Fish Food on Floodplain Farm Fields

Report of the 2017 Pilot Year Investigations

Sacramento Valley

River Garden Farms

Knaggs Ranch **Davis Ranches** **Next Generation Foods**

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ABSTRACT

In the Central Valley of California, approximately 3360 km of state and federal levees (Inamine et al. 2010), along with local flood protection projects, have cut off approximately 95% of historical floodplain wetlands from their river channels. The goal of the 2017 pilot year of the Fish Food on Floodplain Farm Fields project was to survey existing wetland habitat types over a broad swath of the primarily privately owned Sacramento Valley, both inside and outside the levee footprint. By comparing and contrasting hydrologic conditions and aquatic food web dynamics across the spectrum of existing wetland habitat types, we hoped to 1) better understand aquatic food web productivity as in occurs currently at the landscape scale in the Sacramento Valley and 2) assess the potential for diverse off-channel aquatic habitats, including the hundreds of thousands of acres of floodplain farm land and managed wetlands, to contribute food resources to the main-stem river ecosystem and bolster in-river aquatic food webs. The pilot year is attended to lay the groundwork and inform development of experimental designs of subsequent investigations which will be designed to better understand how floodplain productivity can be exported to the river and its impact on river, and potentially delta, food webs.

In the winter of 2016-2017 a survey of water quality, zooplankton biomass and community assemblage was carried out at 33 locations across six counties. Three primary aquatic habitat types were surveyed: mainstem Sacramento River, flood bypasses, flooded “dry side” rice fields. Two additional, off-channel habitat types were represented by only a single location each, a remnant floodplain within the levee footprint, and a wetland managed for waterfowl. The river and rice field habitat types had distinct zooplankton communities. Zooplankton biomass and species assemblage varied across the rice field sites and through time but average zooplankton biomass was always substantially higher in rice field habitats than in adjacent river sites. Bypass food webs appeared relatively similar to those in adjacent river habitats during high flows events when river water inundated bypasses, but differentiated rapidly when flows began to recede. As flows across the bypass diminished and slowed prior to disconnection zooplankton biomass began to increase sharply. After hydrologic disconnection zooplankton communities in bypass habitats became more diverse and densities increased as much as 5 orders of magnitude.

When high flows connected the remnant floodplain to the river, the two habitats exhibited similarly sparse food webs. As flows diminished and slowed across the remnant floodplain in the days just before and after hydrologic disconnection of river and remnant floodplain, the floodplain food web resembled food webs found at bypass sites. In the weeks following disconnection, the remnant floodplain showed zooplankton assemblages and densities similar to those found at rice field sites. This study found that off-channel habitats generally exhibited productive aquatic food webs as exhibited by dramatically elevated densities of nutrients, phytoplankton and zooplankton compared to river channel habitats. These data show the importance of seasonal shallow inundation of floodplains as a driver for productivity and abundance in the Sacramento Valley aquatic ecosystem.

INTRODUCTION

In the Central Valley of California, approximately 3,360 km of state and federal levees (Inamine et al. 2010) along with local flood protection projects have cut off approximately 95% of the historical floodplain wetlands from their river channels (Hanak et al. 2011). The ecosystem response to this landscape-scale hydrologic divorce of river channel and floodplain have only recently begun to be quantified (Opperman et al. 2009). Recent state-wide analysis of the conservation status of freshwater fishes have concluded that lack of floodplain and other off-channel habitat is an important contributor to widespread decline of many fish species (Moyle et al. 2011, Katz et al. 2012). In the Central Valley, studies have shown that when flood waters inundate floodplains, the floodplains are generally warmer due to increased surface area and residence time compared to the relatively cool and swift river channel (Ahearn et al. 2006, Grosholz and Gallo 2006). Elevated phytoplankton growth in these floodplain habitats provide food resources for grazing zooplankton and other invertebrates, which ultimately become food resources for fishes (Sommer et al. 2001, Müller-Solger et al. 2002, Ahearn et al. 2006, Grosholz and Gallo 2006, Jeffres et al. 2008). Due to the limited amount of floodplain habitats remaining within the levee footprint, there has been much focus on how the flood bypasses–which still hydrologically connect to river channels during high flow events– may be modified to better mimic historical shallow flooding patterns that once sustained aquatic food webs and were important drivers of fish and wildlife abundance.

Recent research has shown that agricultural fields in the Yolo Bypass and the Sutter Bypass can also provide a productive food web and abundant food resources for juvenile salmonids when intentionally flooded using existing irrigation infrastructure. The overall rapid growth and robust body condition of the salmon in these studies demonstrates that winter flooding of agriculture fields during the non-growing season can provide high quality habitat for rearing juvenile Chinook salmon in all water years. These results suggest that changes to agricultural management and infrastructure that increase the frequency and extend the inundation duration of bypass flood events may allow bypass agriculture fields to serve as large-scale surrogates for floodplain wetlands (Katz et al. 2017).

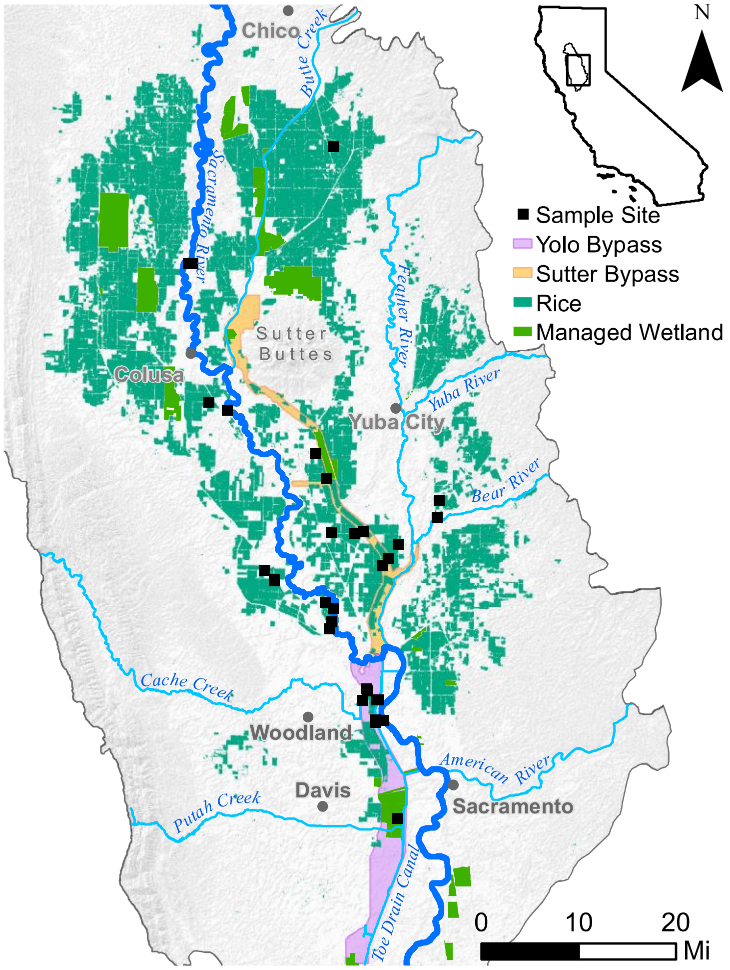


Figure 1. 2017 sampling locations: 33 sites across 6 Sacramento Valley counties.

Unfortunately, only a limited acreage of the Sacramento Valley's rice fields lie within the flood bypasses that receive relatively regular flooding and are accessible to juvenile salmonids. Approximately 500,000 acres of rice ground lie on historical low-elevation floodplains of the Sacramento Valley that are now cut off from river channels by flood protection levees. New management practices on these “dry-side” rice fields presents an opportunity to investigate how these historical floodplain wetlands may be able to reintegrated into the food web productivity of the Sacramento River and Delta aquatic ecosystem. Over the last three decades, rice growers in the Sacramento Valley have adopted and continued to refine farm practices that provide wetland habitat for waterfowl and shorebirds on winter rice fields that remain in active agricultural production during summer (Elphic et al. 1998, Eadie et al. 2008, Strum et al. 2013). One of these practices, which occurs on approximately 300,000 acres of rice ground in the Sacramento Valley annually, is the shallow flooding of rice fields after harvest in fall and early winter to aid in rice stubble decomposition (decomp). This managed inundation produces hydrologic conditions similar to natural shallow, high-residence time flood patterns and has had positive landscape-level effects on native wetland bird species populations which have seen all-time high counts in recent years (Elphick et al. 2010). Under current farm practices, fields are flooded in early fall when relatively warmer autumn temperatures aid in rice stubble decomposition. Water is kept on fields where it percolates into the ground or is lost to evaporation and fields are usually dry by the end of January. Very little of this decomp water, returns back to the canals or to the river.

The goal of the 2017 pilot year of the Fish Food on Floodplain Farm Fields project was to survey diverse wetland habitat types over a broad swath of the Sacramento Valley which is primarily in private ownership. In order to gain access to private lands a group of owners were approached by the project coordinators. These land owners occupy leadership roles within their agricultural communities and have been deeply involved in the piloting and early adoption of past conservation practices, such as winter water management for waterfowl and shorebirds. Collectively the growers engaged in the 2017 pilot year own more than 80,000 acres of Sacramento Valley farm ground. The data collected on these lands will be used to develop a set of “fish food” conservation farm practices. Continued grower outreach efforts facilitated by the Northern California Water Association (NCWA), Reclamation District 108 (RD 108), California Trout (CalTrout) and the California Rice Commission (CRC) will ensure that these operational criteria are compatible with existing agricultural and conservation practices such as variable draw-down of shallow flooding in early-spring for waterfowl and shorebirds. This stakeholder outreach and engagement will increase grower buy-in and expedite adoption of “fish food” conservation practices when they are developed.

By comparing and contrasting aquatic food webs in multiple existing wetland habitat types, both inside and outside the levee footprint, we hoped to 1) better understand the spatial and temporal trends in aquatic food web productivity in the Sacramento Valley and 2) assess the potential of diverse “off-channel” aquatic habitats to contribute food resources to the main-stem river ecosystem and bolster in-river food webs.

