river regulation and maximum spill rates of the dam providing flood protection for the region. An increase in the recurrence interval by approximately double for late small and intermediate floods was observed. Conversely, there was a reduction in the recurrence interval for long duration floods, which is presumably a consequence of capturing the large flood pulse peaks (which would have fallen into the ravaging category) and discharging them in a controlled and extended manner later in the flood event or season. We have also observed a delayed start to the flood season and a trend towards a later center of mass of annual Sacramento River flow. The latter is contrary to expected effects from climate warming which include a reduced snowpack and shift towards increased proportion of precipitation falling as rain instead of snow (Stewart et al. 2005). However, water allocation in Shasta reservoir for agricultural irrigation and municipal needs has led to an increased distribution during the traditional dry period.

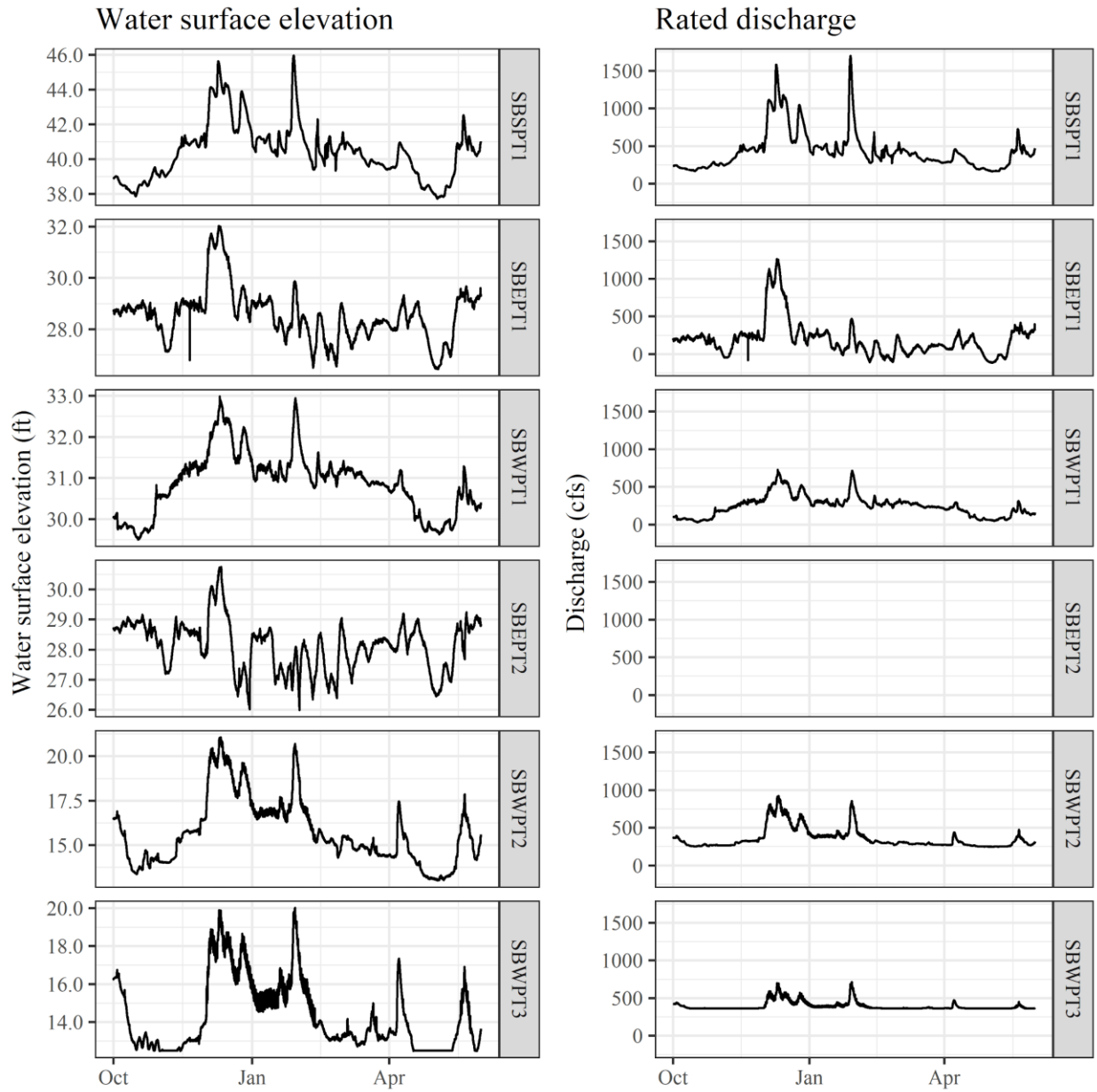


Figure 3. Water surface elevation (left) and rated discharge (right) plots from our network of stage loggers in the Sutter Bypass.

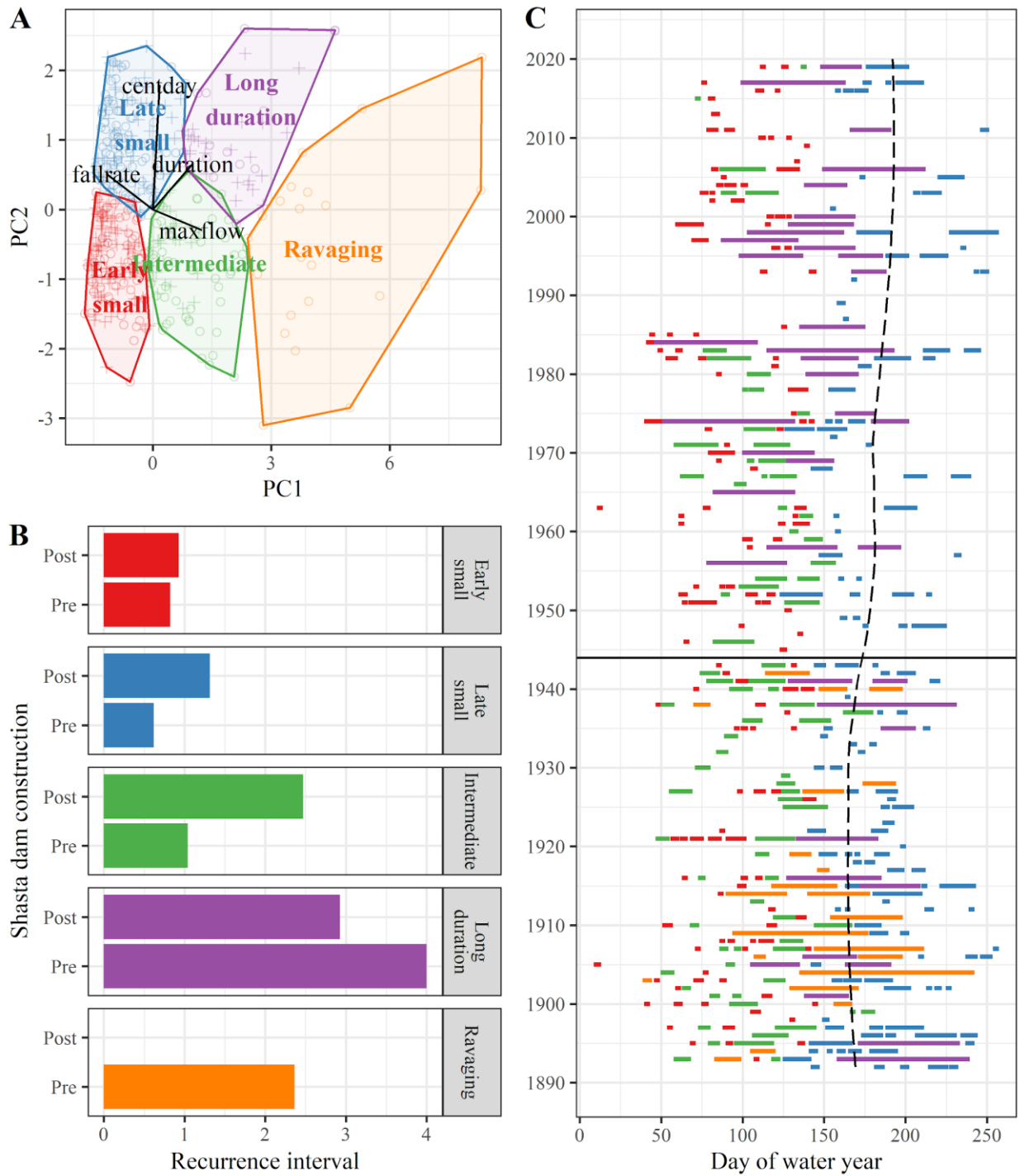


Figure 4. (A) Principal components analysis plot of the first two components (PC1, PC2) grouped by K-means clustering. (B) Recurrence intervals for the five flood types identified by K-means clustering. (C) Historical flood type reconstruction for the Sacramento River at Bend bridge daily flow data. The solid black line represents the construction of Shasta Dam. Dashed line is a smoothed loess line representing the trend in center of mass of annual flow (CT).



