The Experimental Agricultural Floodplain Habitat Investigation at Knaggs Ranch on Yolo Bypass
2012-2013

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Knaggs Ranch on Yolo Bypass: a win, win, win for salmon, waterfowl and agriculture. Photo: J. Katz

A cooperative project of

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Report prepared by: Jacob Katz[1], Carson Jeffres[2], Louise Conrad[4], Ted Sommer[4], Nick Corline[2], Joshua Martinez[4], Steve Brumbaugh[4], Lynn Takata[4], Naoaki Ikemiyagi[4], Joe Kiernan[5] and Peter Moyle[2,3]

[1]California Trout, Central California Region, 930 Shiloh Rd, Bldg. 40, Suite 6
Windsor, CA 95492
[2]UC Davis Center for Watershed Sciences,
[3]Department of Wildlife, Fish, and Conservation Biology,
University of California, 1 Shields Avenue, Davis, CA 95616, USA
[4]Department of Water Resources, Aquatic Ecology Section, Division of Environmental Services, 3500 Industrial Blvd. West Sacramento, CA 95691
[5]NOAA Fisheries, Southwest Fisheries Science Center, Fisheries Ecology Division, 110 Shaffer Road, Santa Cruz, CA 95060

EXECUTIVE SUMMARY

At 24,000 ha, the Yolo Bypass is the Central Valley's largest contiguous floodplain and provides critical fish and wildlife habitat (Sommer et al. 2001a). Flooding occurs in two out of three years on average, typically between the months of December and April. As a result, the Yolo Bypass represents one of the most frequent large-scale connections of river and floodplain left in the Central Valley. Located approximately 8 km west of the city of Sacramento, the Yolo Bypass is seasonally inundated when the Sacramento River over tops Fremont Weir, routing high flows away from the Sacramento metropolitan area, thereby relieving pressure on urban levees during flood events. The Yolo Bypass is covered by floodway easements held by the state of California making all other land uses subservient to flood control. A major land use in the Yolo Bypass is agriculture, with rice the primary crop.

To better understand how management of rice fields may affect water quality, invertebrate assemblages and abundance, juvenile salmon growth, survival, and behavior, three concurrent studies were conducted in the northern portion of the Yolo Bypass on the Knaggs Ranch (Figure 1). The specific study elements were 1) food web and salmon responses to agricultural management; 2) behavior of salmon in different agricultural habitat types; 3) a pilot study evaluating the feasibility of extending inundation duration after natural flood events to prolong salmon rearing in floodplain habitats.

Food Web and Salmon Responses to Agricultural Management: Nine 0.79-ha replicated experimental rice fields were built with a common layout and water source and randomly assigned to one of three habitat treatments; rice stubble, stomped, or fallow (Figure 3). Fields were stocked with approximately 4,500 juvenile fall run Chinook from Feather River Hatchery on February 11, 2013. Invertebrate, water quality and fish sampling was conducted for approximately 6 weeks after which fields were drained and fish counted and released.

Results demonstrated that experimental inundation of Yolo Bypass rice fields during winter can create productive aquatic food webs. High densities of zooplankton were observed across all substrate treatments providing a robust food resource exploited by juvenile Chinook salmon. Growth of juvenile Chinook averaged 0.93mm per day for the six-week experiment, with growth

of 1.5mm per day observed during specific two-week intervals. Fish condition was also excellent, with an average Fulton's condition factor of 1.19 at the end of the study. These are the fastest growth rates and highest condition factors ever documented in freshwater in California.

Overall survival was variable between fields and experiments. Free-swimming survival ranged within fields from 0% to 29.3% while fish in the enclosures survived at a much higher rate ranging from 35% to 98%. In addition 50 fish were PIT tagged and released to swim freely in one of the replicate fields concurrent with the tagging of the enclosure fish. Of these PIT tagged fish, 44% (22 of 50) survived until draining of the field. These variable survival estimates highlight the diverse conditions that the fish experienced across experiments. Perhaps the major issue in the 2013 study was that the project was started later than hoped because of delays in the availability of hatchery and wild fish, resulting in substantial differences in water quality and exposure to avian predation as compared to 2012.

We therefore conclude that winter inundation of rice fields creates high-quality growth opportunities for juvenile Chinook salmon. Although this study suggests that agricultural landscapes can function as rearing habitat for juvenile Chinook salmon, our results should not be interpreted to suggest that suitable natural (i.e. non-agricultural) habitats are not essential to establishing self-sustaining runs of naturally produced Central Valley Chinook. Rather, the study demonstrates the potential to reconcile management of agricultural landscapes with the management of Chinook salmon populations through use of existing agricultural infrastructure. Managed inundation of rice fields in winter and early spring appears to mimic historical floodplain processes, re-exposing salmon to an approximated version of the hydrologic selection regime under which they evolved and to which they are adapted.

Behavior Of Salmon In Different Agricultural Habitat Types: In order to better understand how juvenile salmon will distribute themselves across a variable landscape; whether they exhibit any preference for specific habitat types, and whether their performance across habitat types varies, the habitat preference pilot component of the study compared habitat use by fish given free access to the three agricultural substrates used in the larger, 2-acre single habitat type experimental fields. This information will inform design of restoration efforts in the Yolo Bypass. A second goal of the study was to compare the efficacy 8mm and 12mm passive integrated transponder (PIT) tags under floodplain conditions.

Two circular mesh enclosures were built in a 0.3-acre field. One enclosure contained the three agricultural treatments explained above, the other was a control containing only the stomped (bare dirt) treatment. PIT-tagged fish were stocked into the enclosures and their locations tracked via an array of PIT tag antennae.

Juvenile Chinook salmon exhibited no strong signal of preference among fallow, rice stubble, and stomped agricultural substrates. In contrast, detection probability was heavily concentrated toward upstream areas both in the presence and absence of substrate variation. While further studies will be necessary to assess habitat preference in natural floodplain environments, results from this study indicate that post-harvest treatment of rice fields may not influence the likelihood of juvenile salmon occupancy, although there may be land treatment effects on other aspects of habitat (chapter 1 of this report). This result suggests in potential management scenarios utilizing rice fields as managed floodplains during the non-growing season, that farm managers may have some flexibility in post-harvest land treatment.

Floodplain Extension Pilot Study: This pilot was designed to evaluate the feasibility using local agricultural infrastructure and water sources to extend inundation duration after natural flood events to prolong salmon rearing in floodplain habitats. The study occurred in January and February of 2013, following a short high flow event that started in late December 2012. Fremont Weir began to spill late on Christmas Eve, 2012. Overflow ceased five days later on Dec. 29, 2012. Field 8 rice boards topped by grated screens were put in place in expectation of flooding. Boards held water elevation in the field as the floodwaters receded allowing fish to utilize shallowly inundated habitat that would have otherwise rapidly drained. Fish were allowed to rear on the fields after floodwaters receded through the end of January, when the flashboards were pulled accelerating draining. Because of its large volume Field 8 did not fully drain until February 14th.

Few salmon were caught through the course of the flood extension pilot study, likely due to some combination of the following four scenarios: 1) sampling for the salmon was inefficient, 2) fish were widely dispersed and we were unable to adequately concentrate fish into our study cell, 3) fish escaped during the short period where a screen was lacking in one of the drains, or during overtopping of the surrounding levees, or 4) relatively few wild juvenile salmon entered Yolo Bypass during this early season flood event. The latter three scenarios are more likely than the first, since the methodologies employed for sampling have been used extensively in the past in the Yolo Bypass system. Our hope is that conducting a more intensive effort in a future year with later (more normal) Fremont Weir overtopping will generate higher densities of salmon migrants in Yolo Bypass. Despite the small number of fish captured, the study provides limited evidence that flood extension may provide juvenile salmon with growth benefits similar to prolonged historical natural flooding events.