METHODS

Project coordinators, lead by RD 108 and assisted by NCWA the CRC and CalTrout, approached a select group asking them to participate in this pilot survey of in-field bio-productivity. Growers were selected based on established relationships, capacity for in-kind contribution and commutiy standing. Sample locations were informally selected through corridantion betwen landowners, project coorinators and research staff based on geographic location, flooding schedules, water availability, access and logistic considerations.

To survey the aquatic food web production within various wetland habitats in the Sacramento Valley, 33 locations in the Sacramento River, Feather River, Colusa and Butte Basins were sampled for water quality, chlorophyll, and zooplankton diversity and abundance (Figures 1,2). Habitat types were classified as river, remnant floodplain (referred to as an oxbow in Figure 2), bypass, rice field, or wetlands managed for waterfowl (here-to-fore called pond). Off-channel habitats (rice, bypass, remnant floodplain and managed wetlands) were paired with a nearby river location.

Table 1. Partner Roles

Partner	Role
Northern California Water Association	Project Administrator
RD 108	Project Coordinator
California Rice Commission	Grower outreach and program development
California Trout	Science Coordinator
UC Davis Center for Watershed Sciences	Monitoring and Analysis

Table 2. Project Team

Grower outreach Coordinator	Lewis Bair, Reclamation District No 108
Science Coordinator	Jacob Katz, CalTrout
Project Administrator	Todd Manly, Northern California Water Association
Project Funding	Metropolitan Water District ($200,000), San Luis Delta Mendota Water Authority ($100,000), In-Kind from Public Agencies and Sac Valley landowners (~$250,000)
Technical Advisory Committee	Representatives mentioned above plus: David Guy–NCWA, Jason Peltier–SLDMWA, Paul Butner–CRC, Ted Sommer–DWR, Brian Ellrott–NMFS, Jeff McCreary–DU, Collin Purdy–CDFW, Carson

	Jeffres–UC Davis, Kris Tjernell–CNRA, Alison Collins–MWD, Chuck Hanson–SWC, Laura Valoppi–SFCWA

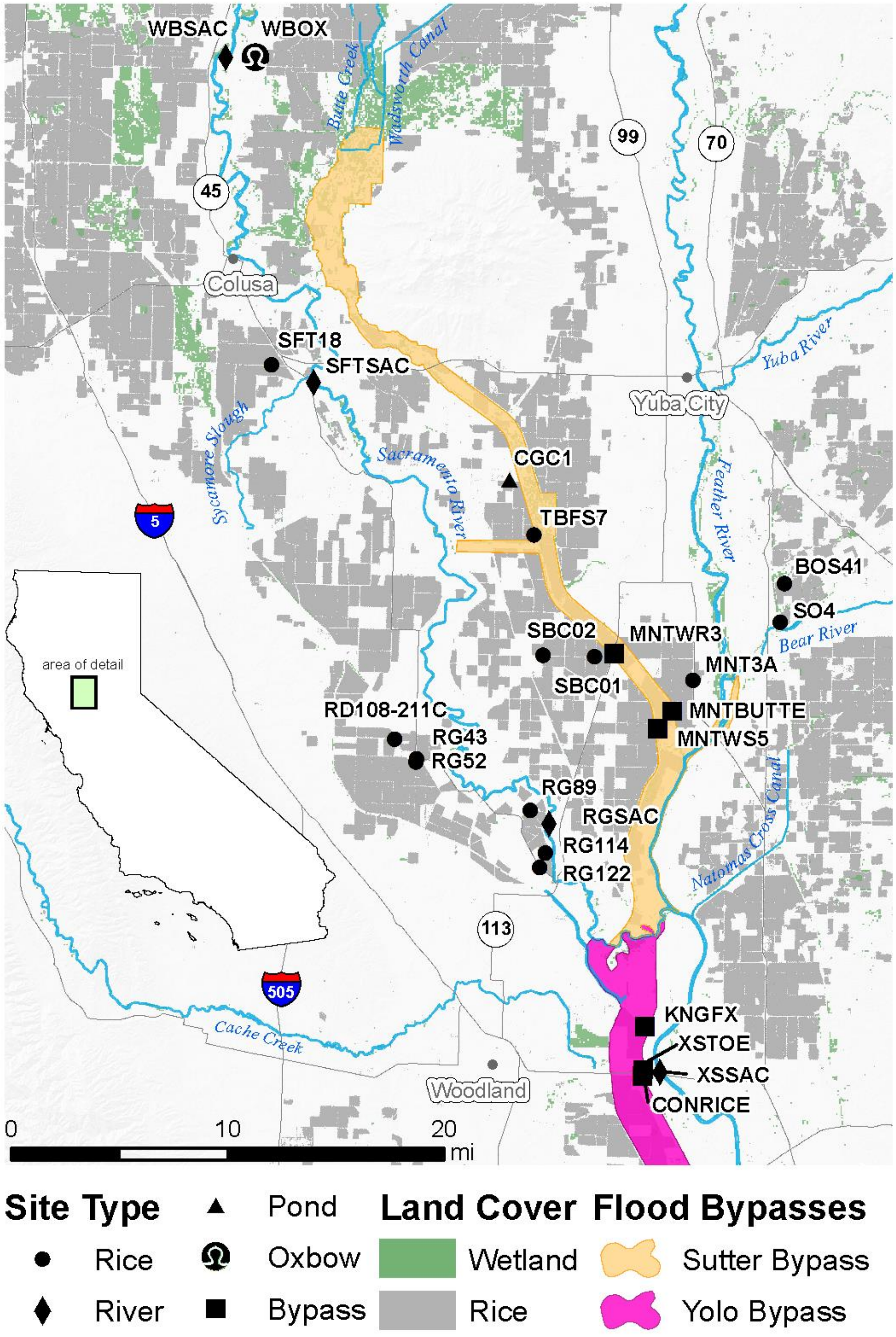
Flooding of rivers and bypasses in subject to vagries and uncertainties of the weather. Bypasses only flood under relitively high water conditions when storm-driven flow volume in rivers is sufficient to overtop wier crests and inundate the bypass floodplain. Flooding-up of post-harvest rice fields and managed wetlands is subject to the complexities of water rights and diversion schedules, cropping, soil types, drainage configurations, and myriad other farm and water considerations according to the specific management strategies prescribed by the individual land owner or farmer on a field by field basis. Hence, each field sample location was flooded when water was available and could be delivered. Weekly samplng began when water became deep enough to permitt zooplankton net pulls. Accordingly some rice fields were flooded for several months and others for only weeks resulting in diffiering numbers of weekly samples taken across locations.

Bypass sites included agricultural fields located in the Yolo and Sutter Bypasses and the Toe Drain canal of the Yolo Bypass. All bypass sites were subject to flooding during high flow events. River sampling locations were located adjacent to bypass or rice field sites. The Willow Bend remnant floodplain habitat is an approximately 30-acre perched floodplain within an abandonded oxbow within the flood protction levees of the eastern (left) bank of the Sacramento River at River Mile (RM) 159.8, directly upstream of the Colusa Weir in northern Colusa County. The Willow Bend Preserve is approximately 60 miles north of the Sacramento, California. The pond category included a managed pond located at the Chesepeake Duck Club just to the west of to the Sutter National Wildlife Refuge.

Water quality was assessed by collecting point measurements with a YSI Exo2 multi parameter sonde. The water quality parameters collected were: temperature (degrees C), dissolved oxygen (mg/L), turbidity (NTU), chlorophyl (ug/L), electrical conductivity (ug/cm), salinity (PSU), and pH. Grab samples for chlorophyll and nutrient analysis were also taken during each sampling period and processed within 24 hours and sent to the Dahlgren water quality lab at UC Davis. Onset HOBO dissolved oxygen probes and temperature loggers (which were limited in availability due to cost) were deployed in the River Garden and Sycamore Family Trust rice fields, the Knaggs Ranch bypass and adjacent Sacramento River site, and at the Willow Bend remnant floodplain logging at 15 minute intervals.

All sites were sampled for zooplankton diversity and abundance once a week using net tows. In rice field, bypass, remnant floodplain and pond sites where shallow water precludes the use of a larger net, a 15 cm diameter, 150 µm mesh zooplankton net was thrown five meters and retrieved through the water column four times. The net was thrown from the same location within the site each sampling session. When fields were draining, the zooplankton net was cast within the remaining area deep enough to submerge the net completely. In the river sites, where current speed influences volume of water sampled, a 30 cm diameter, 150 µm mesh zooplankton net fitted with a flowmeter was thrown five meters and retrived through the water column four times, two upstream and two downstream. Prior to and following sampling, flow meter data was recorded to quantify the volume of water sampled. During high flow events, some sites were inaccessable, in which case sampes were taken from the nearest accessible point within the same water body.

All samples were preserved in a solution of 95% ethanol. Sampling in the rice field, bypass, pond and remnant floodplain sites ceased when water levels were too shallow to cast the zooplankton net. Subsampling of the zooplankton samples was necessary due to the high density of invertebrates within some of the samples. Subsampling included rinsing the sample through a 150-µm mesh and then emptied into a beaker. The beaker was filled to a known volume to dilute the sample, and then sub-sampled with a 1mL, 2ml or 5ml large bore pipette depending on sample density. If densities were still too great for enumeration, the subsample was then split using a Folsom splitter. The dilution volume, number of splits, and number of aliquots removed was recorded and used to obtain total estimates of invertebrates. Zooplankton samples were sorted as follows: taxa were enumerated in successive subsamples until a minimum of 100 individuals were counted for each taxon, continuing until 10% of the sample was sorted. If fewer than 100 members of the dominant taxon were counted within 10% of the total sample, then subsampling continued until counts of least 100 individuals were achieved. Invertebrates were identified with the aid of a dissecting microscope at 8x magnification to the lowest taxonomic level possible using keys from Pennak's Freshwater Invertebrates of the United States (4^{th} edition)(Smith 2011), An Introduction to the Aquatic Insects of North America (4th edition) (Merritt and Cummins 1996), and An Image-Based Key to the Zooplankton of North America (New Hampshire Center for Freshwater Biology, 2013). Copepods were identified to order with the exception of genus Acanthocyclops. Terrestrial invertebrates were counted as a single category.