## Water quality

Water temperature was more variable in the wetland sites with larger diurnal fluctuation in values. Both river and canal channel sites had more consistent temperatures which gradually increased during the course of the experiment (Figure 5A) compared to the wetland sites which displayed higher diurnal variability. Similarly, dissolved oxygen showed much more diurnal variation in the off-channel wetlands compared to the river which remained near saturation for the duration of the experiment (Figure 5B). The average diurnal fluctuation in dissolved oxygen flux was  $0.58 \pm 2.88$  SE,  $1.46 \pm 13.1$  SE, and  $5.96 \pm 35.6$  SE in the river channel, canal channel, and wetland habitats respectively.

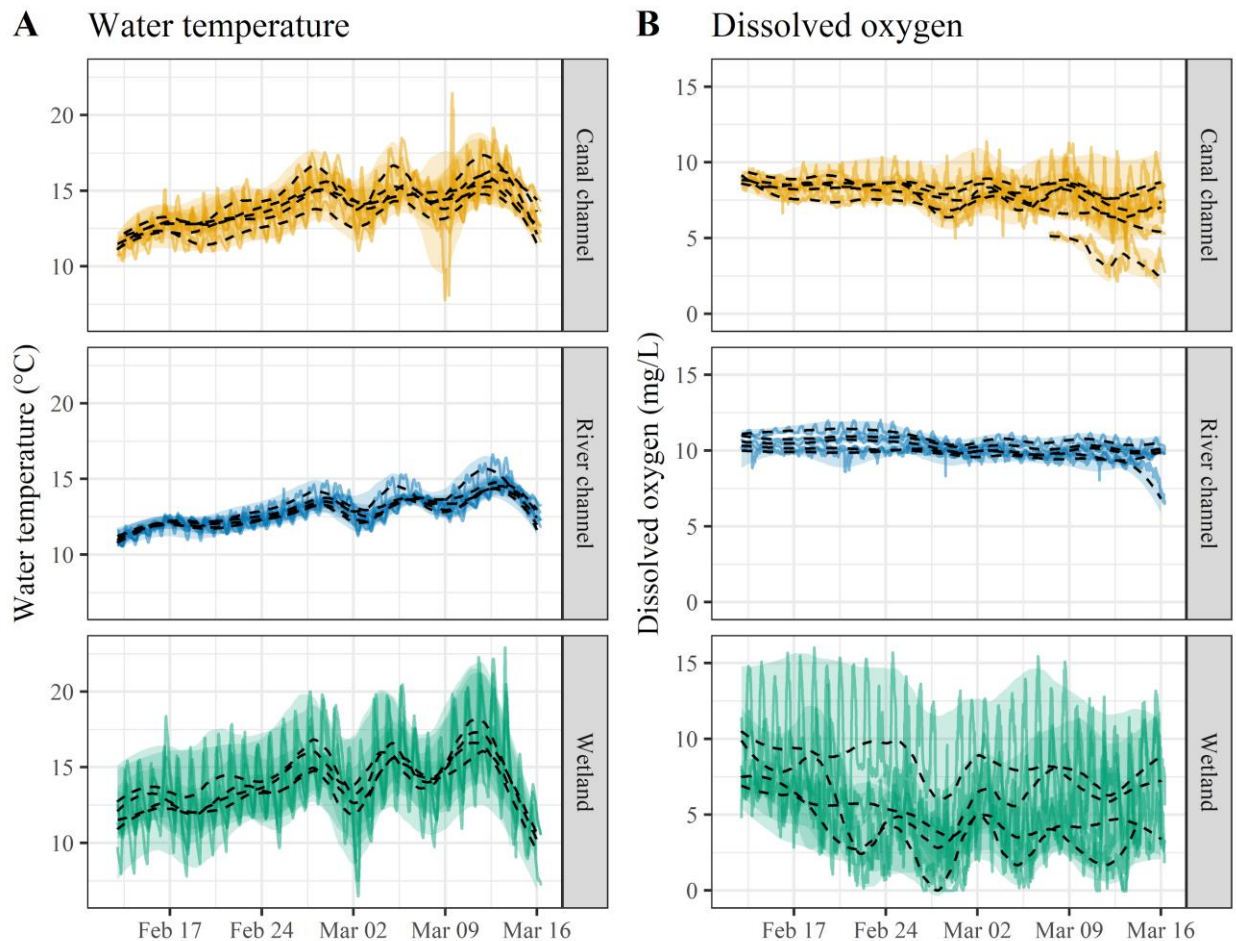


Figure 5. Continuous water temperature ( $^{\circ}\text{C}$ ) (A), and dissolved oxygen (mg/L) (B) from sonde data, at a 15-minute interval and for each cage location. Colored lines indicate the actual data. The black lines show smoothed loess regressions through the daily mean data for each cage

location. Transparent ribbons show smoothed daily temperature and dissolved oxygen ranges for each cage location.

We observed differences in conductivity (EC), salinity (Sal), and Turbidity (Turb) among habitat types, indicating differences in residence time (Figure 6). Wetland habitats had higher conductivity and salinity than both river and canal channel habitats indicated by the observed increased concentrations of salts left behind after evaporation in the wetlands which have an increased surface area and water residence time. Primary productivity indicators (Blue Green Algae (BGA) and Chlorophyll-a (CHL)) provided a mixed signal across habitat types. BGA and CHL followed a similar trend for each habitat type. pH was higher in river channel habitats. Turbidity was higher in canal channel habitats, but stayed relatively low across all habitats due to the lack of significant flow events in the river. Turbidity spikes in the wetlands were often due to congregations of waterfowl or wind events. These localized and sporadic events can also cause spikes in turbidity in canal channel sites downstream of effluent points.