INTRODUCTION

Characterized by high biodiversity and productivity, floodplains are ecologically important components of riverine ecosystems that provide vital habitat and resources for both aquatic and terrestrial animals (Junk et al. 1989, Tockner and Stanford 2002). As flood waters leave main river channels to flow over adjacent floodplains, they slow, spread out, and warm (Ahearn et al. 2006). This combination of factors allows for high levels of primary and secondary production and can create 10-100 times greater zooplankton and insect biomass on floodplains than adjacent river channels (Junk et al. 1989, Bayley 1995, Sommer et al. 2001b, Schemel et al. 2004, Ahearn et al. 2006, Grosholz and Gallo 2006). Abundant food resources and shallow, low velocity water conditions found on inundated floodplains represent especially high quality foraging habitats for larval and juvenile fish which feed heavily on the invertebrates that colonize floodwaters (Sommer et al. 2001a, Jeffres et al. 2008, Limm and Marchetti 2009). Elevated invertebrate abundance on floodplains compared to adjacent river channels increases food availability which likely increases fish foraging success (Humphries et al. 1999, Sommer et al. 2001b, Jack and Thorp 2002, Sommer et al. 2004, Limm and Marchetti 2009, Górski et al. 2013). Floodplains may provide additional bioenergetic advantage in the lower water velocities found on floodplains compared to river channels; calories not expended fighting river current is energy that can be allocated towards somatic growth (Fausch 1984, Henery et al. 2010).

Many fish species have evolved life history strategies such as seasonal spawning and rearing migrations adapted to exploit the high quality habitat created by predictable seasonal flood-pulses (Junk et al. 1989, Bayley 1995, Humphries et al. 1999). In the Sacramento River of California's Central Valley a suite of migratory native fishes have evolved spawning and/or foraging migrations timed to coincide with floodplain inundation (Sommer et al. 2001a). For instance, adult splittail (*Pogonichthys macrolepidotus*) migrate upstream during floods from estuarine locations to spawn over inundated floodplain vegetation. Young splittial utilize the floodplain habitat prior to emigrating to over-summering habitat downstream (Feyrer et al. 2006). In contrast Chinook salmon (*Oncorhynchus tshawytscha*) spawn upstream prior to seasonal flooding, positioning juveniles in space and time to be swept onto floodplains during flood-pulses (Moyle et al. 2007).

Within the Central Valley, habitats inundated by adjacent river channels on the Yolo Bypass and the Cosumnes River have been shown to provide high quality rearing habitat resulting in rapid growth for juvenile Chinook salmon during natural flood events (Sommer et al. 2001a, Sommer et al. 2005, Jeffres et al. 2008). However, more than 95% of historic Central Valley floodplain wetlands have been destroyed, primarily diked and drained for conversion to agriculture (Hanak 2011, Whipple 2012). Today, the Central Valley is a patchwork of agricultural lands and communities separated from rivers by high, steep levees which have fundamentally altered riverine topography, natural flow regimes and severed hydrologic, sediment, nutrient and fish connectivity between Central Valley river channels and adjacent floodplain wetlands (Mount 1995). Most former floodplain wetlands are now only inundated during major floods when levees either fail or when high water spills into managed floodways. As a consequence, juvenile salmon are seldom able to access ancestral floodplain rearing habitats where they historically grew large and robust before migrating to sea (Sommer et al. 2001b). Access to floodplain habitats and the associated high growth rates achieved during even very limited floodplain occupancy may be critical in improving return rates for Central Valley salmon populations. For many species of anadromous salmonids (e.g., Atlantic salmon, steelhead, Chinook salmon) size at ocean entry is an important, if not the primary, indicator of an individual fish's probability of returning as an adult to spawn (Unwin 1997, Hayes et al. 2008, Satterthwaite et al. 2012). Presumably, most fall run juvenile Chinook salmon in the pre-development Central Valley reared for 1-3 months on winter floodplains, growing rapidly in the process (Sommer et al. 2001b) and entered the ocean in spring coincident with seasonal increase in food production in the marine environment (Lindley et al. 2009). In addition to increased growth, use of floodplain habitats diversify juvenile salmon habitat usage, allowing expression of a broader portfolio of life history strategies which in turn may increase the resiliency of the overall population to environmental variation (Carlson and Satterthwaite 2011).

Inundation of agricultural lands during the non-growing winter season has been demonstrated to allow Central Valley rice fields to function as ecological surrogates for lost natural wetland habitat for many species of waterbirds (Elphick 2000). Can rice fields inundated during winter provide similar ecological surrogacy for Chinook salmon floodplain rearing habitat? Pilot efforts in the Yolo Bypass suggest that managed inundation on rice fields may provide valuable nursery habitat, as juvenile Chinook reared in purposely flooded rice fields during the winter of 2012 exhibited rapid growth and 60% survival rates (Katz et al. 2012). However, post-harvest rice fields can be treated differently depending on farming practices, crop rotation, and wildlife management. Understanding how different agricultural practices affect juvenile salmon rearing on fields inundated during the non-growing season is therefore critical to management of flood-prone agricultural lands if they are to be managed to provide increased benefit to native fishes.

To understand how rice field management may affect water quality, invertebrate abundance and assemblages, juvenile salmon growth, survival, and behavior, we conducted three concurrent studies in the northern portion of the Yolo Bypass on the Knaggs Ranch (Figure 1). The specific study elements are treated in Chapters: 1) food web and salmon responses to different agricultural management treatments; 2) behavior of salmon in different agricultural habitat types; 3) extension of natural flood events to provide salmon rearing habitat. As will be described below, within each of the study elements there are multiple study questions and approaches.

CHAPTER 1: Salmon and Food Web Responses to Agricultural Treatments

Study Location - Yolo Bypass: At 24,000 ha, the Yolo Bypass is the Central Valley's largest contiguous floodplain and provides critical fish and wildlife habitat (Sommer et al. 2001a). Flooding occurs in two out of three years on average, typically between the months of December and April. As a result, the Yolo Bypass represents one of the most frequent large-scale connections of river and floodplain left in the Central Valley. Inundation duration is variable depending on water year type and specific storm event and ranges from 1-68 continuous days. The seasonal wetlands of the Yolo Bypass are a critical component of the Pacific Flyway, a migration pathway used by 20% of North America's waterfowl (Garone 2011). The flooded bypass also supports 15 native fish species, providing important rearing habitat for juvenile Chinook salmon (Sommer et al. 2001b).

Located approximately 8 km west of the city of Sacramento, the Yolo Bypass occupies a portion of the historical Yolo flood basin (Figure 1). The current configuration is a partially-leveed basin that is seasonally inundated by local tributaries and when the Sacramento River over tops simple weirs routing high flows away from the Sacramento metropolitan area, thereby relieving pressure on urban levees during flood events. The Yolo Bypass is covered by floodway easements held by the state of California making all other land uses subservient to flood control. A major land use in the Yolo Bypass is agriculture, with rice the primary crop. Additionally, wild rice, tomatoes, corn, safflower and melons are grown and substantial areas are managed as irrigated pasture or kept fallow. Extensive areas within the bypass are also managed for waterfowl habitat and hunting.