CA Teale Albers NAD83 Source: USGS, USDA NASS © Gabe Saron 2017

Figure 2. Sampling locations represented by habitat type.

Table 3. Site name, description, habitat type and sampling period

Site	Description	Habitat	Start Date	End Date	Samples
BOS41	Bosworth field 41	Rice field	2/6/17	3/6/17	2
LFF01	Lundburg Family Farms 1	Rice field	2/6/17	2/6/17	1
MNT3A	Montna field 3A	Rice field	12/12/16	2/27/17	12
RD108-211C	RD 108 field 211C	Rice field	1/25/17	3/6/17	4
RG114	River Garden Farms field 114	Rice field	11/14/16	1/30/17	9
RG122	River Garden Farms field 122	Rice field	11/7/16	1/30/17	11
RG43	River Garden Farms field 43	Rice field	1/25/17	1/25/17	1
RG52	River Garden Farms field 52	Rice field	2/6/17	2/27/17	3
RG89	River Garden Farms field 89	Rice field	11/28/16	2/6/17	10
SBC01	Sutter Basin Corporation field 1	Rice field	2/6/17	2/20/17	3
SBC02	Sutter Basin Corporation field 2	Rice field	2/6/17	2/20/17	3
SFT18	Sycamore Family Trust field 18	Rice field	11/29/16	3/6/17	15
SO4	Shady Oaks field 4	Rice field	2/6/17	2/27/17	4
TBFS7	Tule Basin Farms field S7	Rice field	2/8/17	2/27/17	4
CONRICE	Conaway rice field	Bypass	4/3/17	5/4/17	3
KNGFX	Knaggs flood extension field	Bypass	12/26/16	5/4/17	24
KNGREP1	Knaggs replicated field 1	Bypass	4/3/17	4/10/17	2
KNGYBW	Yolo Bypass at Wallace Weir	Bypass	1/16/17	1/30/17	3
MNTBUTTE	Montna Butte Creek at Kirkville	Bypass	12/19/16	5/15/17	21
MNTWR3	Montna Westrope field 3	Bypass	12/12/16	1/2/17	3
MNTWS5	Montna Willow Slough field 5	Bypass	12/12/16	4/3/17	5
MNTWSP	Montna Willow Slough Proxy	Bypass	3/13/17	5/1/17	3
YBWA	Yolo Bypass Wildlife Area	Bypass	1/17/17	5/9/17	11
WBOX	Willow Bend Remnant floodplain	Remnant Floodplain	12/19/16	5/15/17	21
KNGFXTOE	Toe drain adjacent to Knaggs flood extension field	River	3/10/17	3/10/17	1
KNGKLRC	Knights Landing Ridgecut at Knaggs Ranch	River	1/9/17	3/8/17	3
RGSAC	Sacramento R. @ River Garden	River	11/7/16	5/15/17	28
SFTSAC	Sacramento R. @ Sycamore	River	11/29/16	5/15/17	25
WBSAC	Sacramento R. @Willow Bend	River	3/20/17	5/15/17	9
XSSAC	Sacramento R. @ Conaway	River	3/13/17	5/15/17	17
XSTOE	Toe Drain at Road 22 bridge	River	3/13/17	5/15/17	17
CGC1	Chesapeake Gun Club 1	Pond	2/8/17	5/15/17	15

Data

All data and assocaited graphical analyses are available at this link.

Develpoment of "Fish Food" Farm Practices

The data collected will be used in year two of this study to develop a set of operational criteria for surrogate floodplain agricultural field flooding depth and duration, draining, drain canal operation and return flow pumping (fish food practices). The team coordinated efforts to streamline operational criteria into a set of on-farm grower practices with the goal of integrating fish food practices into rice farming practices over large scale of privately owned acres of historic floodplain wetland. The California Rice Commision will engage its growers and seek grower feed back to ensure that operational criteria are compatible with agricultural and existing conservation practices such as variable draw-down of shallow flooding in early-spring for waterfowl and shorebirds. A subsequent objective will be to develop criteria to integrate these practices into a format suitable for funding through the Natural Resources Conservation Service's Environmental Quality Incentives Program. The Nature Conservancy will also advise on integrating fish and fish food practices into their existing Bird Returns program.

RESULTS

Stakeholder Engagement

All growers approached to participate in the study agreed to allow sampling of their lands. Logistical constraints differed across sites depending on a complex set of variables and land uses such as hunting, water rights, water availability, water delivery infrastructure, drainage infrastructure, river level, etc. However, all of these concerns and considerations which reflect the reality of conducting research in the midst of private working landscape were manageable and ultimately we had far more willing landowners than our sampling schedule could accommodate.

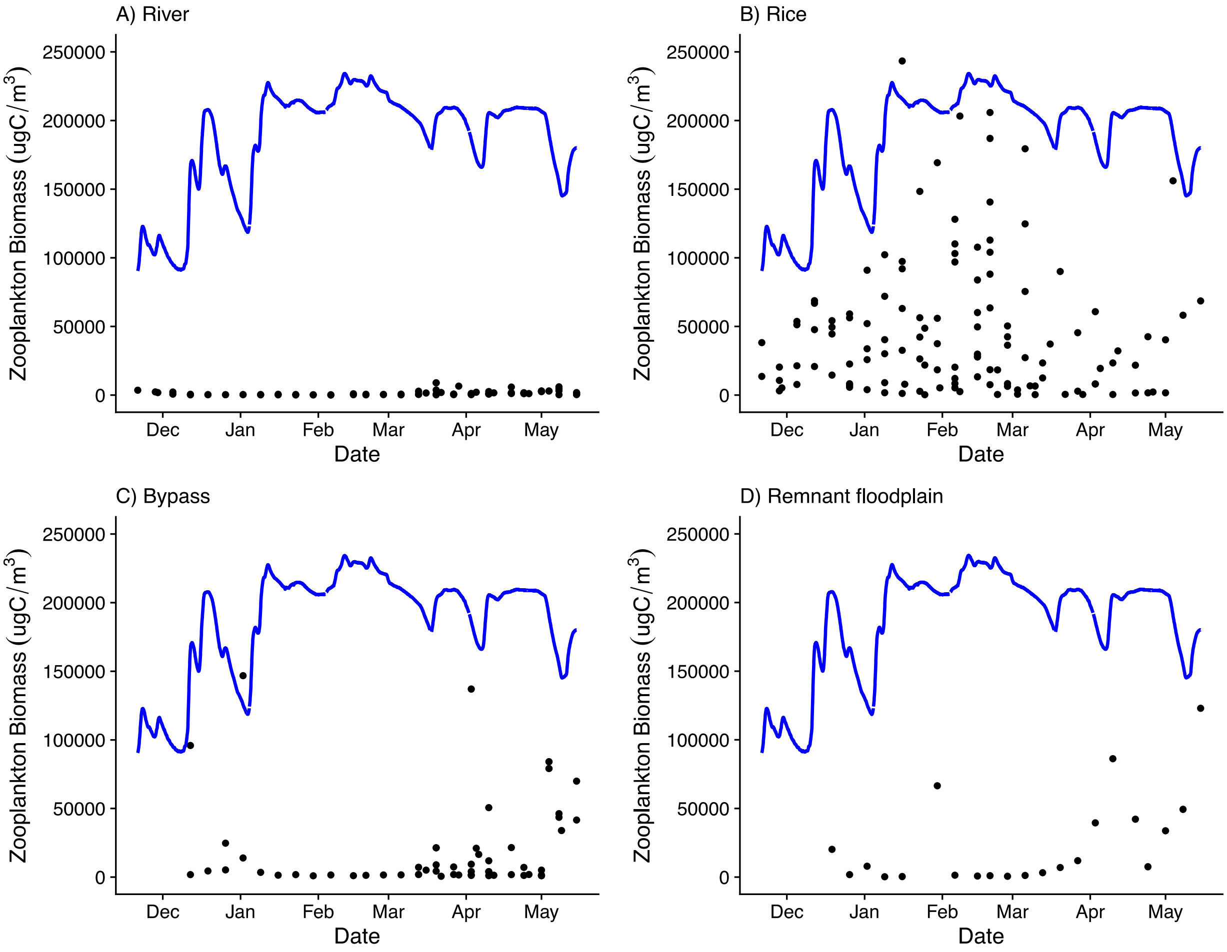


Figure 3. Zooplankton densities (micro grams dry carbon per cubic meter of water) across habitat types. Blue line representing river hydrogrpah presented for context.