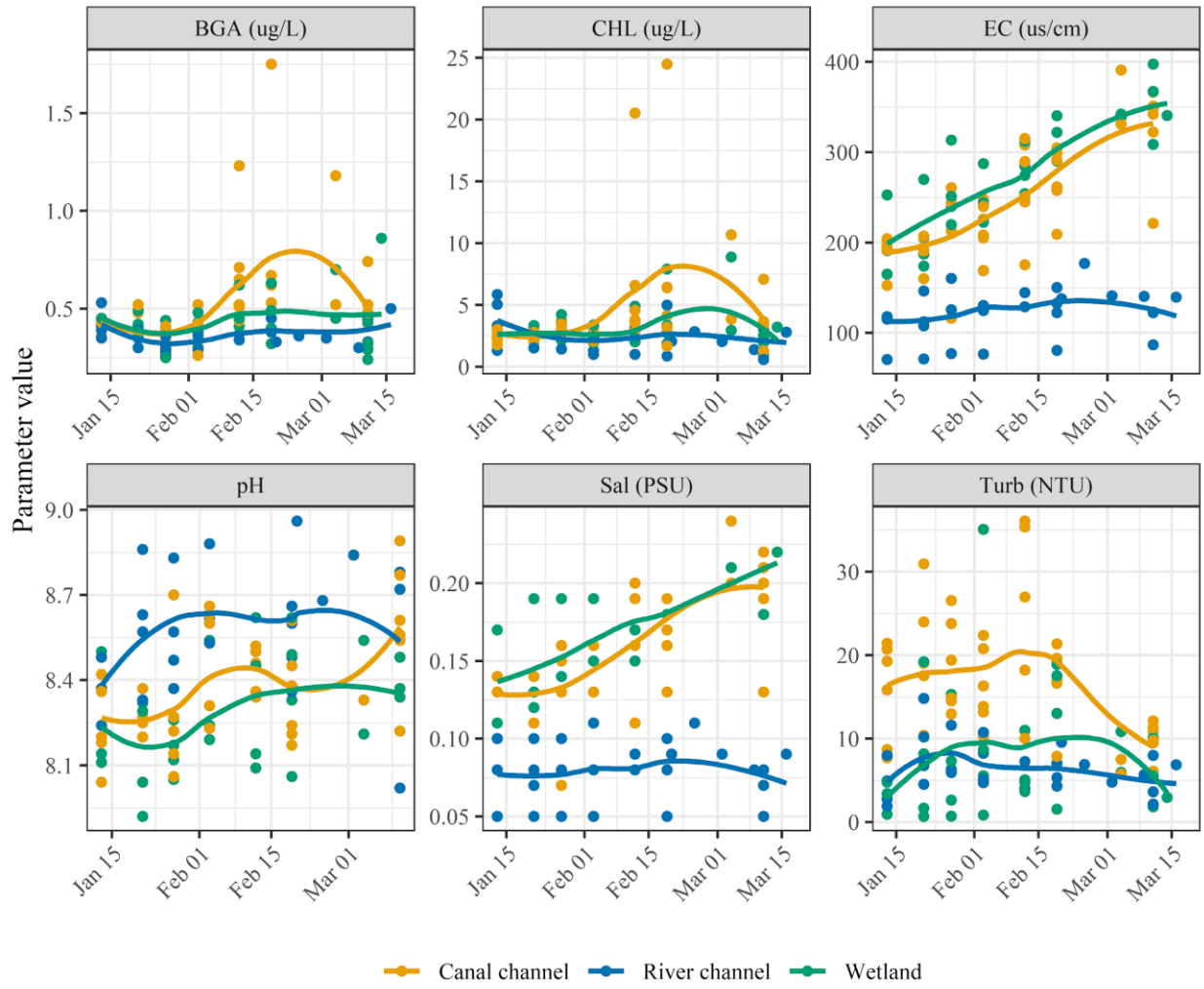


Figure 6. Point water quality measurements grouped by habitat type. Colored dots indicate the actual data. The colored lines show loess linear regressions through the weekly water quality measurements for each habitat type.

### Ambient zooplankton abundance and composition

Higher zooplankton densities were observed in wetland cage locations, in comparison to channel locations (Figure 7A). Canal channels generally had higher concentrations of zooplankton than river channels. There was a slightly increasing zooplankton density trend later in the season, across all habitat types.

Zooplankton community analysis showed distinct separation of habitat types. Wetland communities were distinguished by high densities of large bodied cladoceran species. Canal

channel communities were defined by a community including species of small bodied cladocera species. River channel cage locations were defined by low densities of cladocera and rotifera but had higher densities of insects. Copepods were more ubiquitous to all locations, but wetland habitats had much higher densities than channel habitats (Figures 7B and C).

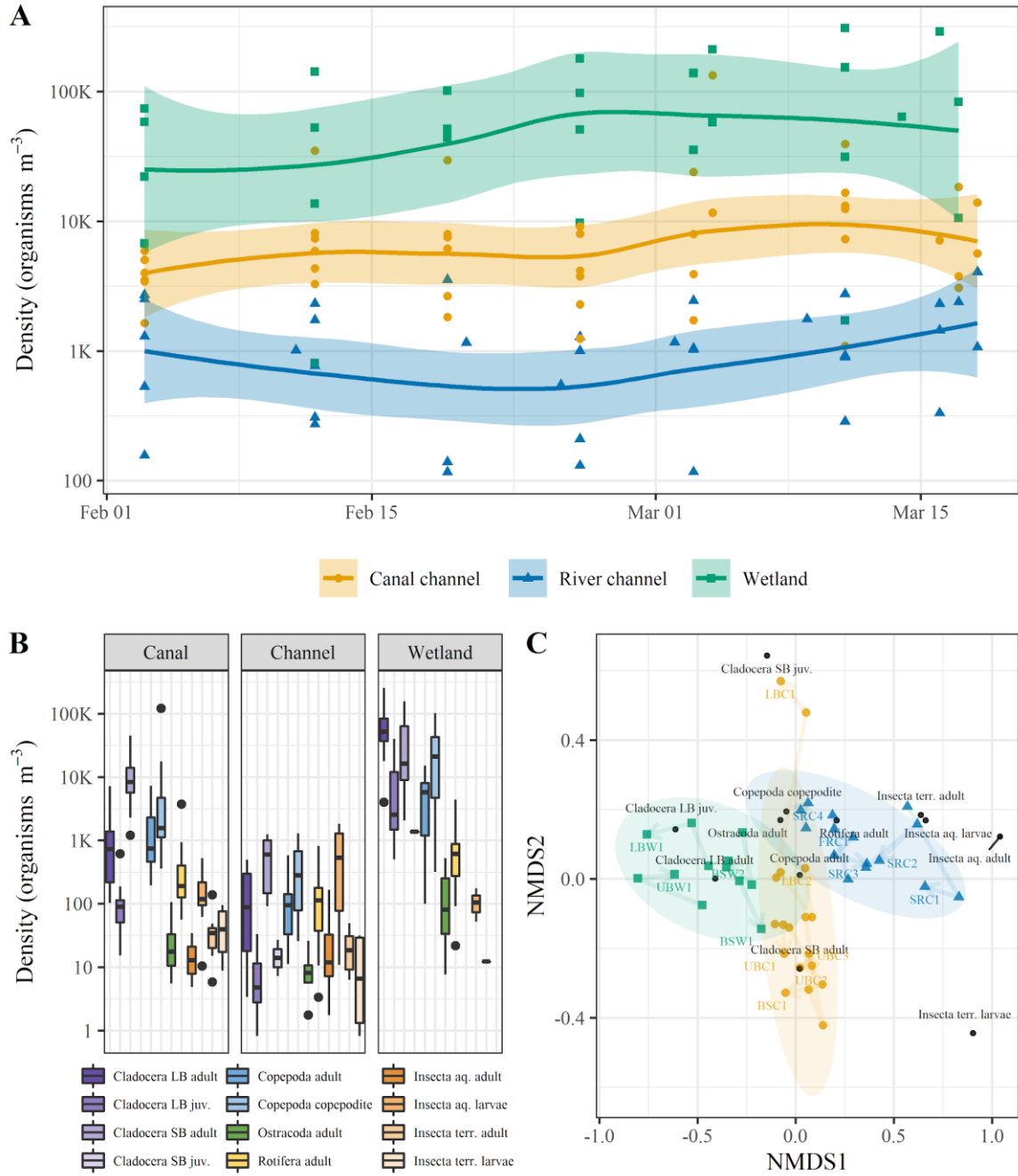


Figure 7. (A) Trends in total zooplankton abundance grouped by habitat type on a logarithmic scale. Colored dots indicate the actual data. The colored lines show smoothed loess regressions

through the weekly zooplankton density estimates for each habitat type. Transparent ribbons show weekly zooplankton density ranges for each habitat type. (B) Boxplots of zooplankton density grouped by operational taxonomic units (OTU) for each habitat type on a logarithmic scale. (C) NMDS plot of ambient zooplankton assemblages, colored by habitat type.

### **Cage salmon's diet abundance and composition**

Wetland cage fish diet was generally composed of higher prey weights than in channel habitats (Figure 8A). The only exception was at BSW2 which had comparable prey weights to channel fish diets. Caged fish in river channel locations situated downstream of known off-channel effluent points (i.e., SRC2, SRC3, SRC4) had prey compositions with more cladocera and copepods than did fish from channel locations above these inputs (i.e., SRC1, FRC1) which were composed primarily of insects (Figures 8B and C).