The study was located on the Knaggs Ranch (Figure 2), an agricultural parcel in the northern Bypass with a total acreage of 670 ha. A drainage canal called the Knights Landing Ridge Cut enters the Knaggs property at its northwest corner. This canal was built early in the 20th century to allow accumulated floodwaters in the Colusa Basin to flow into the Yolo Bypass and prevent local flooding during heavy drainage periods, and it is today the primary source of local irrigation water. Currently 636 ha of the ranch are farmed to rice and irrigated with water from the Knights Landing Ridge Cut, supplemented with groundwater from on-site wells.

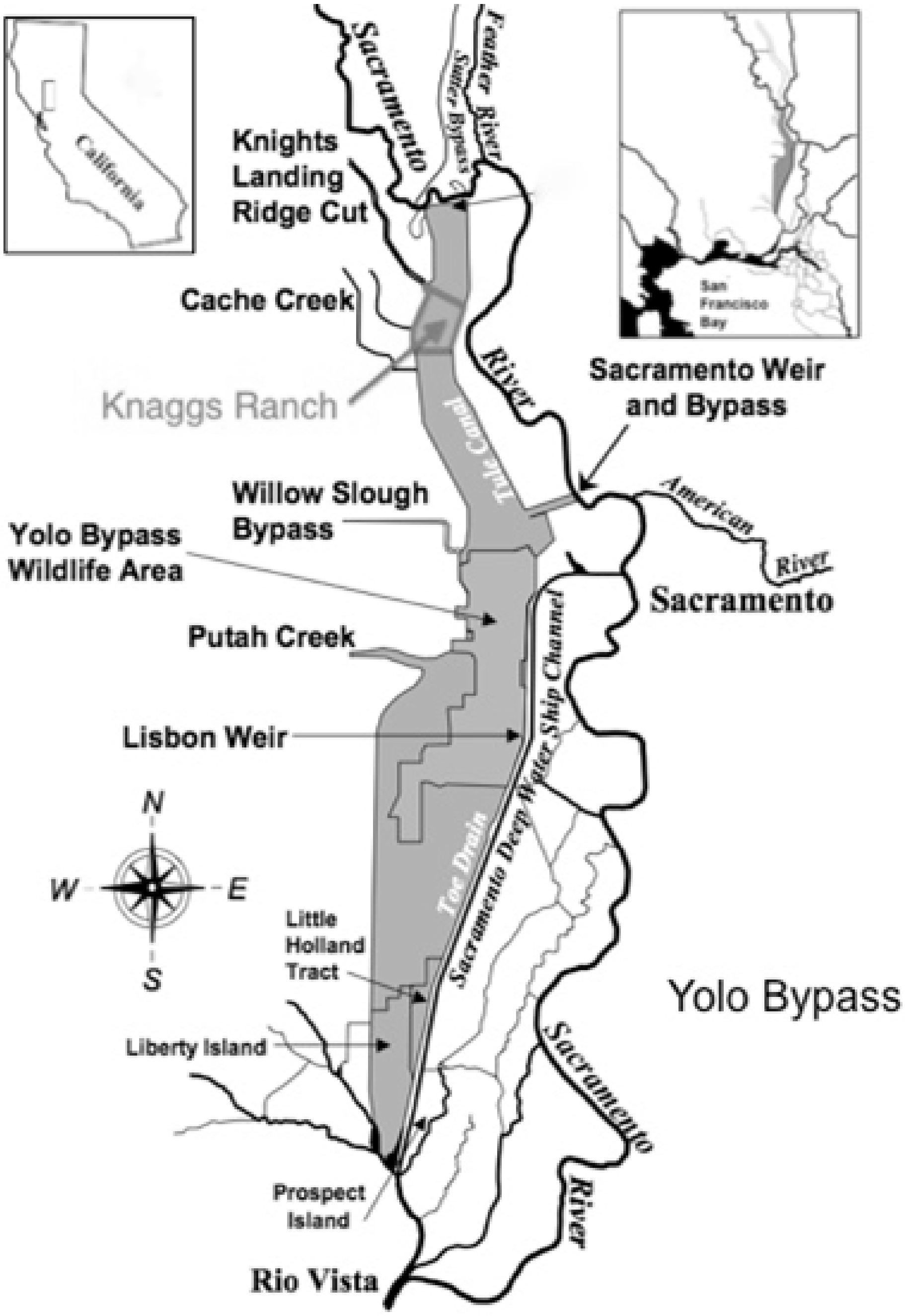

Figure 1. Location of Yolo Bypass and important landmarks including Knaggs Ranch.

Reporting Status: Despite hiring of additional staff, the immense volume of field samples collected prohibited all zooplankton samples collected from being sorted, identified and enumerated before the reporting deadline. It was therefore decided to sort, identify and enumerate a representative subsample (a full time series for a single field of each treatment type) in order to report preliminary findings. One third of a time series from three additional fields (one of each substrate type) were also analyzed and compared to the fully analyzed time series as an informal means of checking for anomalies in the fields. Abundance and temporal zooplankton patterns were broadly similar between sub-sampled and fully analyzed fields of the same substrate type giving us confidence in the preliminary results reported here. Laboratory analysis of Chlorophyll-a is ongoing. We are also waiting for receiver data from NMFS for the J-sat acoustic tagging experiment designed to track out-migration success of fall-run Chinook salmon reared at Knaggs.

When complete statistical analyses are available, the results will be communicated to BoR in an updated report. This complete data set will also be the foundation of scientific manuscripts to be written and submitted to appropriate peer-reviewed journals. Laboratory analysis of the full suite of data from all experiments is expected to be complete by December 1, 2013 and manuscripts readied for submission by March 1, 2014.

Hypotheses: Seven null hypotheses were tested to explore the effects of rice field substrate on water quality, aquatic food web productivity and the quality of Chinook salmon rearing habitat.

Hypothesis one: No difference in water quality (temperature, dissolved oxygen concentration, pH, conductivity and turbidity) across treatment types.
Hypothesis two: No difference in abundance of invertebrates across treatment types.
Hypothesis three: No difference in diversity of invertebrates across treatment types.
Hypothesis four: No difference in growth of juvenile Chinook salmon across substrate habitat treatment types.
Hypothesis five: No difference in survival of juvenile Chinook salmon across substrate habitat treatment types.
Hypothesis six: No difference in growth of juvenile Chinook salmon of in-river or hatchery origin.
Hypothesis seven: No difference in survival of juvenile Chinook salmon of in-river or hatchery origin.

METHODS

In order to test the above hypotheses, water quality, zooplankton and invertebrate abundance and diversity as well as salmon survival and growth rates were assessed approximately bi-weekly in each field for the 6-week duration of the study. To examine fish responses, two general approaches were used: 1) free-swimming fish; and 2) fish kept in enclosures throughout the study.

Replicated Field Treatment Study Design: Nine 0.79-ha replicated experimental fields were built on the Knaggs Ranch in Yolo Bypass (Figure 2). All fields shared a common layout and water source (Figure 3). Water was fed from a supply canal through a 60 cm diameter “rice box” - a plastic culvert equipped with a face-mounted slot into which 2x6 inch flashboards were placed – at the field’s Northwest corner. Fields were drained through a similar rice box at the southeast corner. The number of boards placed in the slot on the face of the rice box controlled flow at the inlet and field water elevation at the outlet. Both inlet and outlet rice boxes were screened with 3 mm plastic mesh in order to pass water but retain fish in the fields. Water elevations within the fields varied from 0.3 to 0.5m depending on wind and flow conditions. Flow rates into the fields ranged from 0.0 to 2.3 cfs (0.0 to 0.06 cms).