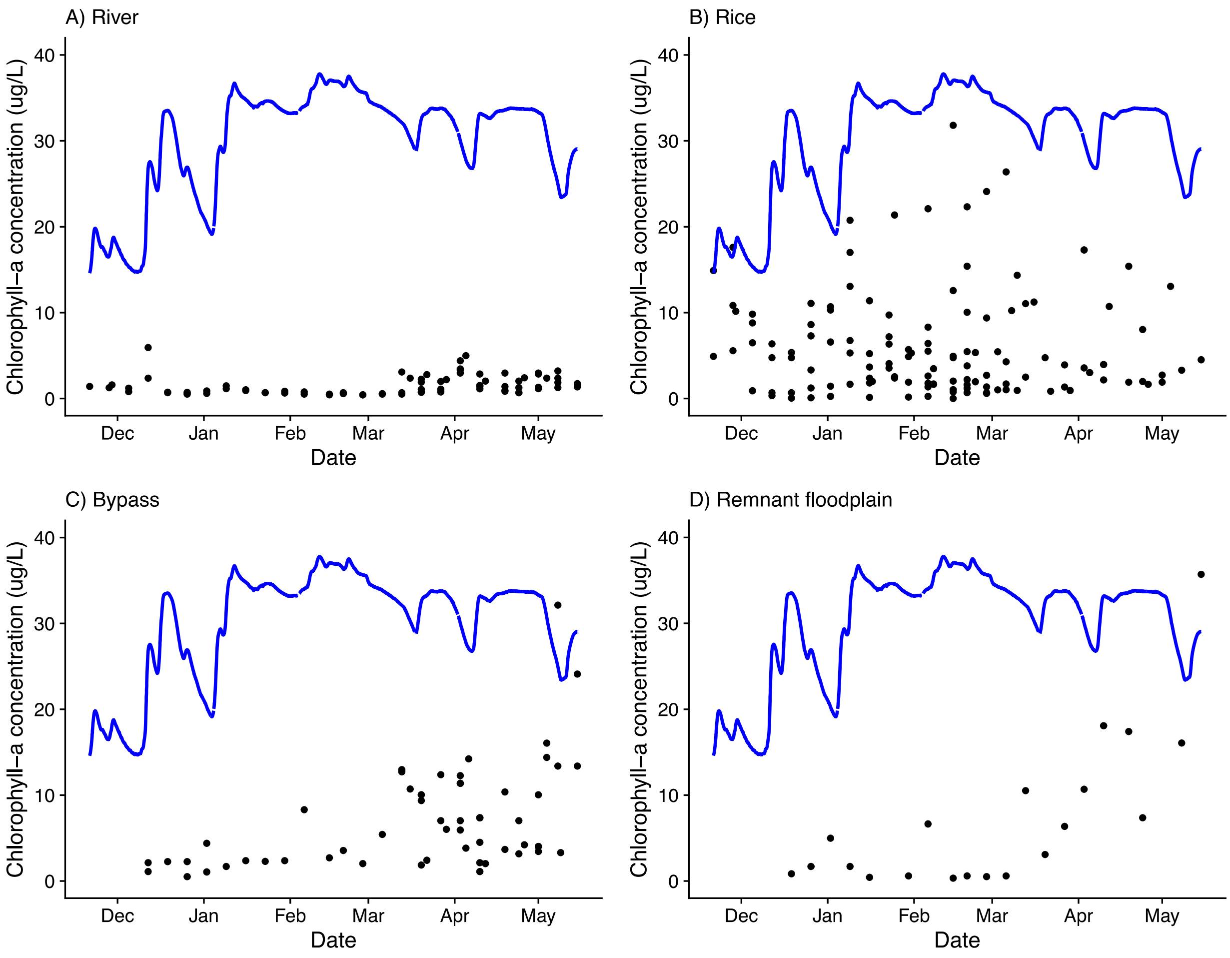


Figure 4. Chlorophyll-a densities (micro grams dry carbon per liter of water) across habitat types. Blue line representing river hydrogrpah presented for context.

River Garden

All three river garden fields were flooded in the first week of November. Sampling began on November 7th. RG89 and RG122 were flooded for the duration of the study. RG114 was drained after four weeks of inundation and then re-flooded for the remainder of the study. Each field exhibited distinct patterns in zooplankton biomass and community assemblage (Fig. 2). RG89 had low zooplankton biomass until late December, after which biomass increased to over 240,000 µg/m^3. RG89 had high biomass of cladocerans and copepods in the latter half of the study period and the highest diversity of the three sites. The first inundation cycle of RG114–November 7th to mid-December–resulted in a range of 10,000-53,000 µgC/m^3 zooplankton biomass dominated by copepods. The second inundation cycle–mid-December through February 1) of RG114 resulted in 4,000-32,000 µgC/m^3 zooplankton biomass dominated by cladocerans. RG122 zooplankton biomass was predominantly cladocerans with values from 25,000-97,000 µgC/m^3.

All three River Garden Farm sites maintained higher zooplankton biomass than the Sacramento River which ranged from 200-5,800 µgC/m^3.

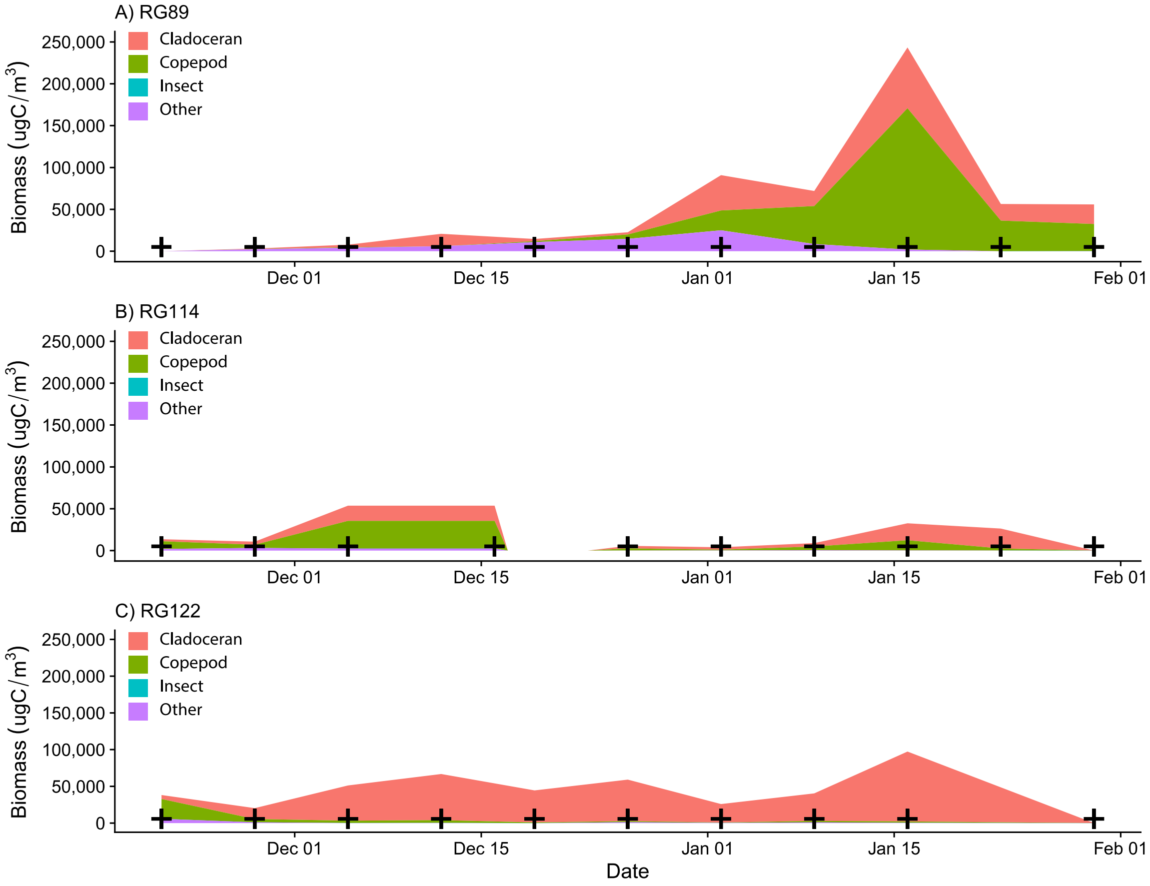


Figure 5. River Garden Farm rice field zooplankton biomass (µgC/m^3) at (A) Field 89, (B) Field 114, and (C) Field 122. Fields were flooded up immediately prior to the first sampling on November 7, 2016. Fields were sampled weekly through January 29, 2017. RG89 and RG122 were continuously flooded for the duration of the study. RG114 was drained on December 18th and re-flooded for the remainder of the study when they were drained. Crosses denote date of samplings.

Willow Bend

The remnant floodplain at Willow Bend experienced two major inundation events from the Sacramento River (January 9 through 29, 2017 and February 4 through March 8, 2017) followed by one minor reconnection event (April 21-22, 2017). Zooplankton biomass was predominantly copepods during the first and second inundation events, with a small proportion cladoceran biomass developing later (Figure 3). Zooplankton biomass values ranged from 250-123,000 µgC/m^3. Zooplankton biomass in the remnant floodplain was lowest during the first two prolonged inundation events and greatest after three-four weeks of disconnection from the Sacramento River. Zooplankton biomass in the Sacramento River adjacent to the remnant floodplain ranged from 200-2,900 µgC/m^3.