Tight grouping of wetland cage locations was observed, driven by amphipods and cladocera dominated diets (Figure 8D). Canal channel habitats showed a copepod and small cladocera dominated diet. The river channel locations were split between “headwater” and “off-channel subsidized” groupings where the latter had evidence of increased zooplankton dependence likely from off-channel inputs.

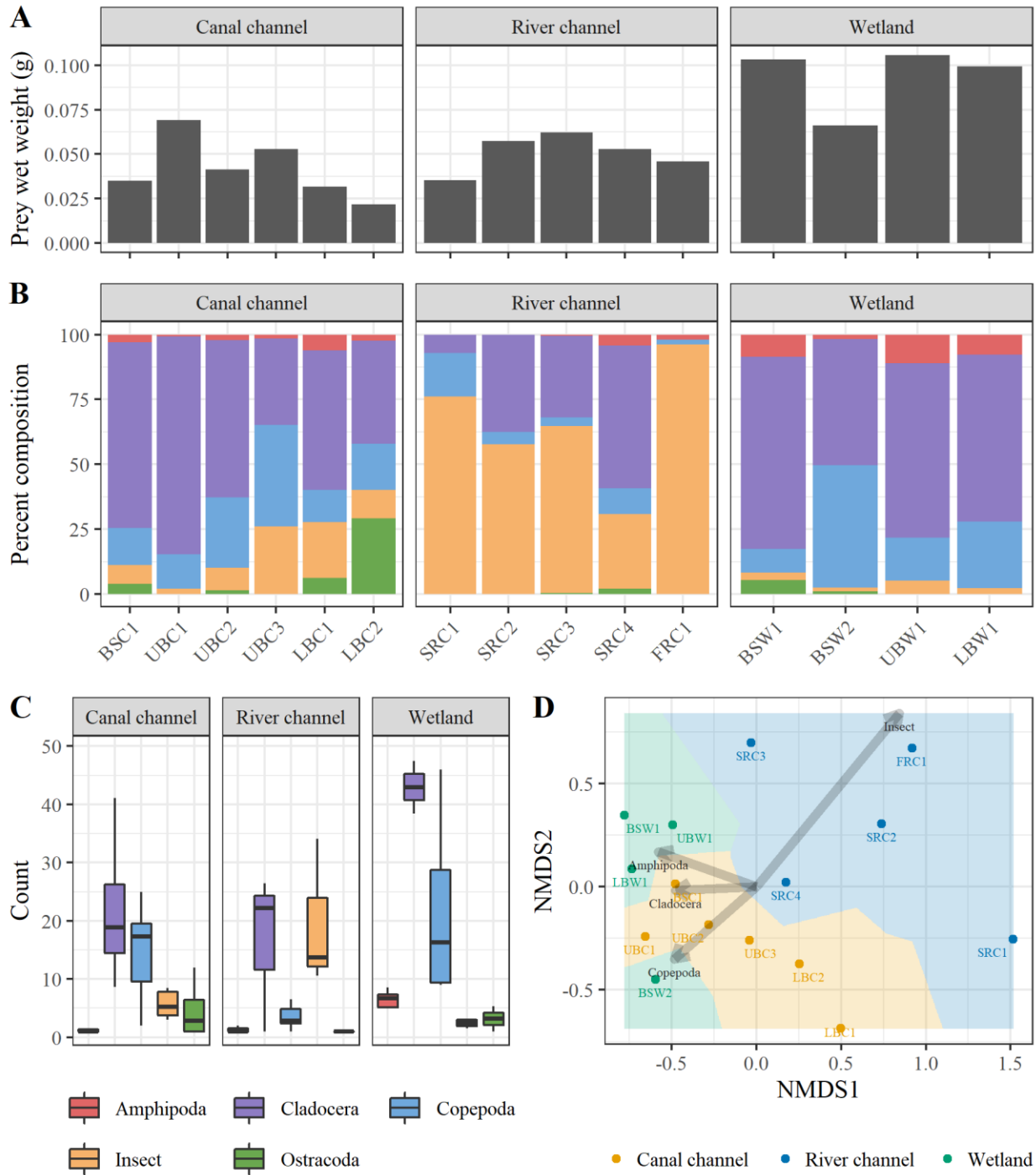


Figure 8. (A) Mean prey wet weight (in grams) summary for each cage fish diets, grouped by habitat type. (B) Percent composition of caged fish gut OTUs grouped by habitat type. (C) Boxplots showing quantiles of stomach content counts colored by OTU category and grouped by habitat type. (D) NMDS plot of caged fish gut compositions at the end of the experiment colored by habitat type.

## Cage salmon's growth

Initial fork length (mm) and weight (g) at the time of stocking for the growth cage salmon was  $51.1 \pm 2.7$  mm SD and  $1.39 \pm 0.25$  g SD. At the end of the 5-week experiment, size ranged from  $54.4 \pm 2.6$  mm SD and  $1.52 \pm 0.32$  g SD at BSC1 (Butte Creek at Gridley Rd.) to  $84.75.7 \pm 6.7$  mm SD and  $7.15 \pm 1.59$  g SD at UBW1 (Sutter Bypass refuge wetland; Figures 9A and B). Percent change in fork length and weight ranged from 5.2% and 10.8% respectively at SRM3 to 66.8% and 409.7% respectively at UBW1.

Following the zooplankton densities trend, caged fish growth was observed to be larger in wetland than channel habitats, with the highest growth rate found in the upper Sutter Bypass region (Figure 9C). The average daily growth rates ranged from 0.08 mm/day and 0.004 g/day at BSC1 to 0.98 mm/day and 0.17 g/day at UBW1.

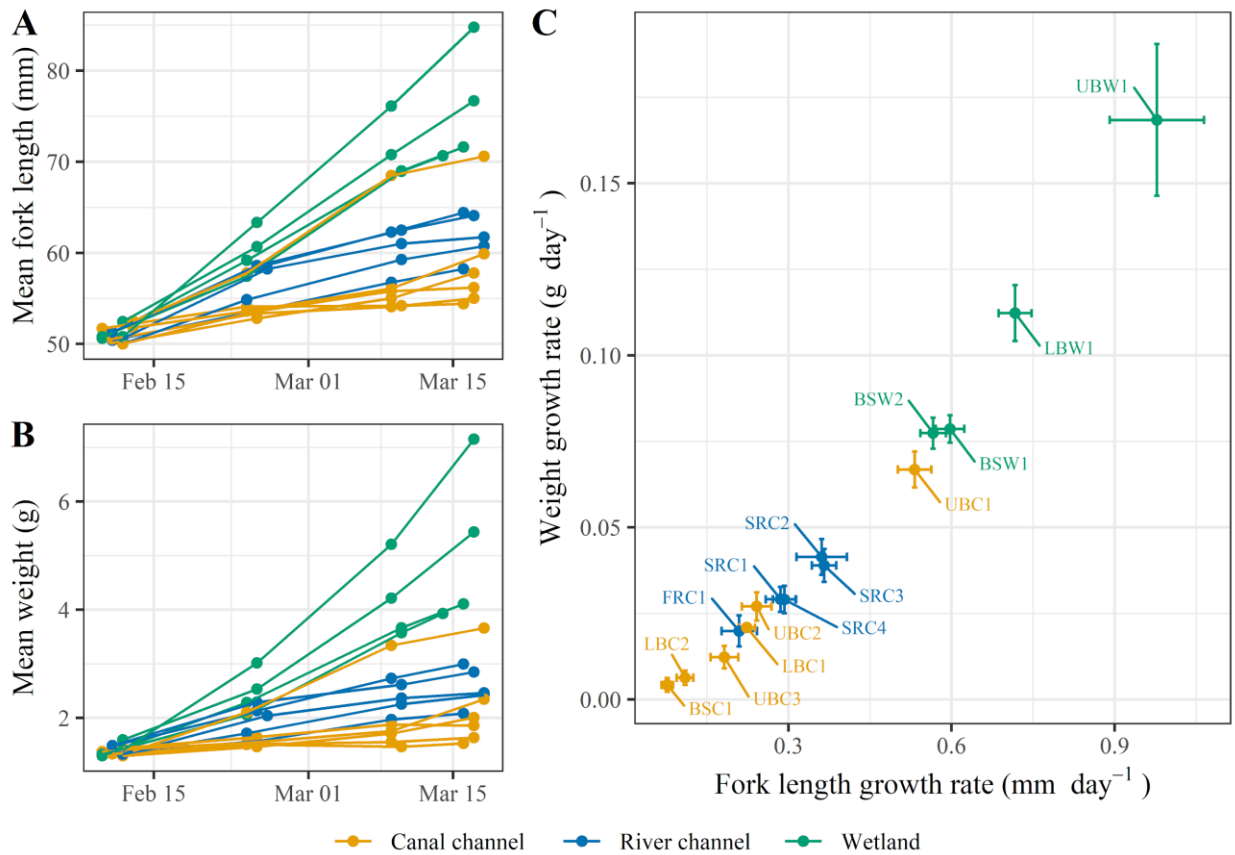


Figure 9. (A) Mean fish fork length (mm) time series, (B) mean fish weight (g) time series, and (C) mean daily growth rate biplot for each cage location, and grouped by habitat type.