The nine fields were randomly assigned to one of three habitat treatments; rice stubble, stomped, or fallow (Figure 3). The rice stubble habitat treatment consisted of the standing stalks that remained after harvest. Stubble height ranged from 0.23-0.35m but was uneven due to irregular harvest of rice. The stomped habitat type was created by discing the field and then using a Caterpillar D-3 track-type bulldozer to further compact rice straw to promote decomposition. The fallow habitat type was not planted to rice during the previous growing season but instead consisted of "weedy" plants that grew naturally. Stem density was highest in stubble fields and lowest in stomped fields. Stem diameter was similar between fallow and rice stubbles fields. Fallow fields had taller grasses that lodged over during the course of the study.

Table 1. Stem density, diameter and height across substrate treatments

	Stem Density (#/m^2)	**Stem Diameter (mm)**	**Stem Height (m)**
Fallow	35	3.5	0.51
Stomped	0.5	-	-
Stubble	60	4	0.23-0.35

Water Quality: Onset HOBO Temperature Pro loggers (Bourne, MA) were deployed in the middle of the water column on the north side of the southernmost cage in each field and at the inlet and outlet of fields 1 (stubble), 6 (stomped), and 9 (fallow) (Figure 3). The loggers recorded the water temperature every15 minutes. Discrete water quality data were collected weekly using a handheld YSI 6600 data sonde, equipped with probes for temperature, dissolved oxygen, pH and electrical conductivity. Weekly water samples were collected at the inlet and in center of each field. Samples were analyzed by UC Davis for turbidity, total nitrogen, nitrate, ammonia, total phosphorus, and orthophosphate.

Invertebrates: *Field collection* - To assess invertebrate diversity and abundance across different substrate types, two sampling protocols were used; zooplankton net tows and benthic sweeps. A 30cm diameter, 153 µm zooplankton net attached to five meters of rope was thrown the full five meter distance and retrieved four times. Benthic sweeps were conducted with a 500 µm D-frame net and a 0.56-meter diameter barrel with the bottom removed. The barrel was placed flat on the benthos, and bottom substrate was swept continuously for one minute. Zooplankton was sampled once per substrate plot, while benthic collections were performed on three separate substrates per sampling period. Sampling locations were determined randomly within substrate test plots via selection of random x and y distances from a random number table. Zooplankton collection was performed at initial flooding and was sampled every week thereafter, while benthic samples were taken in two-week intervals. All samples were preserved in a solution of 95% EtOH.

Subsampling: Due to the density of invertebrates within the samples, sub-sampling was used. Samples were rinsed through a 150-µm mesh and then emptied into a beaker. The beaker was filled to the desired volume, depending on the number of individuals within the sample, and then sub-sampled with a 1 mL large bore pipette. If densities were still too great for enumeration the sample was split using a Folsom zooplankton splitter. The volume and number of aliquots removed was recorded and used to obtain total estimates of invertebrates. Zooplankton samples were sorted until greater than 300 *D. pulex* were counted. Benthic samples were sorted in fractions to until 300 invertebrates were counted.

Sorting/Identification: Invertebrates were enumerated and identified with the aid of a dissecting microscope at 4 times magnification. Invertebrates were identified to the lowest taxonomic level possible using keys from *Ecology and Classification of North American Freshwater Invertebrates (3rd edition)*(Thorp and Covich 2009), *Recent Ostracoda of the World* (Karanovic 2012), and *An Introduction to the Aquatic Insects of North America (4th edition)* (Merritt and Cummins 1996). Copepods were only identified to family. Terrestrial invertebrates were rare and not included in final counts.

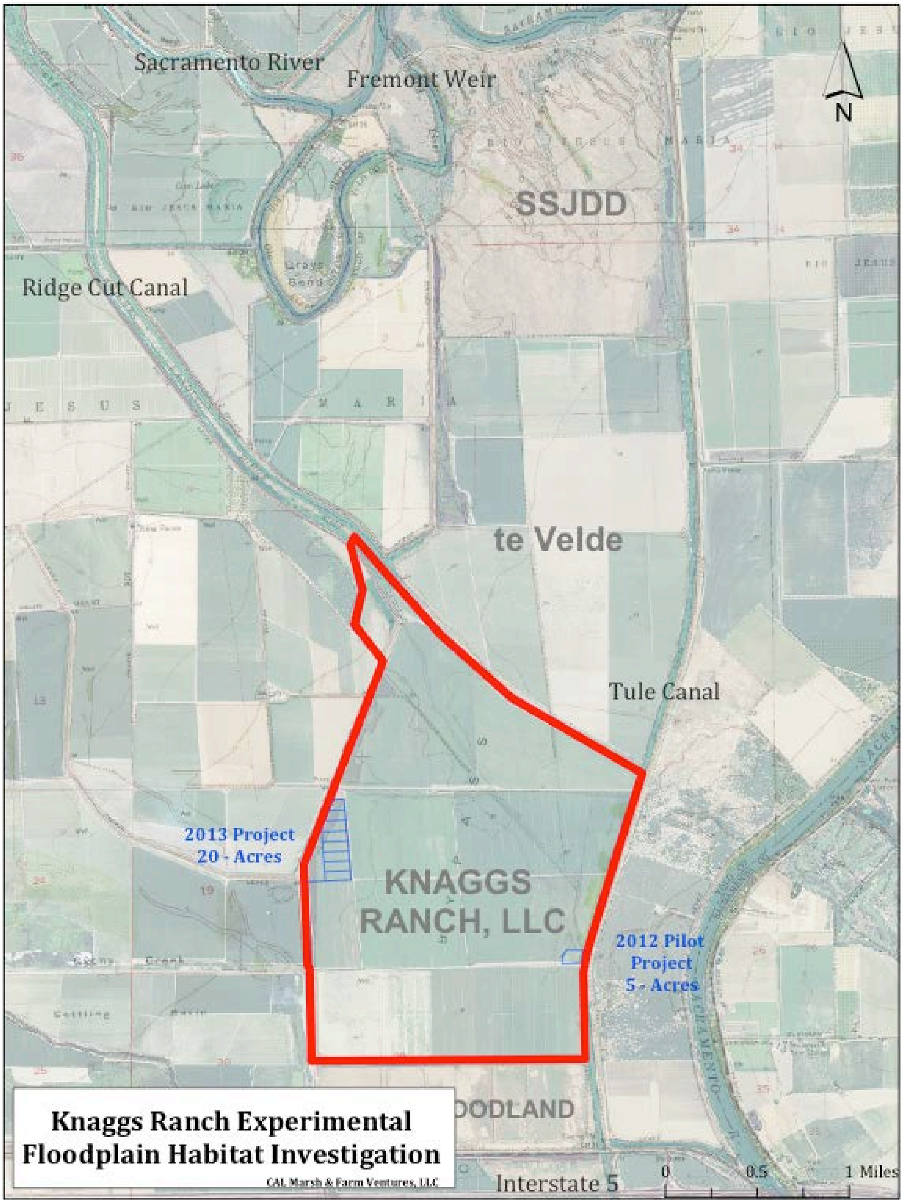

Figure 2. Location of 2013 replicated fields on Knaggs Ranch.