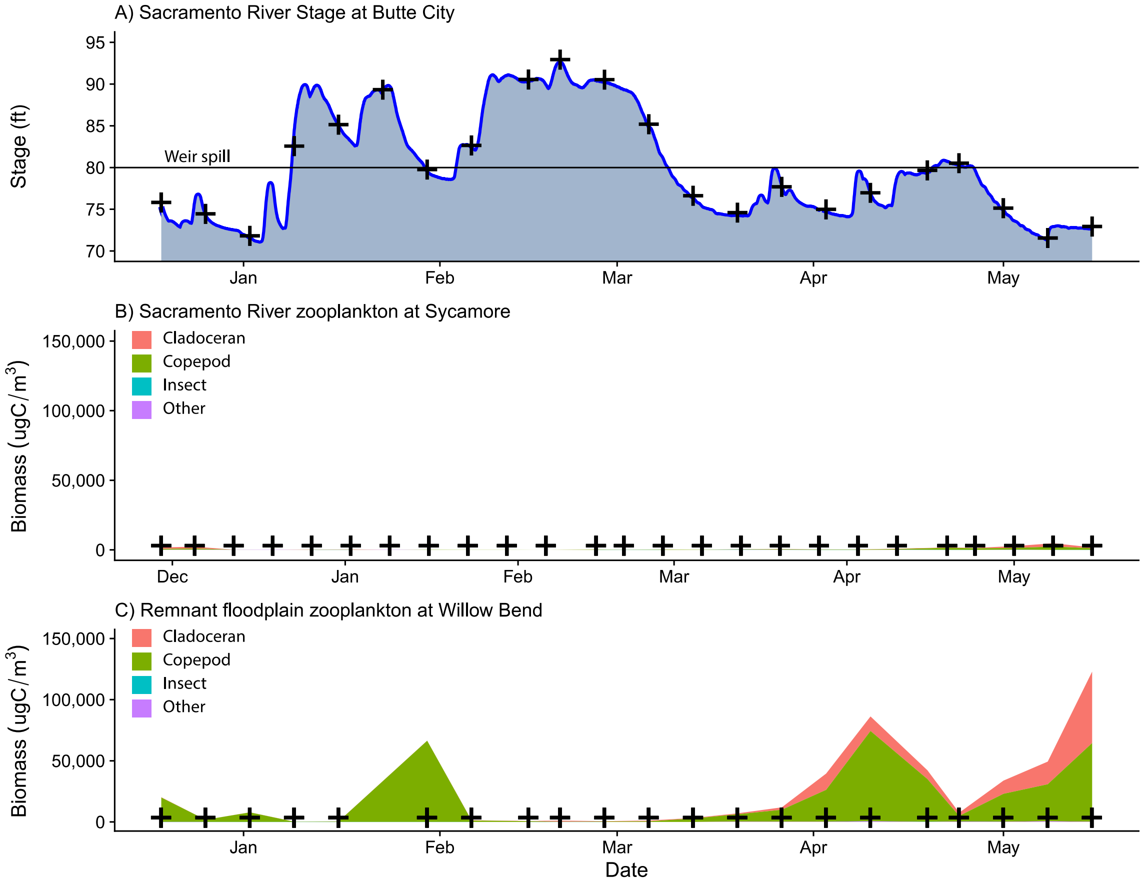


Figure 6: Zooplankton Biomass and Sacramento River stage at Willow Bend remnant floodplain. (A) Sacramento River stage at Butte City (ft). The horizontal line at y = 80 represents the stage at which the Sacramento River inundates the remnant floodplain at Willow Bend. (B) Sacramento River zooplankton biomass (µgC/m^3) at Sycamore just downstream of Willow Bend. (C) Zooplankton biomass (µg/m^3) at Willow Bend. Data were collected from December 19, 2016 through May 15, 2017. Crosses denote date of samplings.

Bypasses

Sacramento River spilled over Fremont Weir three times (January 9 through March 13, 2017; March 19 through 31, 2017; and April 9 through May 2, 2017) over the study period, hydrologically connecting the River Channel directly with the Yolo Bypass sampling sites. Zooplankton biomass on the Yolo Bypass ranged from 300 -6,700 µgC/m^3 from December 19 to March 13 and had several subsequent periods of high biomass that coincided with periods subsequent to hydrologic disconnection from the Sacramento River from March 14 to May 4 (Fig. 4). Biomass values from March 14 to May 4 ranged from 400-

156,000 µg/m^3. Copepods contributed the most to the zooplankton biomass on the Yolo Bypass, while cladocerans were a relatively minor proportion until mid-April. The Sacramento River had biomass values that ranged from 500-6,500 µgC/m^3 and was dominated by copepods.

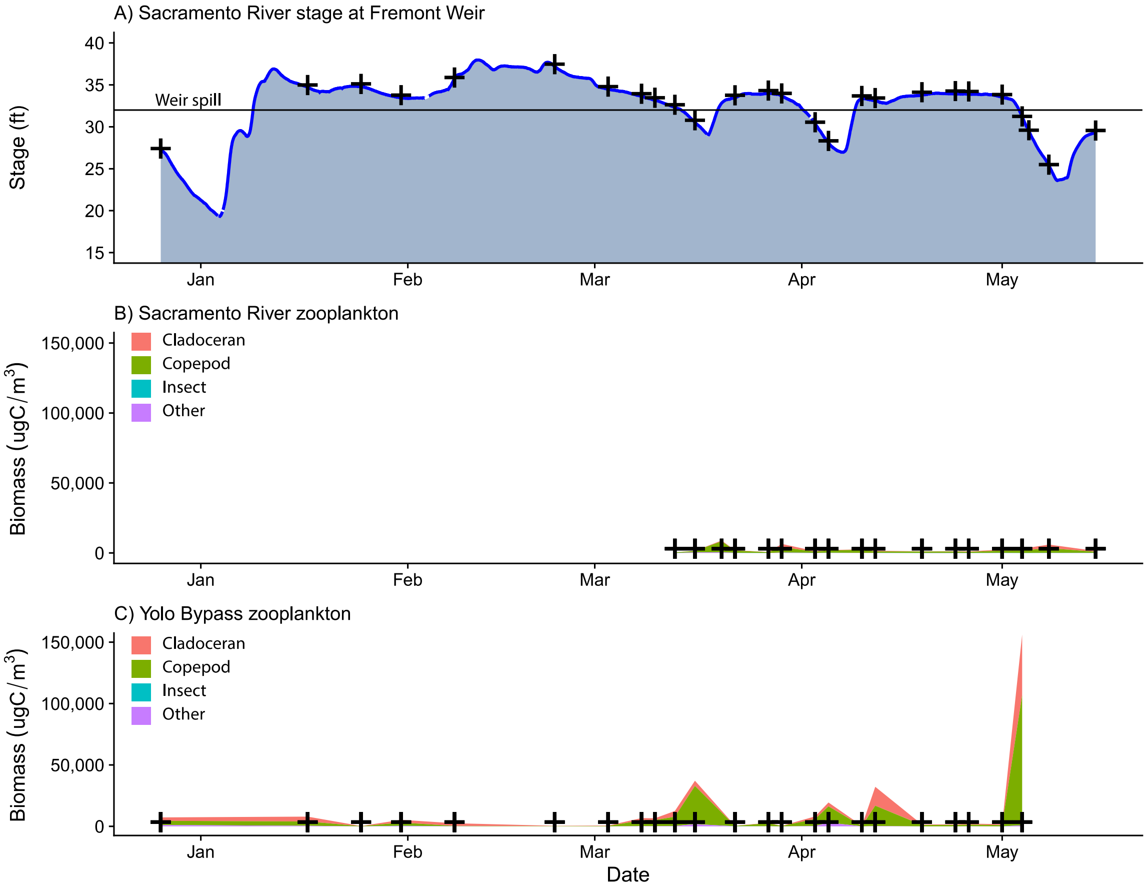


Figure 7. Sacramento River stage and Zooplankton Biomass at Yolo Bypass. (A) Sacramento River stage at Fremont Weir (ft). The horizontal line at y = 32 represents the stage at which the Sacramento River spills over Fremont Weir to inundate the Yolo Bypass. (B) Sacramento River zooplankton biomass (µgC/m^3) at I-5 crossing. (C) Yolo Bypass zooplankton biomass (µgC/m^3) at Knaggs Ranch. All data were collected from December 19, 2016 through May 4, 2017. Crosses denote date of samplings.

Comparison of food webs across sites and habitat types

Non-parametric multidimensional scaling (NMDS) ordination was used to determine similarity of food web characteristics among sites (Fig. 5). Results show discrete clustering of river and rice field sites. Bypass sites and the remnant floodplain, which both experience periodic hydrologic connection to the Sacramento River fluctuate between clustering with either the river (if connected) or rice sites (in periods after hydrologic disconnection). The pond site is a discrete cluster but is most similar to rice fields. The parameter with the most leverage, or influence over the distribution of points in the plot, was biomass of cladocerans.

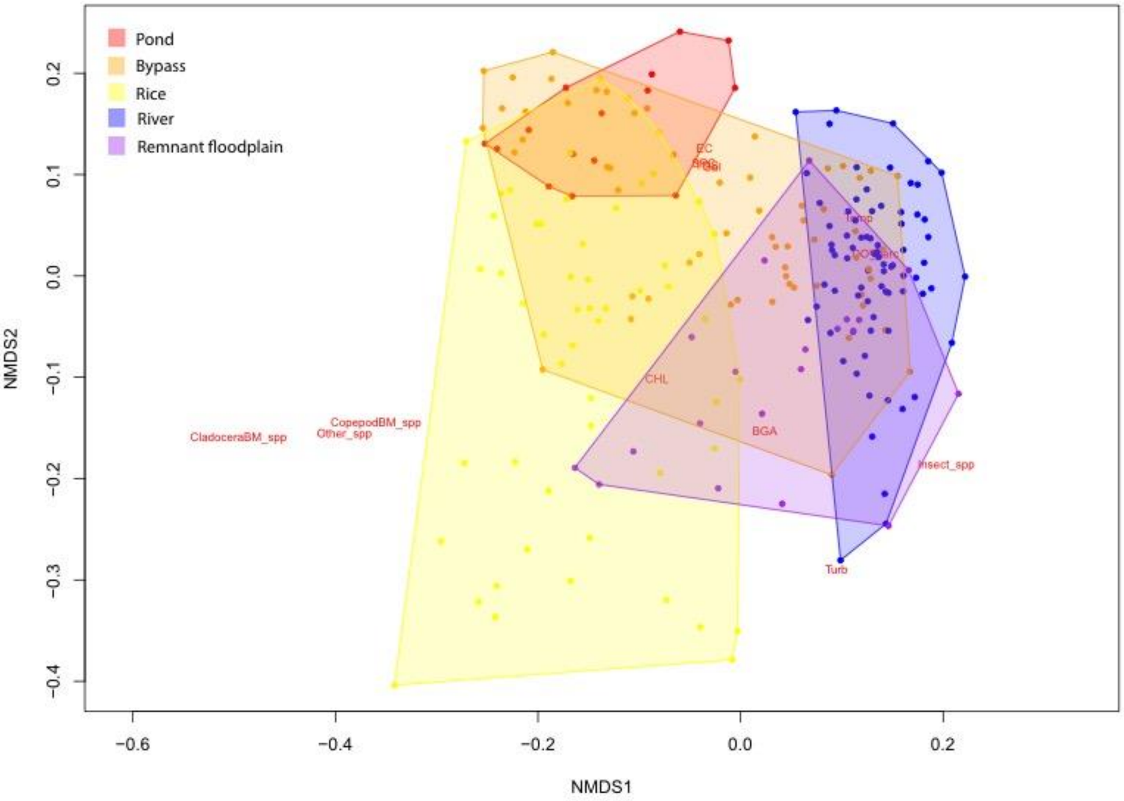


Figure 8. Non-parametric multidimensional scaling (NMDS) ordination plot for all water quality and grouped zooplankton biomass data from November 7, 2016 through May 15, 2017. Water quality parameters included were: chlorophyll-a concentration, turbidity, temperature, electrical conductivity, specific conductivity, total dissolved solids, salinity, blue-green algae concentration, and dissolved oxygen.