A statistically significant effect of habitat type on the mean daily growth rates was found from the ANOVA test ( $p$ -value  $< 0.0001$ ). Some growth variability was also observed across regions. In particular, in canal channel and wetland habitats, growth was overall higher in the Upper Sutter Bypass and lower in the Butte Sink (Figure 10).

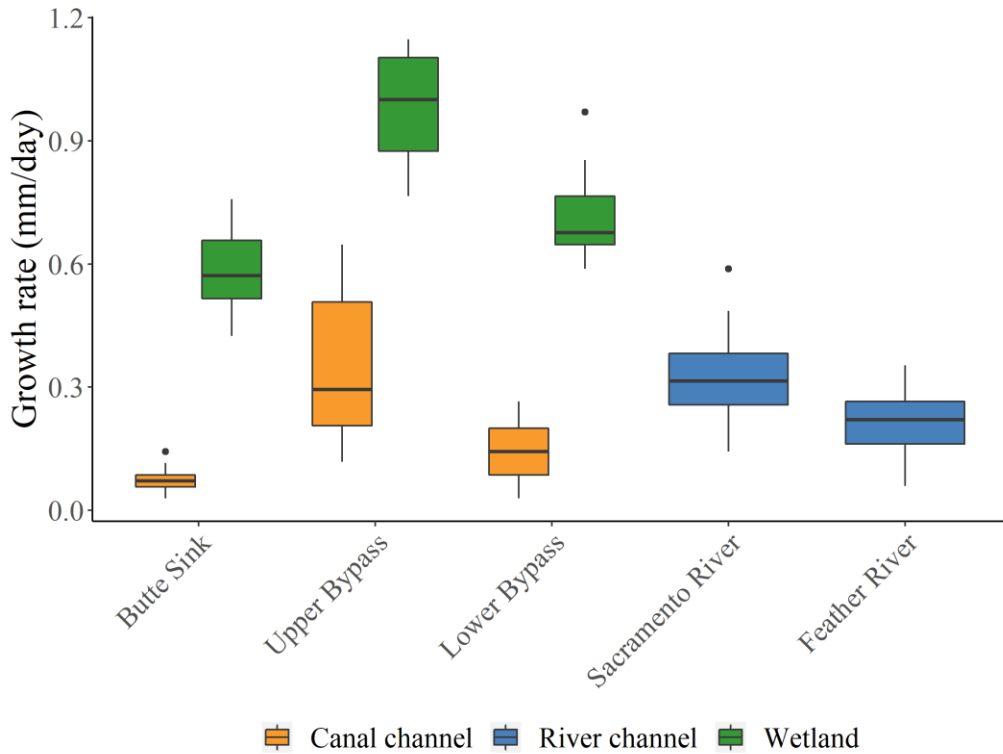


Figure 10. Mean daily fish growth rates (mm/day) boxplot grouped by region and habitat type.

Out of all the factors tested in the modelling exercise, DO range was the variable that best described fish growth (Table 4). In addition, in interaction with DO range, density of large cladocera, temperature range, and EC had a significant influence on fish growth (Table 4; models with  $\Delta AIC < 4$ ). DO range squared was also found to be an important factor, suggesting a non-linear relationship between fish growth and DO. DO and temperature ranges, EC, and large cladocera density were all positively correlated with fish growth (Figure 11).



Table 4. Comparison of FL growth rate mixed effect models, with habitat type used as a random variable. K= number of model parameters, AICc = Akaike's information criterion corrected for small sample size, and  $\Delta AICc$  = difference in AICc score between the given model and the most parsimonious model. Models are ordered from lowest to highest AICc. Lower AICc scores indicate greater relative model parsimony.

<b>Model</b>	<b>K</b>	<b>AICc</b>	<b><math>\Delta AICc</math></b>	<b>AICcWt</b>
DOrange + 1 Type	4	-10.2676	0	0.315524
DOrange + Loglargecladocera + 1 Type	5	-9.28633	0.981275	0.193175
DOrange + Temprange + 1 Type	5	-7.82888	2.438725	0.093212
DOrange + EC + 1 Type	5	-7.5571	2.710509	0.081368
DOrange + DOrange <sup>2</sup> + Loglargecladocera + 1 Type	6	-7.50232	2.765288	0.079169
DOrange + DOrange <sup>2</sup> + 1 Type	5	-7.47953	2.788079	0.078272
Temprange + Loglargecladocera + 1 Type	5	-6.03574	4.231868	0.038027
Temprange + 1 Type	4	-5.40714	4.860464	0.027771
Temprange + Temprange <sup>2</sup> + Loglargecladocera + 1 Type	6	-5.15854	5.109063	0.024525
DOrange + DOrange <sup>2</sup> + EC + 1 Type	6	-4.51267	5.754937	0.017757
Temprange + Temprange <sup>2</sup> + 1 Type	5	-3.71939	6.548217	0.011943
Temprange + EC + 1 Type	5	-3.71915	6.548459	0.011941
EC + 1 Type	4	-2.17944	8.088164	0.00553
Loglargecladocera + EC + 1 Type	5	-1.53866	8.728944	0.004014
Loglargecladocera + 1 Type	4	-1.33996	8.927644	0.003634
EC + EC <sup>2</sup> + DOrange + DOrange <sup>2</sup> + 1 Type	7	-0.93541	9.332199	0.002969
Logtotzoop + 1 Type	4	0.437702	10.70531	0.001494
EC + EC <sup>2</sup> + Temprange + Temprange <sup>2</sup> + 1 Type	7	0.765429	11.03304	0.001268
EC + EC <sup>2</sup> + 1 Type	5	0.807772	11.07538	0.001242

EC + EC <sup>2</sup> + Loglargecladocera + 1 Type	6	1.205169	11.47278	0.001018
1 + 1 Type	3	1.383932	11.65154	0.000931
DO + 1 Type	4	1.590553	11.85816	0.00084
Temp + 1 Type	4	1.904565	12.17217	0.000718
Turb + 1 Type	4	2.648848	12.91645	0.000495
Logterrestrialinsect + 1 Type	4	2.977317	13.24492	0.00042
Logaquaticinsect + 1 Type	4	3.231018	13.49862	0.00037
CHL + 1 Type	4	3.505436	13.77304	0.000322
Temp + Temp <sup>2</sup> + 1 Type	5	3.634344	13.90195	0.000302
Logostracoda + 1 Type	4	3.699815	13.96742	0.000292
Logcopepoda + 1 Type	4	3.858688	14.12629	0.00027
Logrotifera + 1 Type	4	4.068233	14.33584	0.000243
pH + 1 Type	4	4.092577	14.36018	0.00024
Logsmallcladocera + 1 Type	4	4.111771	14.37938	0.000238