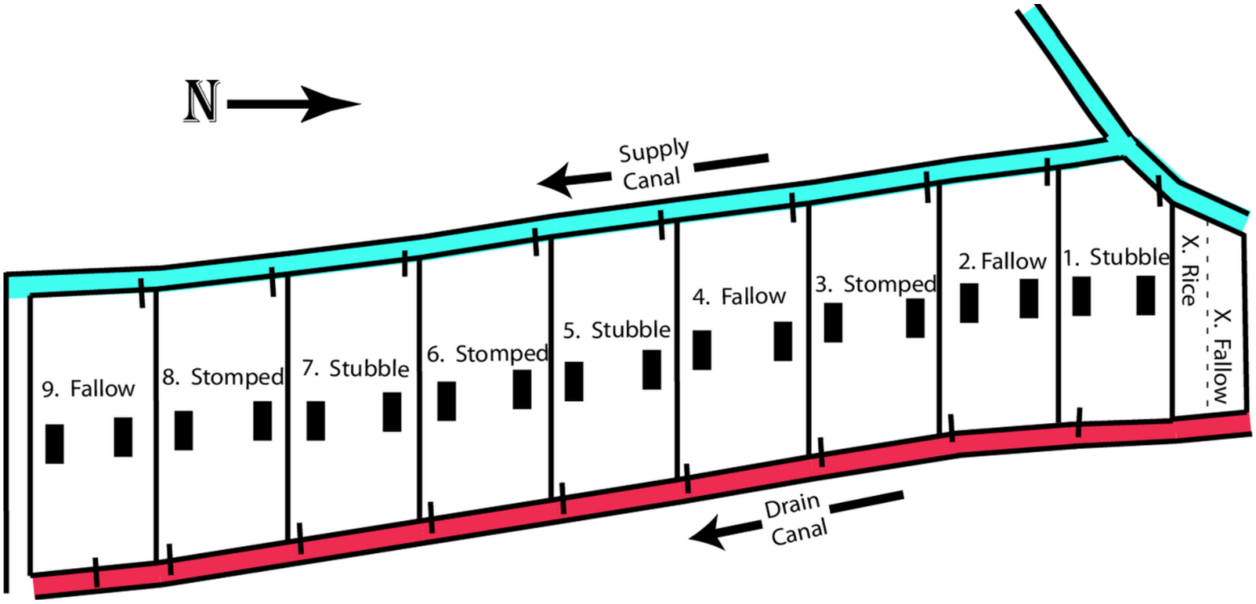

Figure 3. Schematic of replicated fields on Knaggs Ranch with field number, habitat type, and enclosure locations (black boxes).

Source of Fish Stocked into Replicated Fields: On February 19, 2013, approximately 45,000 fish were delivered by tanker truck from the Feather River Hatchery and enumerated by weight (648 fish/kg). An average of 4,614 fish were placed into each of the nine experimental fields.

Growth and Survival of Free-swimming Fish in Replicated Fields: Seventy fish were weighed and fork length measured to obtain a baseline measurement of the group. Approximately every seven days thereafter each field was sampled using a 3x10m, 3mm mesh beach seine. The first 30 fish (or as many as could be collected) were weighed and measured. Ten fish were euthanized from each field and immediately frozen for later gut content analysis. All remaining fish were released back into the field from which they were collected. The replicate fields were drained after 37-41 days. As the water drained, fish were captured in mesh holding pens attached to exit pipes. Before being counted and released into the exit ditch, 30 fish from each field were weighed and measured and ten were euthanized and immediately frozen for later gut content analysis. The exit ditch flowed approximately 2.25 km east before connecting to the Tule Canal. Tule Canal flows south approximately 40 km before connecting with the Sacramento River near Liberty Island (Figure 1).

Diet of Free-swimming Fish in Replicated Fields: Weekly during the study, 10 fish collected from the fields during sampling were euthanized and immediately placed on ice to be utilized for subsequent gut content analysis. Collected samples were kept in a freezer at UC Davis at -10˚C until being thawed for analysis at which time stomachs were removed and the contents were emptied into water filled slide trays. The contents were identified and enumerated as explained in the invertebrate methods section above.

Table 2: Date, sample size and location of free-swimming fish measured and weighed

Field Number	Substrate	Sample 0	(n)	Sample 1	(n)	Sample 2	(n)	Sample 3	(n)	Sample 4	(n)
1	Stubble	19-Feb	(70)	8-Mar	(30)	15-Mar	(30)	22-Mar	(30)	29-Mar	(30)
2	Fallow	19-Feb	(70)	8-Mar	(30)	16-Mar	(30)	22-Mar	(30)	26-Mar	(22)
3	Stomped	19-Feb	(70)	8-Mar	(30)	17-Mar	(30)	22-Mar	(30)	29-Mar	(30)
4	Fallow	19-Feb	(70)	8-Mar	(30)	18-Mar	(30)	22-Mar	(30)	2-Apr	(30)
5	Stubble	19-Feb	(70)	8-Mar	(30)	19-Mar	(30)	25-Mar	(30)	2-Apr	(2)
6	Stomped	19-Feb	(70)	8-Mar	(30)	20-Mar	(30)	22-Mar	(30)	2-Apr	(30)
7	Stubble	19-Feb	(70)	8-Mar	(30)	21-Mar	(30)	25-Mar	(30)	2-Apr	(30)
8	Stomped	19-Feb	(70)	8-Mar	(30)	22-Mar	(30)	22-Mar	(14)	2-Apr	(30)
9	Fallow	19-Feb	(70)	8-Mar	(30)	23-Mar	(30)	25-Mar	(11)	28-Mar	(30)

Hatchery vs. River Origin Experimental Design: *Enclosures* – Two 13 by 30 m enclosures were built in each field (Figure 3). Enclosures allowed recapture of individually tagged fish permitting collection of high-resolution data to assess potential differences in response of wild and hatchery fish to agricultural rearing habitat (Hypotheses 6 and 7).

On February 20, 2013, approximately 400 juvenile Fall-run Chinook salmon from the Feather River Hatchery and 400 naturally produced fish captured at the screw trap on the Feather River were brought to the field site. Due to their small size (mean FL 38.4mm) fish could not be PIT tagged and instead were visible implant elastomer (VIE) tagged. Each group (hatchery and natural origin) was given a unique color implanted into the tissue below the dorsal fin (Figure 4). After VIE tagging, 20 fish of each group were placed into the enclosures in the experimental fields. Enclosures were walled with 1.2 m high extruded plastic fencing (3 mm opening mesh) trenched into the soil and open to the sky (Figure 5).

Figure 4. Photograph of visible implant elastomer (VIE) tagging

Figure 5. Photograph of experimental enclosure in replicated fields of Knaggs Ranch

On March 11, 2013, after 20 days in the enclosures, the fish were large enough to implant passive integrated transponder (PIT) radio frequency identification tags, allowing us to track performance of individual fish during the remainder of the study period. The fish were collected from the enclosures using a seine and brought in 100-quart marine coolers to a tagging station at the field's edge and tagged. After the fish were tagged, 15 naturally produced and 15 hatchery fish were returned to each enclosure except for enclosures 2, 8 and 16 where free-swimming fish collected from the fields were used. Parallel measurements of enclosures 2, 8 and 16 and free-swimming fish recaptured via beach seine from the same fields provided means of quantifying a "pen effect" whereby the enclosures could potentially alter growth rates.