Non-parametric multidimensional scaling (NMDS) ordination was used to determine similarity of food web characteristics among all sites within the levee system (river, bypass, and remnant floodplain). Results show relatively tight clustering of river sites and more wide-spread clusters for bypass and remnant floodplain sites (Fig. 8). River sites group mostly to the right of NMDS1 = 0. Bypass and remnant floodplain sites both show points within the river cluster, but also show many non-river cluster points to the left of NMDS1 = 0. The parameter with the most leverage, or influence over the distribution of points in the plot, were biomass of cladocerans, biomass of copepods, and biomass of insects. Biomass of insects influenced the spread of river site clusters, while biomass of copepods influenced the remnant floodplain cluster, and biomass of cladocerans influenced both Yolo and Sutter Bypass clusters.

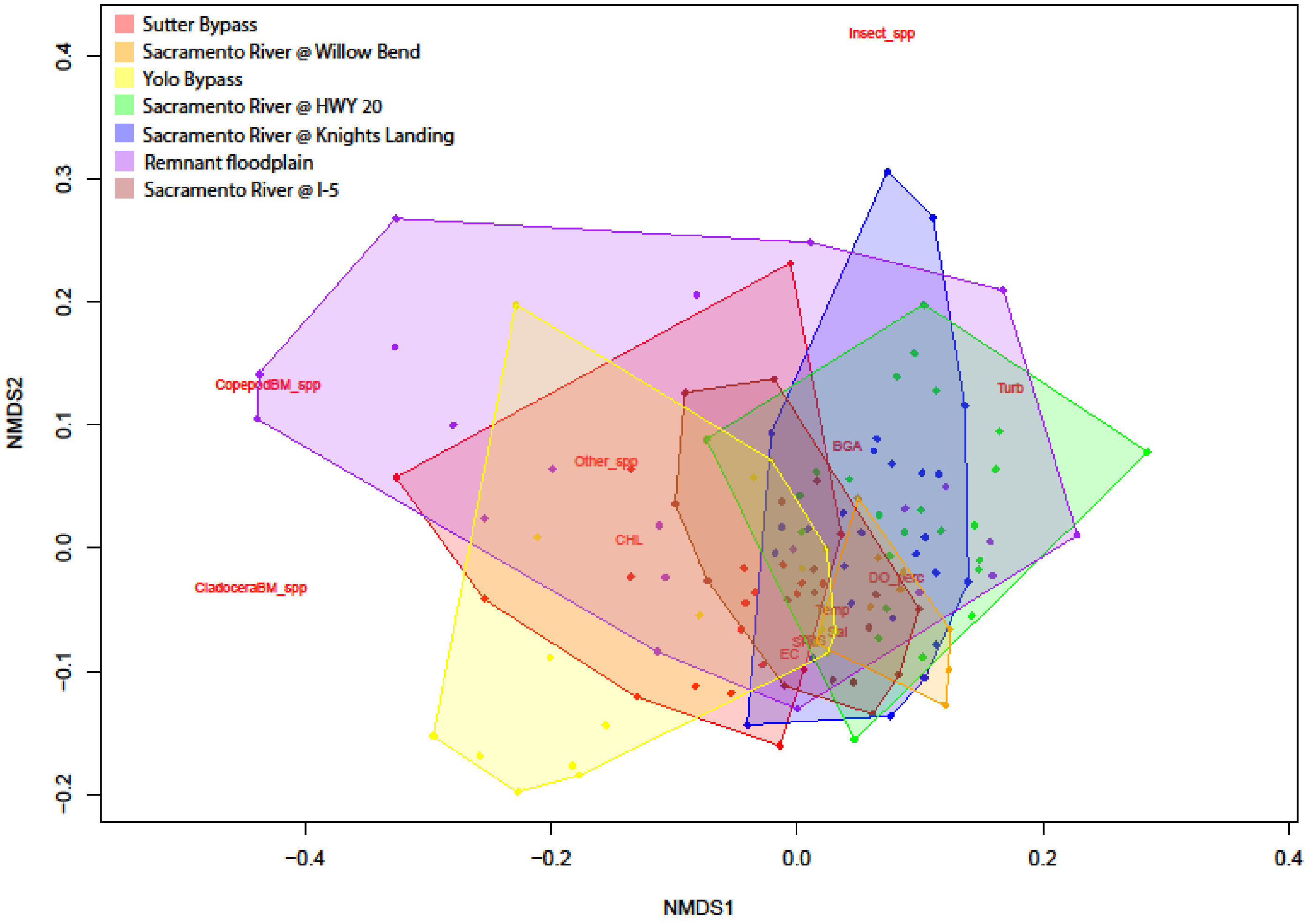


Figure 9: Non-parametric multidimensional scaling (NMDS) plot for all water quality and grouped zooplankton biomass data from November 7, 2016 through May 15, 2017. Water quality parameters included were: chlorophyll-a concentration, turbidity, temperature, electrical conductivity, specific conductivity, total dissolved solids, salinity, blue-green algae concentration, and dissolved oxygen.

Dendrograms expresses degrees of dissimilarity between branches and clusters of data. *I.e.*, lower percent dissimilarity corresponds to branch end-members being more similar to each other. For example, the Sacramento River sites were most similar to each other with dissimilarity values ranging from 0.1 to 0.4, while the other clusters' dissimilarity values ranged from 0.2 to 0.8 (Fig. 7). This example from the month of January 2017 shows a clear separation into four major clusters, two of which were mostly rice field sites, one of which was mostly Sacramento River sites, and the last was mostly bypass sites from both Yolo and Sutter bypasses. The branching pattern of the major clusters indicates that bypass sites are more similar to rice field sites than they were to river sites. The remnant floodplain at Willow Bend and a few bypass sites occasionally group with rice and river clusters. This is likely due to their intermittent connection and disconnection with the Sacramento and Feather Rivers during and after flood events.

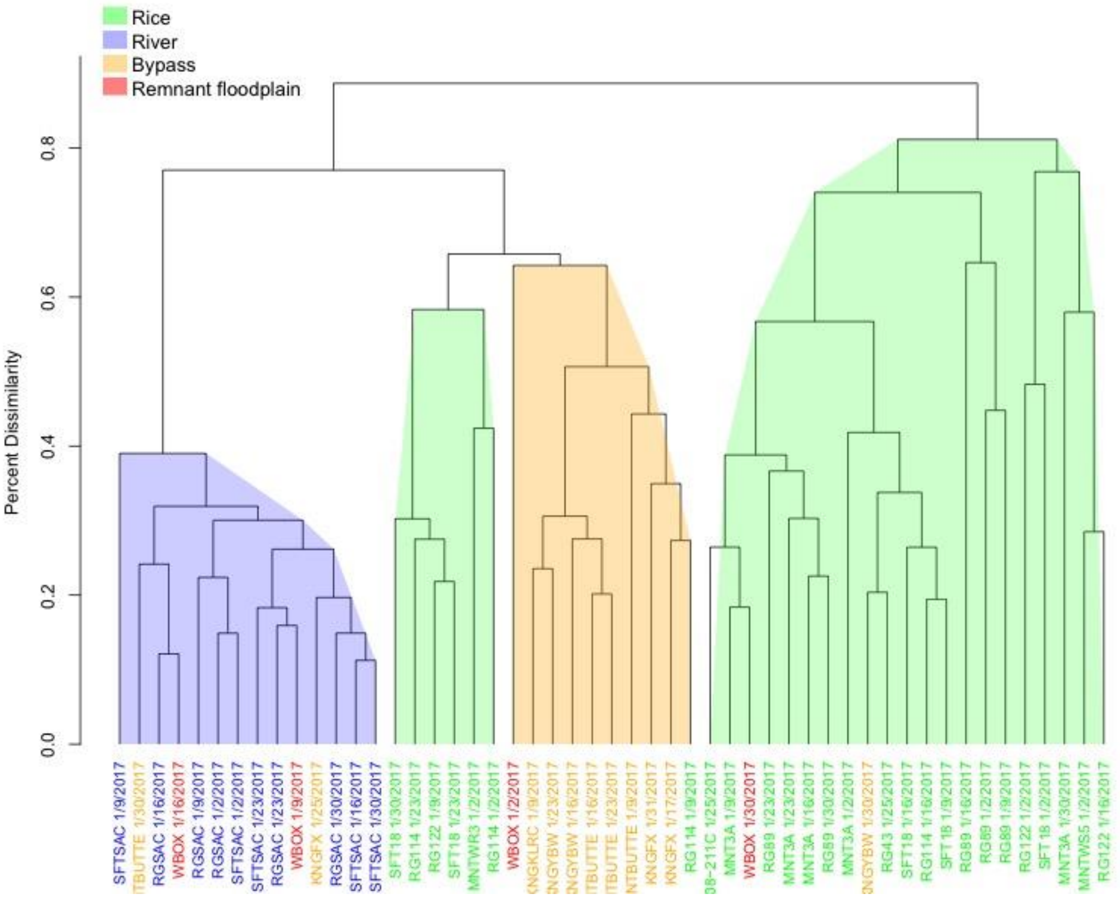


Figure 10: Dendrogram of Bray-Curtis Dissimilarity for zooplankton community abundances at all study sites sampled during the month of January 2017.

Kruskal-Wallis tests were used to assess differences between habitat types, differences between plots at River Garden Farm, and differences between periods of connection and disconnection of the Sacramento River with the Yolo Bypass. There was strong statistical evidence that all physical, chemical, and biological parameters are different between river, bypass, remnant floodplain, and rice field sites (Table 2). Of particular importance to juvenile salmon is the zooplankton biomass. The greatest average zooplankton biomass was observed in rice fields (52,000 µgC/m^3), followed by the remnant floodplain (24,000 µgC/m^3), bypass (19,200 µgC/m^3), and finally the Sacramento River (1,500 µgC/m^3). There was a statistical difference in physical and biological parameters among different rice fields at River Garden Farm. The most important of these differences were observed in potential food sources for zooplankton:

total dissolved solid (TDS) and chlorophyll-a concentrations. However, there was no difference in the observed zooplankton biomass between all five rice fields at River Garden Farm.