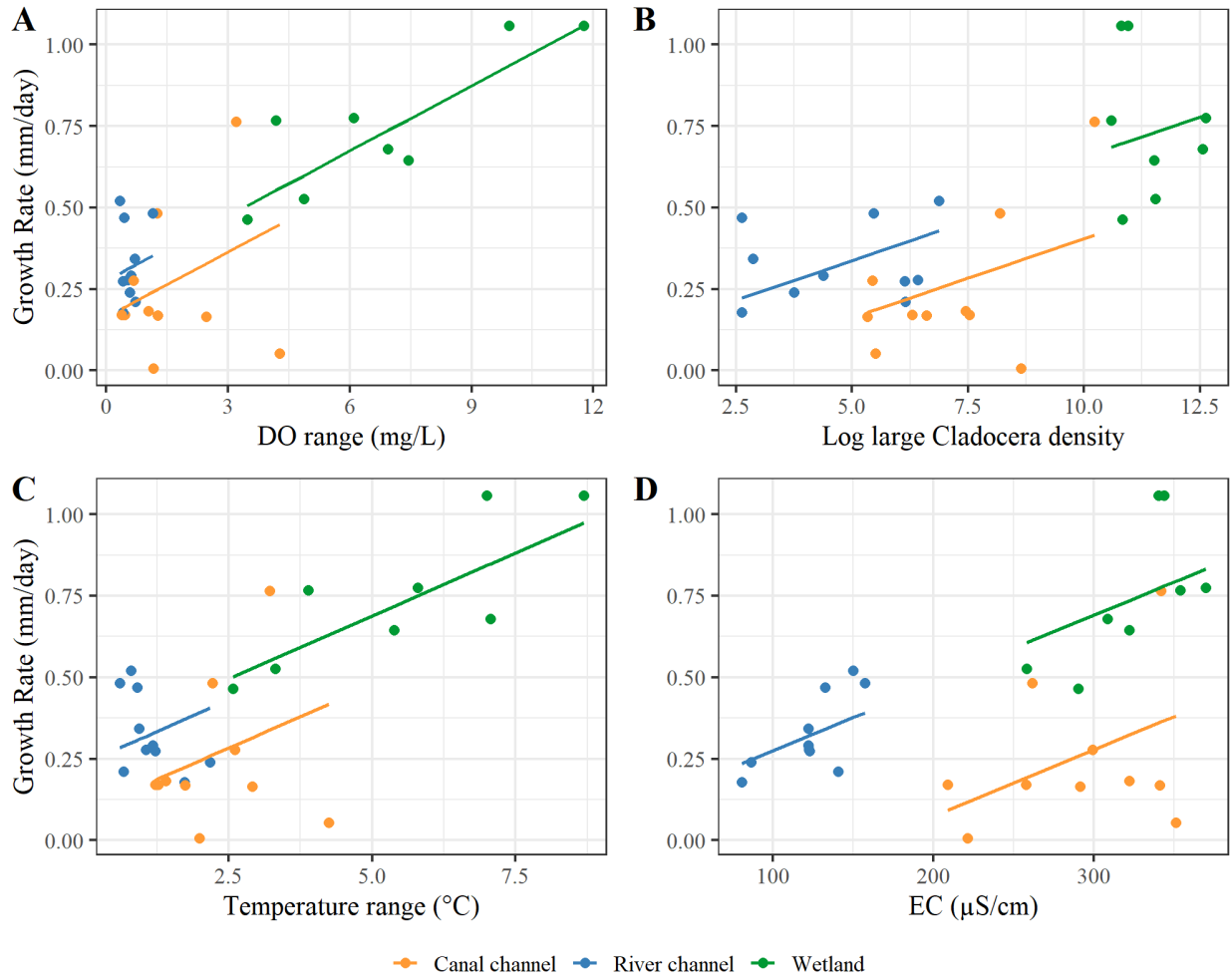


Figure 11. Relationships between caged fish mean daily growth rate (mm/day) and (A) dissolved oxygen range, (B) Log large cladocera density, (C) temperature range, and (D) EC, grouped by habitat type. The dots represent the raw data, and the lines show habitat specific growth rate predictions from the mixed effects model.

## Wild fish sampling

Various native and non-native fish species were caught during the wild fish sampling events (Table 5). Among them several juvenile spring- and fall-run Chinook Salmon were sampled (Figure 12). Salmon run identification is currently based on the Length-At-Date criteria, as genetic identification has been delayed due to COVID-19 shutdown and no completion date is available at the moment.

Table 5. Fish species caught during the wild fish sampling events.

Species	Common name	Butte Sink wetland				Sutter NWR			Total
		4-Feb	20-Feb	3-Mar	14-Mar	4-Feb	20-Feb	4-Mar	
<i>Ameiurus nebulosus</i>	Brown bullhead	0	0	0	0	0	0	1	1
<i>Cottus asper</i>	Prickly sculpin	0	1	0	0	0	0	0	1
<i>Gambusia affinis</i>	Western mosquitofish	0	0	0	5	2	0	1	8
<i>Lepomis cyanellus</i>	Green sunfish	0	0	0	0	0	0	2	2
<i>Lepomis gulosus</i>	Warmouth	0	0	0	0	0	0	1	1
<i>Lepomis macrochirus</i>	Bluegill	2	0	0	0	4	1	5	12
<i>Notemigonus crysoleucas</i>	Golden shiner	9	0	0	0	4	0	5	18
<i>Oncorhynchus tshawytscha</i>	Chinook Salmon	22	12	12	13	0	6	4	69
<i>Percina macrolepida</i>	Bigscale logperch	0	0	0	0	0	5	3	8
<i>Pomoxis nigromaculatus</i>	Black crappie	1	0	0	0	5	0	6	12