Table 3: Date, sample size and location of fish placed into enclosures within the replicate fields. (H= hatchery origin from Feather River Hatchery, N= natural origin from the Feather River; Y= number of fish PIT tagged and N = number of fish not PIT tagged)

Enclosure Number	Field Number	Substrate	Fish Origin	PIT tagged	Sample 1	Sample 2	Sample 3
1	1	Stubble	15H/15N	All	11-Mar	18-Mar	27-Mar
2	1	Stubble	30H (Free-swim)	15Y/15N	11-Mar	18-Mar	27-Mar
3	2	Fallow	15H/15N	All	11-Mar	18-Mar	27-Mar
4	2	Fallow	15H/15N	All	11-Mar	18-Mar	25-Mar
5	3	Stomped	15H/15N	All	11-Mar	18-Mar	27-Mar
6	3	Stomped	15H/15N	All	11-Mar	18-Mar	27-Mar
7	4	Fallow	15H/15N	All	11-Mar	18-Mar	27-Mar
8	4	Fallow	30H (Free-swim)	15Y/15N	11-Mar	18-Mar	27-Mar
9	5	Stubble	15H/15N	All	11-Mar	18-Mar	27-Mar
10	5	Stubble	15H/15N	All	11-Mar	-	-
11	6	Stomped	15H/15N	All	11-Mar	19-Mar	27-Mar
12	6	Stomped	15H/15N	All	11-Mar	19-Mar	27-Mar
13	7	Stubble	15H/15N	All	11-Mar	19-Mar	27-Mar
14	7	Stubble	15H/15N	All	11-Mar	14-Mar	-
15	8	Stomped	15H/15N	None	11-Mar	19-Mar	26-Mar
16	8	Stomped	30H (Free-swim)	15Y/15N	11-Mar	19-Mar	26-Mar
17	9	Fallow	15H/15N	None	4-Mar	19-Mar	26-Mar
18	9	Fallow	15H/15N	None	4-Mar	19-Mar	26-Mar

Statistical analysis: Fork length at time zero for all experiments was analyzed to determine if all the fish were the same length using a two-way ANOVA. Individually marked (PIT tagged) fish were analyzed used a repeated measures analysis where either substrate or fish origin was nested within each individual tag number. A full factorial analysis was then preformed on either substrate or origin and time. Post hoc comparisons were performed using the Tukey-Kramer for multiple testing. Statistical significance was declared at the 0.05 level. All statistical analysis was done in JMP pro v. 10.0.2 (SAS Institute Inc.).

RESULTS

Water Temperature: There was no observed difference in water temperature across fields. Water temperature generally increased from the inlet to the mid-field sensor during the day as water traveled across the fields. The maximum instantaneous recorded infield temperature was 22.5ºC (March 13) while the minimum instantaneous minimum was 6.1ºC (March 23) (Figure 6). The mean water temperature of all fields from March 4 to March 29 was 15.7ºC.

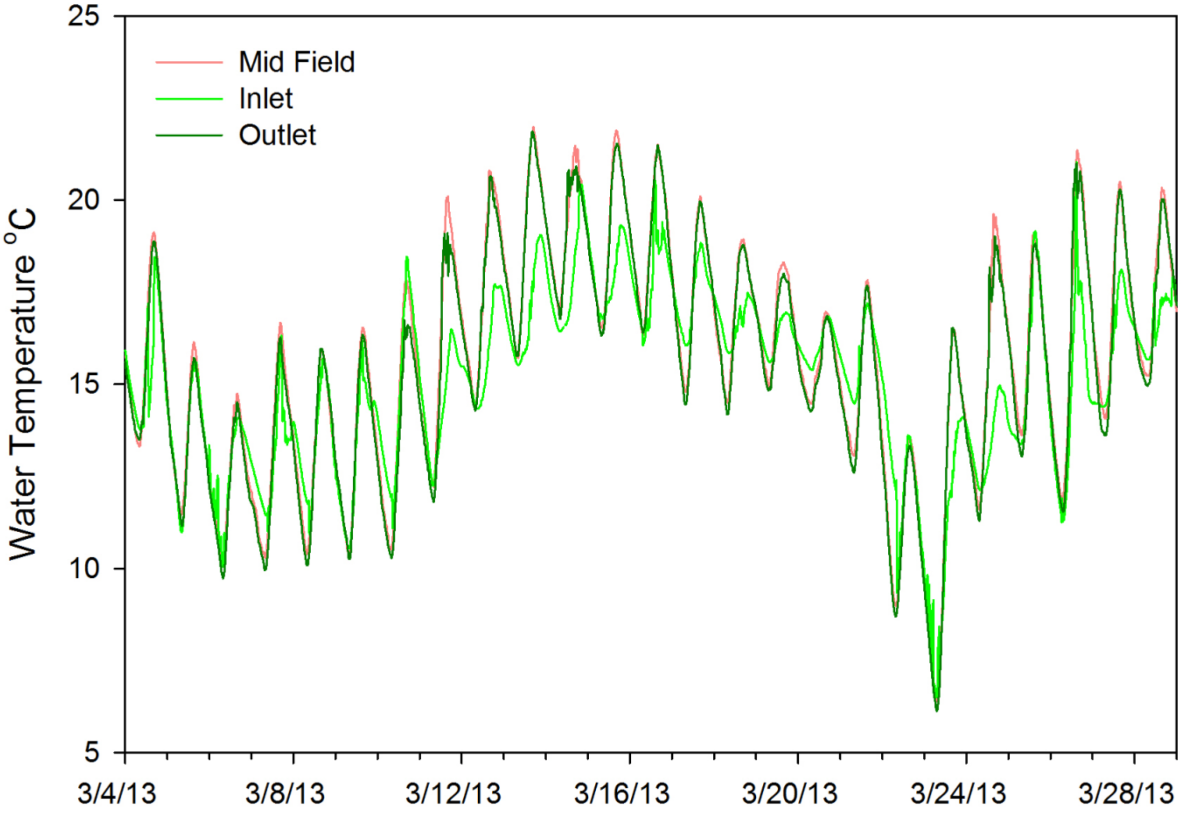

Figure 6: Water temperature collected every 15 minutes at the inlet, mid-field, and outlet of field 6 (stomped).

Dissolved Oxygen: Dissolved oxygen readings were taken in conjunction with zooplankton sampling and as such were not consistent in terms of time of day between dates (Table 4). Dissolved oxygen values ranged from a maximum of 12.19 mg/l to a low of 4.76 mg/l (Table 4).

Table 4: Dissolved oxygen measurements (mg/l) and the time and date of collection.

		2/13/2013	**2/20/2013**	**2/27/2013**	**3/6/2013**	**3/13/2013**	**3/20/2013**
Field 1	Time	10:00	12:34	09:30	10:40	13:06	11:10
	DO	11.5	11.36	11.8	8.22	5.94	7.34
Field 2	Time	10:21	12:20	10:09	10:55	12:41	10:58
	DO	11.41	11.39	11.64	8.76	7.61	8.29
Field 3	Time	10:47	12:08	10:38	11:12	12:17	10:47
	DO	11.27	11.52	11.58	8.77	9.17	7.15
Field 4	Time	11:07	11:51	11:03	11:25	11:32	10:35
	DO	11.28	11.56	11.57	7.66	6.95	8.19
Field 5	Time	11:25	10:25	11:27	11:40	11:09	10:23
	DO	11.16	11.98	11.48	7.54	6.18	5.87
Field 6	Time	11:45	10:11	11:47	11:56	10:53	10:10
	DO	10.92	12.04	11.49	8.67	8.46	7.86
Field 7	Time	12:22	09:57	12:19	12:13	10:35	09:53
	DO	10.85	12.07	11.22	7.72	7.26	4.76
Field 8	Time	12:42	09:45	12:34	12:34	09:37	09:42
	DO	10.75	12.14	11.12	8.3	5.68	7.35
Field 9	Time	12:57	09:32	12:54	12:48	09:17	09:24
	DO	10.77	12.19	11.08	9.14	5.1	6.59

Turbidity: Turbidity varied substantially through time and across and substrate type. Mean turbidity in the stubble, fallow, and stomped substrates were 25.7, 21.6, and 48.5 NTUs respectively (Figure 7). The highest turbidity values were observed in the stomped substrate (202 NTUs).