During periods of river-bypass connection, there are few statistically significant differences between the habitat types with the exception of chlorophyll-a concentration. However, during periods of river-bypass disconnection, physical, chemical, and biological differences arise rapidly between the habitat types. To illustrate the point, during river-bypass connection there is negligible difference in average zooplankton biomass (4,800 µgC/m^3 in bypass compared to 1,400 µgC/m^3 in river). But after river-bypass disconnection zooplankton density rapidly increases in the floodplain habitats compared to the adjacent river (39,000 µgC/m^3 in bypass compared to 1,200 µgC/m^3 in river).

Table 4: Kruskal-Wallis test results from four different comparison groups: among four habitat types (river, bypass, remnant floodplain, rice field), among five fields at River Garden Farm, between the Sacramento River and Yolo Bypass while connected (i.e., water flowing over Fremont Weir), and the Sacramento River and Yolo Bypass while disconnected (i.e., water not flowing over Fremont Weir). "-" indicates no significant difference, "" indicates significant difference at $p \leq 0.05$, "**" indicates significant difference at $p \leq 0.01$, and "***" indicates significant difference at $p \leq 0.001$. All data were collected from 11/7/2016 to 5/15/2017.*

	Among habitat types			Among River Garden plots			Sac v. Yolo connected			Sac v. Yolo disconnected		
	χ^2	p-value	sig	χ^2	p-value	sig	χ^2	p-value	sig	χ^2	p-value	sig
Temperature	29.63	1.65E-06	***	5.87	0.209	-	3.60	0.058	-	3.01	0.083	-
Dissolved oxygen	64.02	8.11E-14	***	10.37	0.035	*	3.54	0.060	-	0.42	0.515	-
Electrical conductivity	91.02	2.20E-16	***	21.19	0.000	***	3.10	0.078	-	10.59	0.001	**
Turbidity	7.95	4.70E-02	*	10.65	0.031	*	1.74	0.187	-	0.11	0.745	-
Total dissolved solids	99.84	2.20E-16	***	20.51	0.000	***	1.22	0.269	-	10.60	0.001	**
Nitrate	98.19	2.20E-16	***	4.52	0.341	-	0.02	0.895	-	10.67	0.001	**
Ammonium	33.23	2.88E-07	***	3.61	0.462	-	0.57	0.449	-	0.05	0.824	-
Dissolved inorganic nitrogen	74.88	3.84E-16	***	2.18	0.703	-	0.03	0.865	-	10.60	0.001	**
Phosphate	28.47	2.90E-06	***	9.75	0.045	*	0.66	0.417	-	2.16	0.141	-
Dissolved organic carbon	127.97	2.20E-16	***	7.06	0.133	-	1.55	0.214	-	10.60	0.001	**
Pheophytin-a	62.69	1.57E-13	***	11.74	0.019	*	0.30	0.582	-	2.54	0.111	-
Chlorophyll-a	65.33	4.26E-14	***	14.95	0.005	**	14.42	0.000	***	9.24	0.002	**
Blue-green algae	55.87	4.48E-12	***	11.23	0.024	*	1.50	0.221	-	1.42	0.233	-
Zooplankton biomass	126.05	2.20E-16	***	7.52	0.111	-	2.86	0.091	-	10.60	0.001	**

Further evidence of important habitat differences among and between habitat types were observed by long-term deployed temperature and dissolved oxygen loggers. In general, temperature trends in off-channel (non-river) habitats are more variable than temperature trends in the Sacramento River (Figure 11). During the study period, temperature in the Sacramento River ranged from 6.9 to 22.6 ^{0}C, River Garden Farm's rice fields ranged from 1.0 to 23.5 ^{0}C, the remnant floodplain at Willow Bend ranged from 8.7 to 34.1 ^{0}C, and the Yolo Bypass ranged from 10.2 to 27.0 ^{0}C.

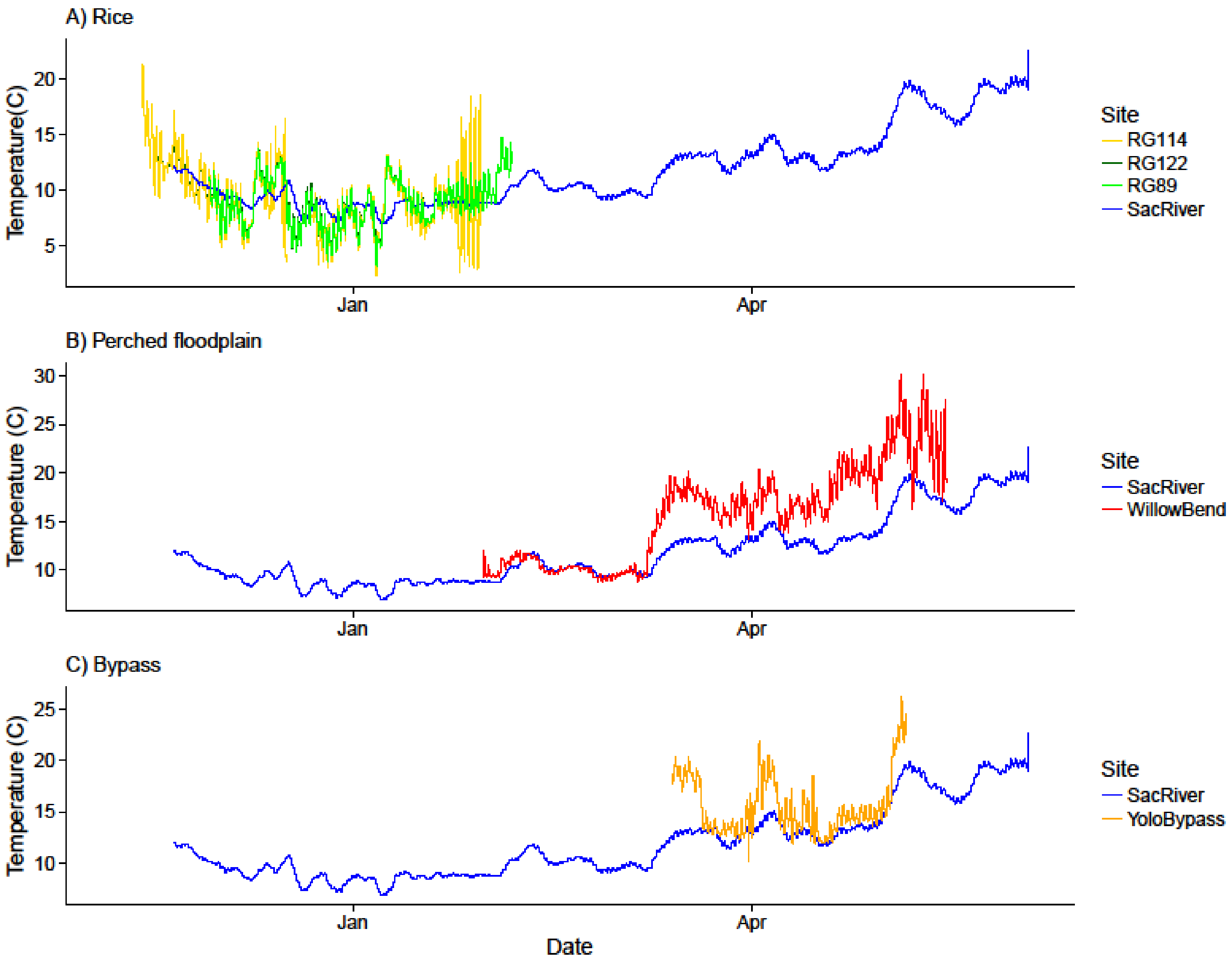


Figure 11: Long-term deployed temperature logger data from (A) three River Garden Farm rice fields, (B) Willow Bend remnant floodplain, and (3) Yolo Bypass compared with the Sacramento River at Knights Landing. All data was collected from 11/7/2016 through 5/15/2017.

Like with temperature, dissolved oxygen trends in off-channel (non-river) habitats were more variable than dissolved oxygen trends in the Sacramento River (Figure 12). During the study period, dissolved oxygen in the Sacramento River ranged from 8.3 to 11.9 mg/L, River Garden Farm's rice fields ranged from 0 to 13.8 mg/L, the remnant floodplain at Willow Bend ranged from 0 to 15.0 mg/L, and the Yolo Bypass ranged from 3.8 to 14.1 mg/L.