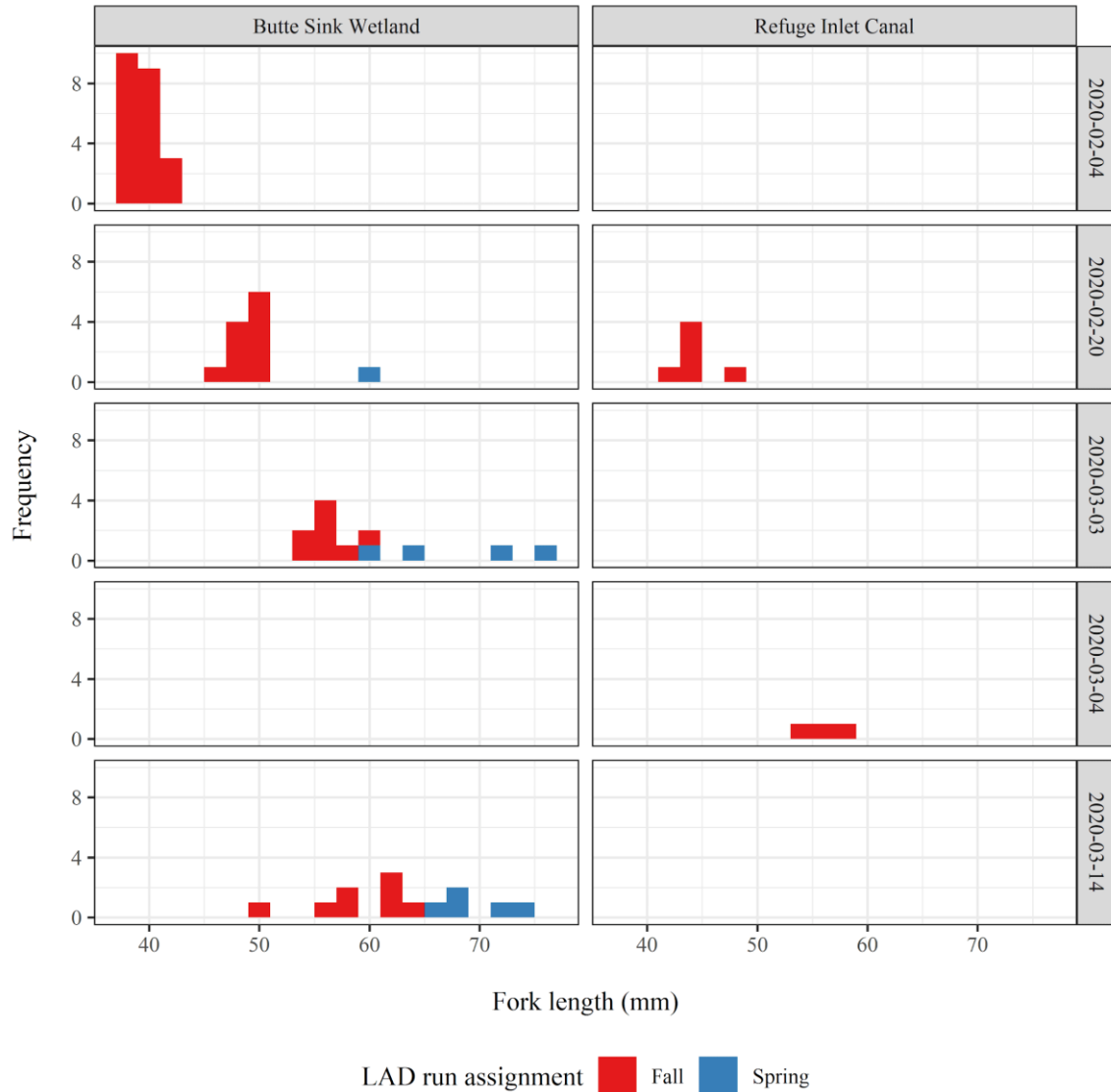


Figure 12. Number of juvenile Chinook Salmon caught during the wild fish sampling events, colored by run type. Length-At-Date (LAD) criteria was used here for Chinook Salmon run identification.

### Caged versus wild salmon diet and apparent growth

The low and stable hydrologic conditions presented a unique opportunity to monitor apparent growth rates and diets of a semi-contained population of wild Chinook Salmon in a Butte Sink Wetland. The low flows in the adjacent Sanborn Slough meant that fish that were in the wetlands likely entered during a brief flow pulse in late January and while they presumably

could have exited the wetland, we sampled the population at a bi-weekly interval concurrent with the deployment of caged salmon. This allowed us to compare growth rates and diets of wild and experimental caged fish residing in the same wetland for an extended period of time. We found similar zooplankton composition and abundance for most caged and wild salmon gut contents, with the majority of their diet composed of cladocera, and a small amount of copepoda and amphipoda (Figures 13A and B). In addition, caged salmon diet also included some insecta and ostracoda which were not found in the wild fish diets. Wild and caged fish lengths at date were also relatively close, suggesting that caged salmon provided a good representation of wild salmon growth through time (Figure 13A).

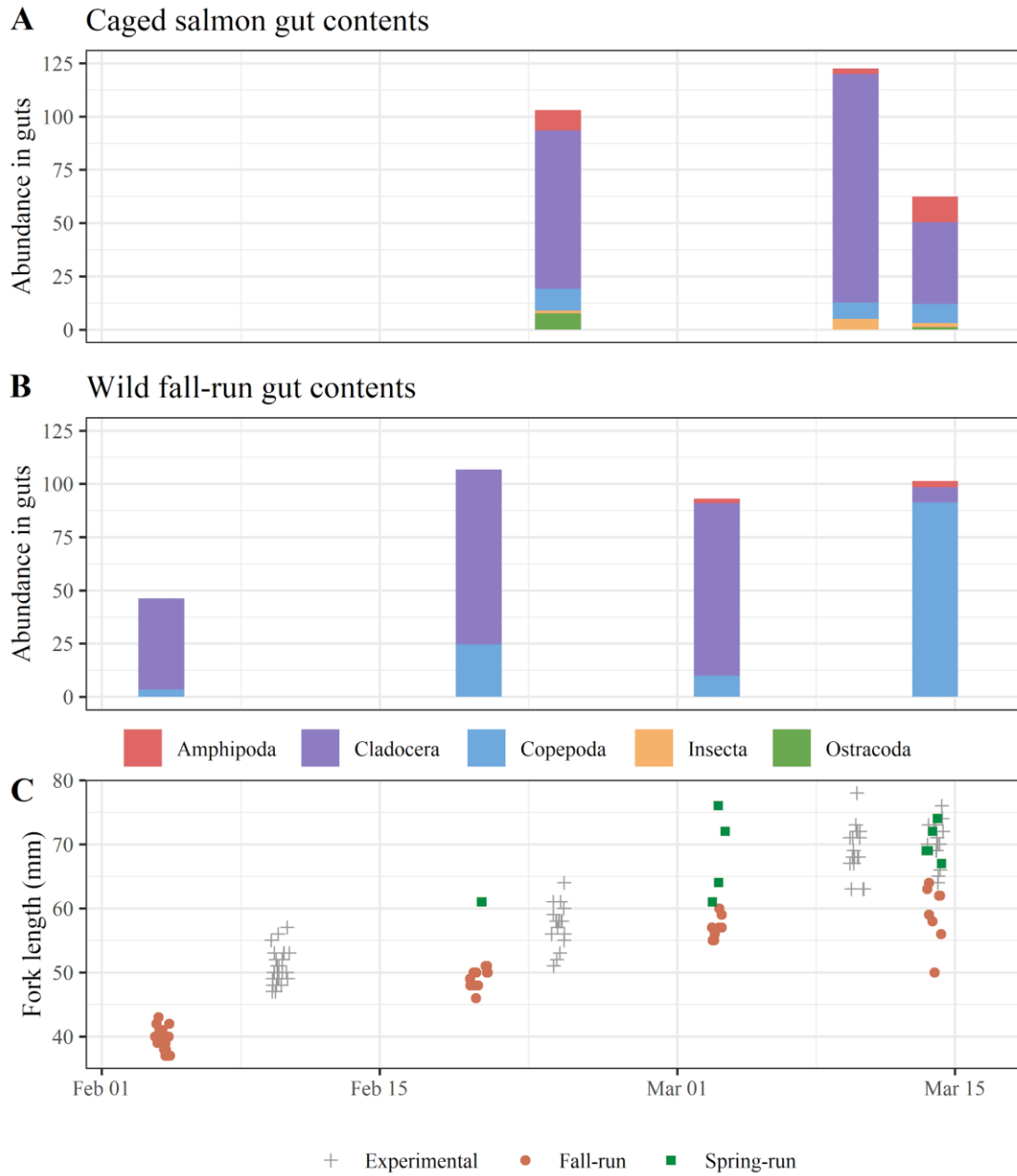


Figure 13. (A) caged fish and (B) wild fall-run Chinook Salmon stomach contents from fish in the wetland at BSW1. (C) Measured size (mm) of caged and wild salmon through time.

## DISCUSSION

The extremely dry nature of the 2020 water year and the particularly dry and stable hydrologic conditions provided a controlled opportunity to determine the habitat characteristics of the Butte Sink and Sutter Bypass wetlands and canal channels without flushing flows from the Sacramento River weirs overtopping and Butte Creek overbank flows. The lack of connection with the Sacramento and Feather Rivers also precluded access to the Butte Sink and Sutter Bypass from those salmon populations. Consequently, we could be reasonably confident that all wild caught salmon sampled in the Butte Sink and Bypass wetlands were fall and spring run populations originating in Butte Creek. The managed wetland habitats were the only off-channel habitats in the region available in the dry year 2020.

The dry hydrologic conditions in 2020 resulted in distinctive conditions forming in each of the three (managed wetland, river channel, and bypass canal channel) habitats studied. The wetland habitat was characterized by high ecosystem metabolism as defined by the large diurnal fluctuation in dissolved oxygen, higher diurnal fluctuation in temperature, higher conductivity, and a dense zooplankton community with a high abundance of large bodied cladocera. Juvenile salmon diets in the wetlands consisted primarily of large zooplankton and amphipods which resulted in high salmon growth rates (0.57mm/day to 0.98mm/day). The river channel sites were characterized by stable and cool water temperatures, stable dissolved oxygen near full saturation, low conductivity, low zooplankton density, and increased numbers of macroinvertebrates. Juvenile salmon diets in the river channels showed increased diet diversity albeit with reduced diet biomass which resulted in lower growth rates. The canal channel sites exhibited characteristics of both river channel and wetland habitats. Notably, the conductivity and pH were more similar to wetlands but the ecosystem metabolism, as estimated by the diurnal fluctuation in dissolved oxygen, which was greater than the river channel sites but muted compared to the wetland habitat. Furthermore, the zooplankton communities displayed greater variability with relatively high densities of zooplankton compared to river channel sites but with a generally low prevalence of large cladocera. The notable exception was at UBC1 which displayed higher densities of large cladocera and coincidentally displayed growth rates near the lower end of wetland habitats (0.53 mm/day). The proximity of this site to the effluent points from the upstream Butte Sink wetlands highlights the potential for large bodied zooplankton food



subsidies to the canal system from wetlands, but also points out the fact that under these conditions the subsidy decreases longitudinally. This longitudinal decrease in large cladocera may be a product of grazing by resident or transient canal fishes, and/or a product of large zooplankton not surviving the higher turbidity and moving water conditions in the canals.