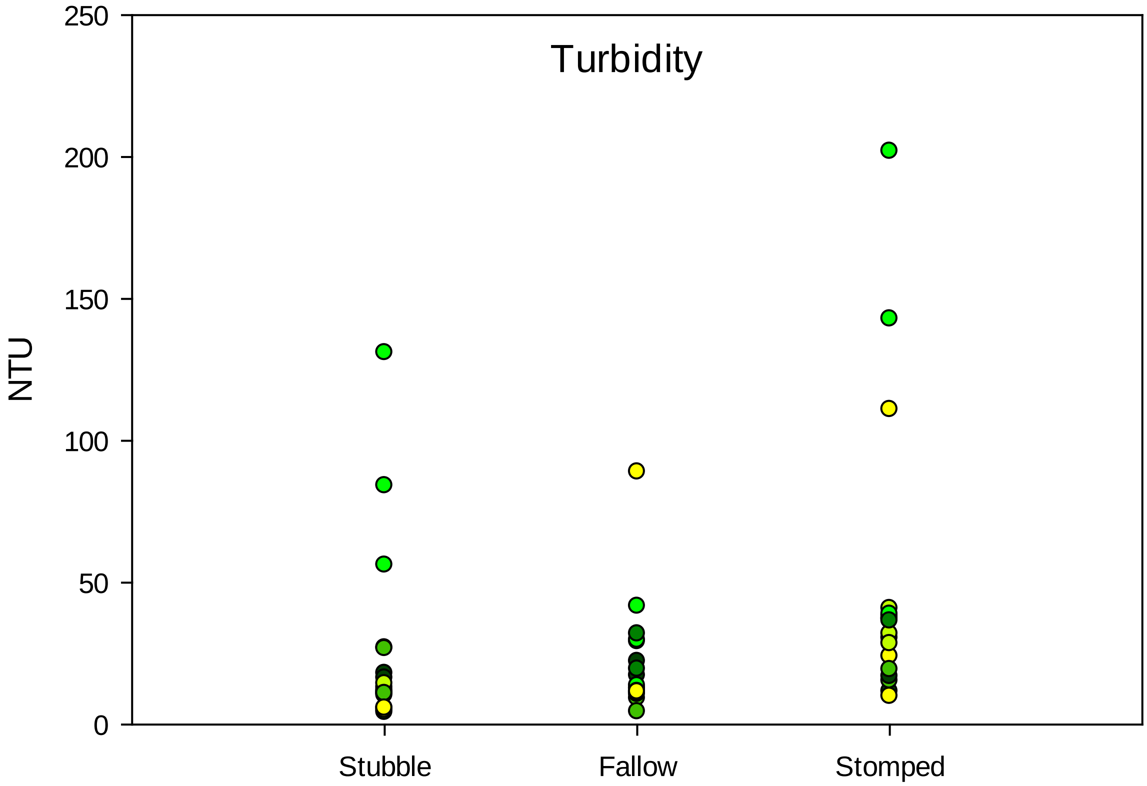

Figure 7: Turbidity samples by substrate type. Different colors denote individual sample days.

Zooplankton Abundance and Diversity by Field Treatment: As noted in the Reporting Approach section above, because of the high volume of samples collected not all zooplankton samples could be processed prior to October 1. One field per treatment was chosen at random and the full time series analyzed to draw comparisons between the different substrate types. Results suggest that: 1) zooplankton levels were relatively high in all treatments; and 2) zooplankton abundance and responses varied among treatments. The stubble field initially had the highest densities of zooplankton but then fell behind the other substrate types until week four when abundances outpaced the other fields for the rest of the study period. Stomped field abundances initially were higher than fallow and stubble, but by week three dropped precipitously. The fallow field initially reached high densities and then plateaued from week two until week six. Detailed observations for the different treatments and species groups are described below.

Stomped: An initial cladoceran abundance of 4,742 ind/m^3 increased over the first three weeks until peaking at 67,234 ind/m^3 (Figure 8). *Daphnia pulex* dominted the assemblage for this period. Abundance of cladocerans then dropped until week five when small-bodied ceriodaphnia populations began to increase. Ostracod and rotifera abundance remained low until week 5 when rotifer abundance began to increase to 16,622 ind/m^3. Copepod density varied from week to week, oscillating between 5,117 ind./m^3 to 37,672 ind./m^3. Cladocerans dominated the assemblage until week five, after which their numbers dropped to be replaced by copepods (Figure 8).

Stubble: Cladoceran abundance increased steadily, starting at 4,295 ind./m^3 and ending at 149,149 ind./m^3 in week six (Figure 8). Initially, copepods had the greatest abundance at 54,694 ind./m^3, but soon declined to under 20,000 ind./m^3 where the population remained until week 5 when the population rose to 32,482 ind./m^3 before returning to 20,638 ind./m^{3}by the study's completion. Rotifer abundance remained low throughout the study period; with none being detected at week three, four, and six. Ostracod abundance oscillated between 24,634 ind./m^3 and 2,879 ind./m^3 throughout the six-week period. Initially copepods constituted the majority of the assemablage, but by week two Cladocerans became and remained dominant (Figure 8).

Fallow: Week one copepod and rotifer abundances were 10,081 ind./m^3 and 9,202 ind./m^3, respectively (Figure 8). At week-two rotifer abundance dropped to 0 and stayed at low densities for the rest of the sample period while copepods increased to 49,212 ind./m^3. Copepod abundance decreased weekly from there to 38,312 to 16, 808 to 17,731 ind./m^3 and finally 8,661 ind./m^3. Ostracod abundance starts at 3,348 ind./m^3 and rises 36,638 ind./m^3 at week two. At week three ostracod abundance dropped to 16,979 ind./m3 and then remained between 25,000 ind./m3 and 16,879 ind./m^3. Cladoceran abundances remained low until the fourth week of the experiment when Cladoceran populations grew from 23,489 ind./m^3 to 72,979 ind./m^3, at weeks five and six cladoceran abundance were at 61,844 ind./m^3 and 85,957 ind./m^3 respectively. From weeks one to three the field was dominated by copepods and ostracods, and from weeks four to six dominated by cladocerans (Figure 8).

The stubble field initially had the highest overall zooplankton abundance with 83,763 ind./m^3 and decreased to 59,663 and 57,887 ind./m3 during weeks two and three (Figure 8). At week-four, Abundance rose to 125,368 ind./m^3 in week four and continued to increase to 140,142 ind./m^3 and 175,957 ind./m3 for weeks five and six respectively. The stomped field started with an overall zooplankton abundance of 21,675 ind./m^3 and grew to 44,823 ind./m^3 by week two, peaking at 99,008 ind./m^3 during week three. After week three abundance dropped to 37,092 ind./m^3 and before steadily climbing to 75,253 ind./m^3 by week six. The fallow field increased from an overall zooplankton abundance of 25,092 ind./m^3 in week one to 101,979 ind./m^3 in week two, remaining between 80,015 ind./m^3 and 114,787 ind./m^3 for the remainder of the study (Figure 8).