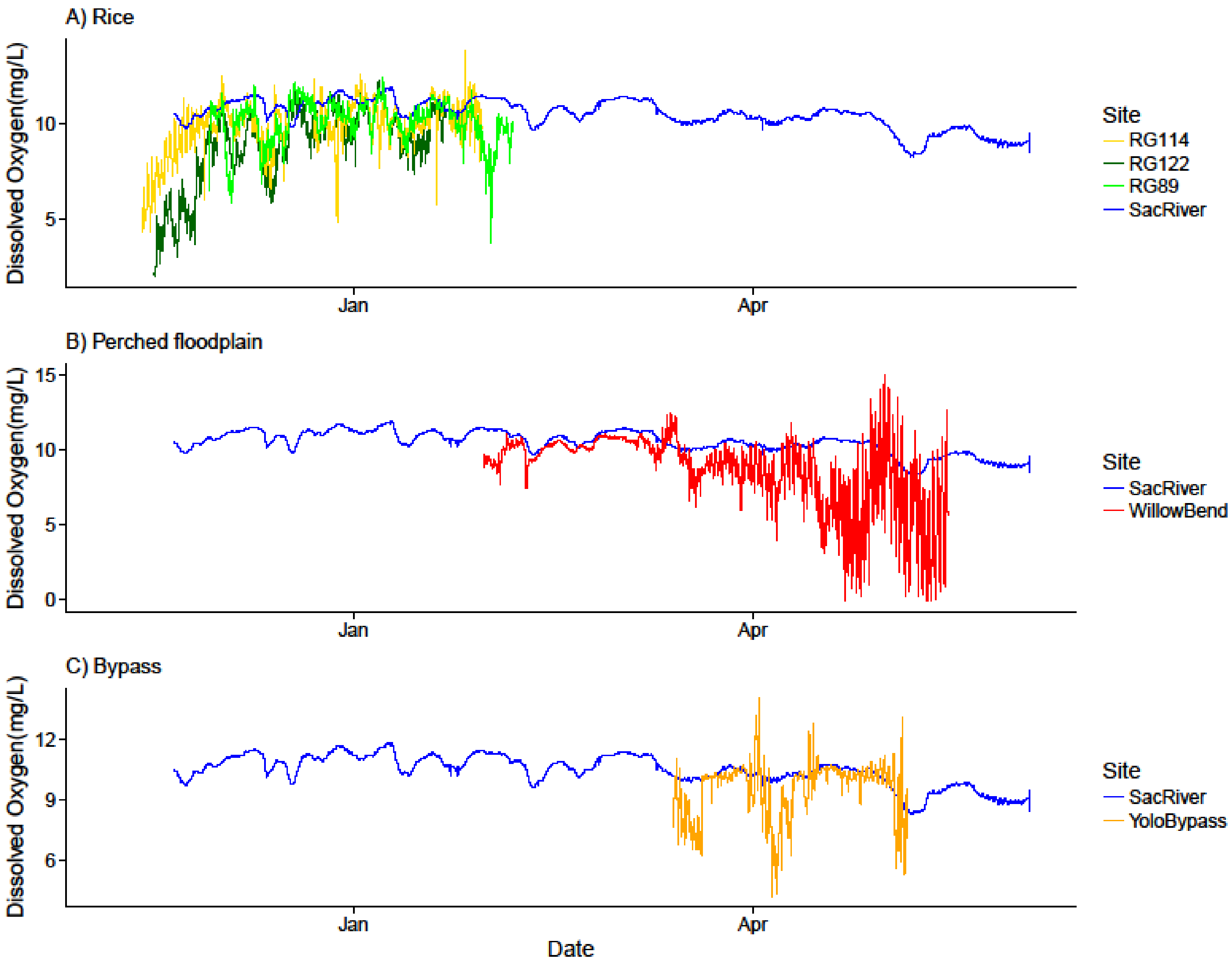


Figure 12: Long-term deployed dissolved oxygen logger data from (A) three River Garden Farm rice fields, (B) Willow Bend remnant floodplain, and (3) Yolo Bypass compared with the Sacramento River at Knights Landing. All data was collected from 11/7/2016 through 5/15/2017.

Although it is understood that zooplankton, particularly in floodplain and flooded rice field habitats use additional food sources in addition to pelagic phytoplankton (Sobczak et al. 2005, Corline et al. 2017), chlorophyll-a concentration is still a widely used metric by which habitat productivity is characterized. In general, all off-channel habitat types had greater average chlorophyll-a concentrations than in-river sites did. Average chlorophyll-a concentration at the Willow Bend remnant floodplain was 8.9 µg/L, followed by the bypasses at 7.2 µg/L, rice fields at 6.2 µg/L, and the Sacramento River at 1.6 µg/L.

DISCUSION

There has been an abundance of literature documenting the increased productivity in off-channel wetland habitats compared to main-stem rivers in the Central Valley of California (Sommer et al. 2001, Ahearn et al. 2006, Grosholz and Gallo 2006, Jeffres et al. 2008, Limm and Marchetti 2009, Opperman et al. 2009, Katz et al. 2017). This productivity is often predicated on high-flow events in the river that spill out onto flood bypasses or remnant floodplains. Another, as of yet relatively unstudied, off-channel habitat is agricultural fields, particularly floodplain rice fields that can be flooded during the non-growing season via existing irrigation infrastructure. When flooded during fall, winter and early spring, these managed agricultural floodplains can mimic natural wetlands and have the potential to generate large amounts of food web biomass (Katz et al. 2017, Corline et al 2017). However, flooded rice fields were variable in both their zooplankton biomass and species assemblage (Fig. 3). For instance, the three adjacent fields at River Garden Farms which (RG89, RG114, and RG122), varied dramatically in zooplankton biomass and assemblage. The reasons for this are unclear and deserve further study. Some variables to consider include source, residence time and flow path of waters, and inundation and cropping history of the fields.

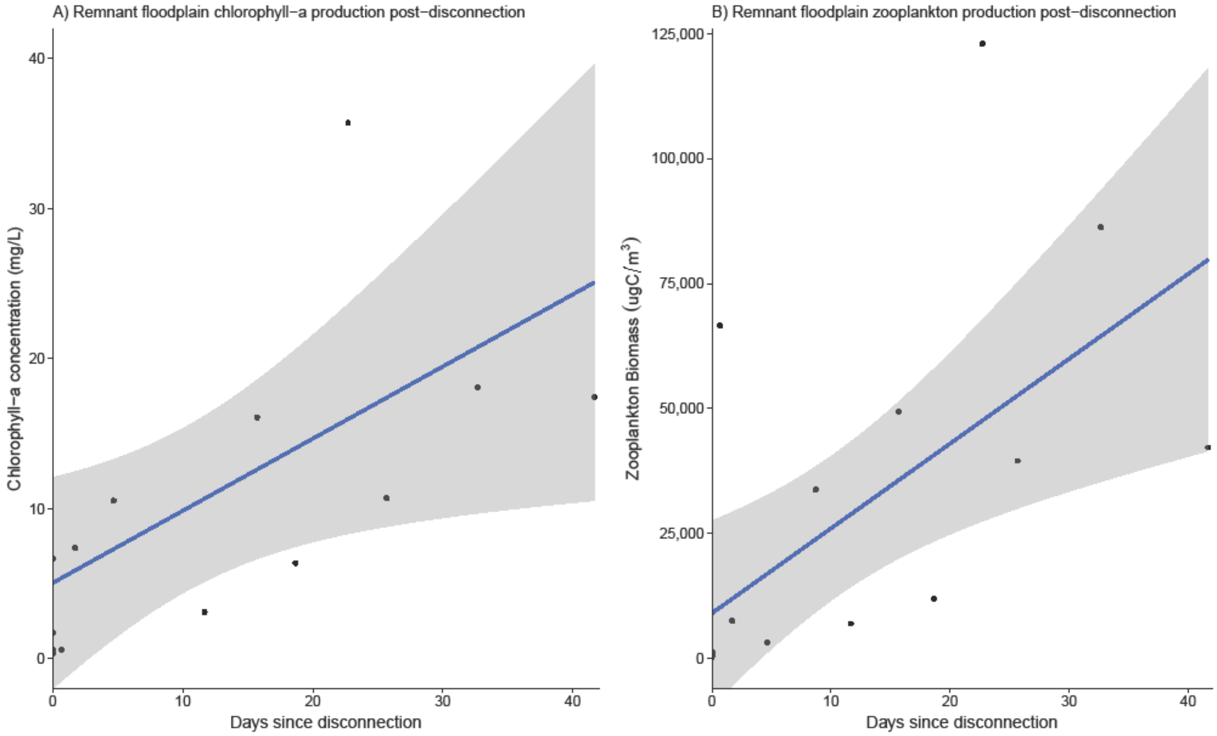


Figure 13: (A) Laboratory-analyzed chlorophyll-a concentration from weekly field sampling on the remnant floodplain at Willow Bend plotted against the time (in days) from last hydrologic disconnection from Sacramento River (B) Zooplankton density plotted against the time in days from last hydrologic disconnection from Sacramento. All data was collected from 11/7/2016 through 5/15/2017.

Under high-flow conditions when rivers flow through bypasses, water quality and zooplankton assemblage and densities appear similar in both habitats. But as water levels drop and bypasses hydrologically disconnect their food webs rapidly change becoming orders of magnitude denser, similar in assemblage and abundance to hydrologically-isolated, off-channel habitats such as rice fields. Habitat type and flow conditions often dictate the species assemblage that utilizes any given habitat. We observed that the rice field, bypass, and river habitats exhibited distinct zooplankton communities (Fig. 10).

The Willow Bend site is a relatively natural remnant floodplain that is regularly inundated at high flows. When Willow Bend was functioning as a flow-through floodplain, its zooplankton community was similar in composition and density to that of the river. But as flows decreased, the zooplankton community on the remnant floodplain became more similar to that of flood bypass sites in both composition and density. When fully disconnected, zooplankton density on the remnant floodplain increased rapidly, taking on food web characteristics similar to those observed in flooded rice field habitats. These observations link food web productivity to hydrologic conditions and highlight the dynamism of floodplain functionality, especially the strong correlation between longer duration of shallow inundation with dramatic increases in aquatic food web productivity (Fig. 13). This analysis quantitatively supports the assertion that bypasses provide far greater food benefit to rearing juvenile salmon when flood waters recede and slow and residence times of waters increase than they do under flood conditions when in-channel river conditions and sparse food webs dominate bypass habitats. These results suggest that increasing the residence time of floodwaters across the floodplain is a major driver of floodplain productivity; a finding that has immediate and important implications for the planning effort currently underway in Yolo Bypass.

CONCLUSIONS

This survey of 33 aquatic habitats of 6 counties in the lower Sacramento Valley found abundant zooplankton and invertebrate production (fish food) in off-channel managed floodplain/wetland habitat types including: rice fields, managed wetland ponds, and flood bypasses. In every habitat type sampled, zooplankton densities were far greater than those found in adjacent river channels. Our results also suggest that increased residence time of waters is strongly linked to robust aquatic food webs. These findings document a substantial floodplain food web resource but it remains unclear how this “standing stock” of invertebrate fish food can be exported to the river.

We suggest that this study expand in 2018 to investigate four key areas pertaining to reintegration of floodplain food resources: (1) how do zooplankton assemblages respond to draining and re-flooding cycles on surrogate floodplain agricultural fields, (2) what are the export dynamics of zooplankton assemblages during surrogate floodplain agricultural field drainage, (3) how do zooplankton assemblages fare as they move through drainage canal systems in various irrigation/reclamation districts across the Sacramento Valley, and (4) are there observable, localized effects from augmenting the Sacramento River and bypasses with drain water rich in floodplain derived forage and nutrients?

We believe that the Fish Food on Floodplain Farm Fields project has yielded and will continue to yield critical information about and insight into management solutions for improving integration of working agricultural landscapes into California's water and ecosystem management for the betterment of fish and people.

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