Current wetland management in the Butte Sink and Sutter NWR wetlands aimed at waterfowl habitat production and weed abatement is inadvertently entraining wild Butte Creek fall- and spring-run salmon into wetland habitats. The entrained salmon are exposed to improved foraging conditions compared to their channel resident counterparts resulting in higher growth rates and body condition. Additionally, the lack of resident predators sampled in these ephemeral habitats compared to channel residents indicates these habitats could provide some survival benefit. The ultimate effect on migratory success cannot be estimated from this data, but suggests that the success of Butte Creek spring-run populations relative to other Central Valley spring-run populations (i.e., Mill and Deer Creek) is due to reliable inundation of wetlands in the region even in the driest of years.

Mixed effect growth modeling pointed to the effects of large-bodied zooplankton abundance, residence time as measured through the proxy of conductivity, and ecosystem metabolism as measured through fluctuation in dissolved oxygen and temperature as being important contributors to salmon somatic growth rates. As expected, increased temperature range, zooplankton density, and residence time were correlated with higher salmon growth, however the positive correlation between salmon growth and dissolved oxygen range was counterintuitive as low dissolved oxygen concentration could impair fish growth. This model outcome might be driven by the disproportionately larger salmon growth and dissolved oxygen variations observed in wetland habitats in comparison to channel cages. Although zooplankton density was found to play an important role in both 2019 and 2020, salmon growth, temperature and residence time had a larger influence in 2020 than in 2019. Additionally, the effect of dissolved oxygen on salmon growth was not assessed in 2019 because it was not measured continuously at all sites that year, but was found to have a strong, likely non-linear, effect on 2020 salmon growth. Those results suggest that the interplay between the local gradient of environmental conditions and salmon metabolism may vary with the system's complex spatio-temporal dynamics, and warrant further investigation on salmon growth across a variety of hydrological conditions and habitat types.

The dry 2020 flood season provided a unique contrast to the extremely wet 2019 flood season in our study area. The contrasting hydrologic years highlighted how the same locations can have two very different physical conditions and resulting food web productivity and fish growth rates. The Central Valley is a complex mosaic of habitats that function differently across space and time for out-migrating juvenile Chinook Salmon. A better understanding of this complexity will help to prioritize habitat management and restoration actions. We hope that data collected during this study will help to provide insight to this complexity and be useful to resource managers and decision makers.

### **ACKNOWLEDGEMENTS**

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## REFERENCES

- Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. In: 2nd International Symposium on Information Theory (Ed. by B.N. Petrov and F. Csaksi), pp. 267–281. Akademiai Kiado, Budapest, Hungary.
- Azat J. 2017. GrandTab 2017.04.07. California Central Valley Population Database Report, California Department of fish and Wildlife. Available from: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84381>
- Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information - Theoretic Approach. 2nd edn. Springer - Verlag, New York, USA.
- Central Valley Flood Management Planning Program (CVFMPP). 2010. State Plan of Flood Control Descriptive Document. Available from: <https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-Projects/USACE/Files/2010-State-Plan-of-Flood-Control-Descriptive-Document.pdf>.
- Greene S. 1992. California Department of Water Resources, Division of Environmental Services. Memo Report to R. L. Brown, Division Chief, DWR Division of Environmental Services. Re: Estimated winter-run chinook salmon salvage at the State Water Project and Central Valley Project Delta pumping facilities.
- Grosholz E., and Gallo E. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. *Hydrobiologia*, 568: 91–109. <https://doi.org/10.1007/s10750-006-0029-z>.
- Hanak E., Lund J., Dinar A., Gray B., Howitt R., Mount J., Moyle P., and Thompson B. 2011. Managing California's water: from conflict to reconciliation. Public Policy Inst Calif, San Francisco.

Johnson R.C., and Lindley S.T. 2016. Central Valley Recovery Domain. Pages 48 – 63 in T.H. Williams, B.C. Spence, D.A. Boughton, R.C. Johnson, L. Crozier, N. Mantua, M. O’Farrell, and S.T. Lindley. 2016. Viability assessment for Pacific salmon and steelhead listed under the Endangered Species Act: Southwest. 2 February 2016 Report to National Marine Fisheries Service – West Coast Region from Southwest Fisheries Science Center, Fisheries Ecology Division 110 Shaffer Road, Santa Cruz, California 95060.

Karanovic I. 2012. Recent freshwater ostracods of the world: Crustacea, Ostracoda, Podocopida. Springer Science & Business Media.

Kelley R. 1989. Battling the Inland Sea American Political Culture, Public Policy, and the Sacramento Valley, 1850-1986.

Legendre, P., Gallagher, E.D. 2001. Ecologically meaningful transformations for ordination of species data. *Oecologia*. 129, 271–280. <https://doi.org/10.1007/s004420100716>

Merritt R.W., Cummins K.W., and Berg M.B. 1996. An Introduction to the Aquatic Insects of North America, 4th Edition. Kendall Hunt Publishing.

Opperman J.J., Galloway G.E., Fargione J., Mount J.F., Richter B.D., and Secchi S. 2009. Sustainable floodplains through large-scale reconnection to rivers. *Science*, 326: 1487-1488. <https://doi.org/10.1126/science.1178256>.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org/>.

Ribiero F., Crain P.K., and Moyle P.B. 2004. Variation in condition factor and growth in young-of-year fishes in floodplain and riverine habitats of the Cosumnes, California. *Hydrobiologia*, 527: 77-84.

Sommer T.R., Nobriga M.L., Harrell W.C., Batham W., and Kimmerer W.J. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences*, 58: 325–33. <https://doi.org/10.1139/f00-245>.

Speir C., Mamula A., and Ladd D. 2015. Effects of Water Supply on Labor Demand and Agricultural Production in California's San Joaquin Valley. *Water Economics and Policy* 1(2):1550003.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger., 2005. Changes towards earlier streamflow timing across western North America. *J. Climate*, 18: 1136-1155.

Thorp J., and Covich A. 2009. *Ecology and Classification of North American Freshwater Invertebrates*, 3rd edition. Academic Press.

Ward P.D, McReynolds T.R. 2004. Butte and Big Chico creeks spring-run Chinook salmon, *Oncorhynchus tshawytscha* life history investigation 1998-2000. Sacramento, CA. State of California. The Resources Agency. CA Department of Fish and Game.

Welcomme R.L. 1979. *Fisheries ecology of floodplain rivers*. London; New York: Longman.

Whipple, A. A., Viers, J. H., and Dahlke, H. E. 2017. Flood regime typology for floodplain ecosystem management as applied to the unregulated Cosumnes River of California, United States. *Ecohydrology*. 10, e1817, <https://doi.org/10.1002/eco.1817>

Williams J. G. 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. *San Francisco Estuary and Watershed Science* 4(3).

Yoshiyama, R.M., Fisher E.W., and Moyle P.B. 1998. Historical abundance and decline of chinook salmon in the Central Valley region of California. *N. Am. J. Fish. Manage.* 18:487-521.

Zuur A.F, Ieno E.N, Walker N.J., Saveliev A.A., and Smith G.M. 2009. *Mixed Effects Models and Extensions in Ecology with R*. Springer-Verlag, New York.

Zuur A.F., Hilbe J.M., and Ieno E.N. 2013. *Beginner's Guide to GLM and GLMM with R*. Springer-Verlag, New York.