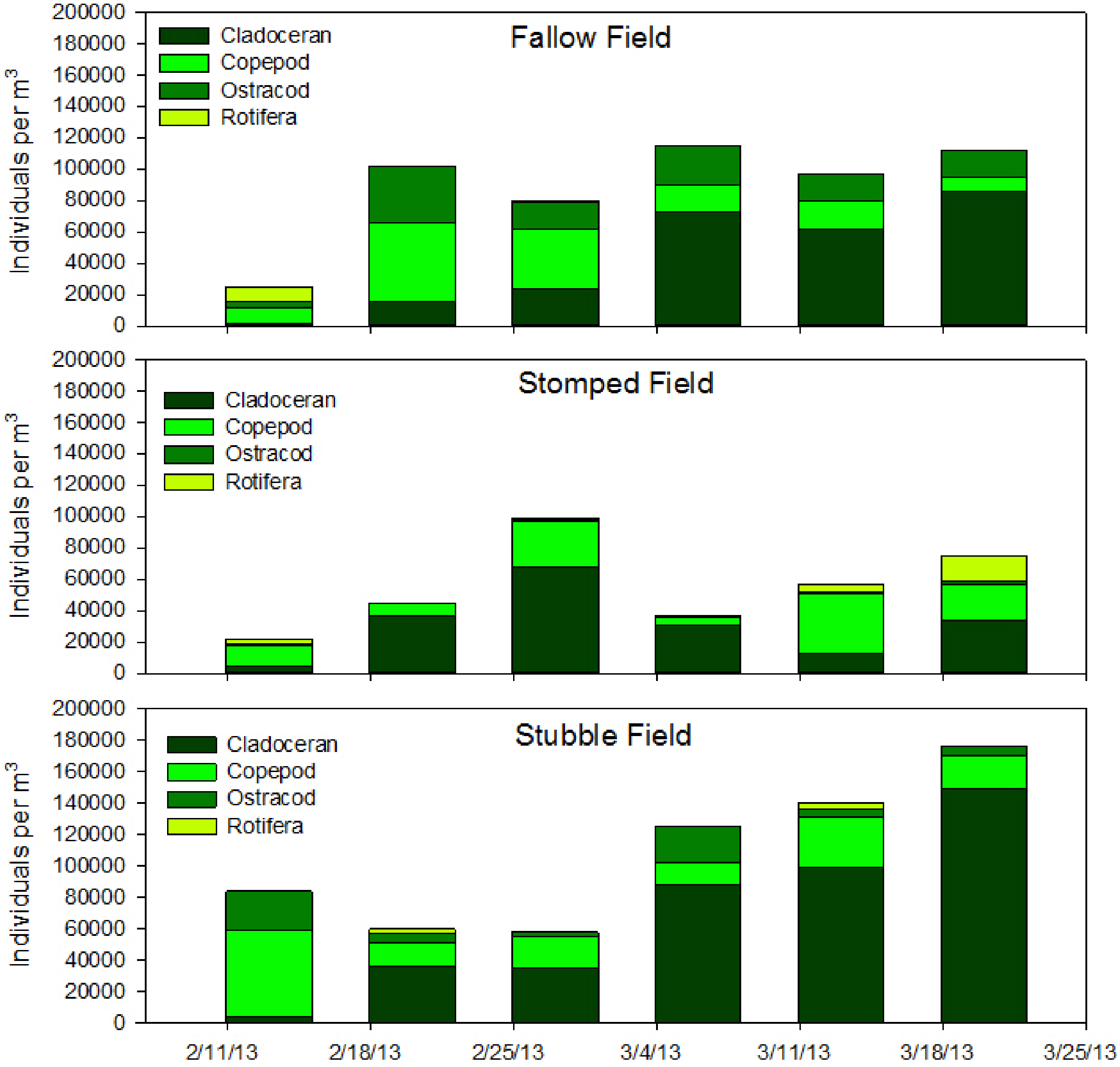

Figure 8: Zooplankton abundance and diversity by substrate.

Cladoceran diversity: Cladocerans are ubiquitous in lentic ecosystems and are an important food resource for young and larval fish (Forró et al. 2008). Lentic systems provide a diversity of habitats for cladocerans; with different species occupying benthic and pelagic niches, as well as niches in complex habitats such as those found in our treatments.

Daphnia pulex was the dominant large bodied Cladoceran in the experimental fields (Figure 9). All fields began with similar densities of *D. pulex*, with fallow having 1,063 ind./m^3, stomped 2,784 ind./m^3, and stubble with 2,008 ind./m^3. Fallow field population densities remained below that of the other fields, not exceeding 49,000 ind./m^3 until week four and then paralleled the stubble field from weeks four to six but at lower densities. Stomped field *D. pulex* densities initially grew to 55,745 ind./m^3 by week three. However, after week three densities declined to, approximately 2,633 ind./m^3. Stubble field *D. pulex* densities grew to over 30,000 ind./m^3 by week two and to 65,106 ind./m^3 by week six (Figure 9).

Simocephalus mixtus densities at inundation were similar for each field (Figure 9). Stomped and stubble fields dropped in densities at the second week to 284 ind./m^3 and 177 ind./m^3, respectively. The fallow field on the other hand increased to 1404 ind./m^3 at the second week. Stubble field densities continued to drop into the third week, to 99 ind./m^3. Fallow and stomped densities grew to 6553 ind./m^3 and 2270 ind./m^3 in the third week and then 9255 ind./m^3 and 4468 ind./m^3 by week four. From weeks four to six *S. mixtus* densities grew in the stubble, from 4583 ind./m^3 to 15,532 ind./m^3 in week six. In week five densities dropped in the fallow and stomped fields, but then grew to 11,575 ind./m^3 and 8,621 ind./m^3. *Simocephalus* densities dropped in fallow field by week 5, while stubble increased. By the sixth week densities were greatest in the stubble field, and second greatest in the fallow (Figure 9).

Ceriodaphnia densities remained low across all substrates until week 4 (Figure 9). The fallow field initially had 131 ind./m^3 and only grew moderately through the six-week period with 3085 ind./m^3 at week four and 5276 ind./m^3 at week six. The stomped field at flood up had 124 ind./m^3 and then grew to 2057 ind./m^3 by week two. For the next 3 weeks the stomped field oscillated between 851 ind./m^3 and 3,340 ind./m^3. The stomped field at week six had 5277 ind./m^3. Rice stubble had the highest density at the beginning of the study with 984 ind./m^3. The rice field stubble steeply increased in *Ceriodaphnia* concentrations at the third week reaching 43,830 ind./m^3 at the end of the study. At this sampling period densities grew dramatically in the stubble field and moderately in the fallow and stomped field. The stubble field's population continued to increase into the end of the study period. The stomped field population grew substantially in the sixth week.

Chydorus sphearicus concentrations in the first week were especially low across all substrate types (Figure 9). The fallow field *C. sphaericus* populations grew dramatically over the six week study period, from initial low densities to 1021 ind./m^3 at week three to 13,787 ind./m^3 at week six. Stubble field oscillated between 160 ind./m^3 and 443 ind./m^3 for the first four weeks. However, after the fourth week the stubble field numbers grew to 5,106 ind./m^3 in week five and to 19,574 ind./m^3 during week six. The stomped field by comparison grew slowly although it had similar *C. sphaericus* densities in the beginning of the study (Figure 9).

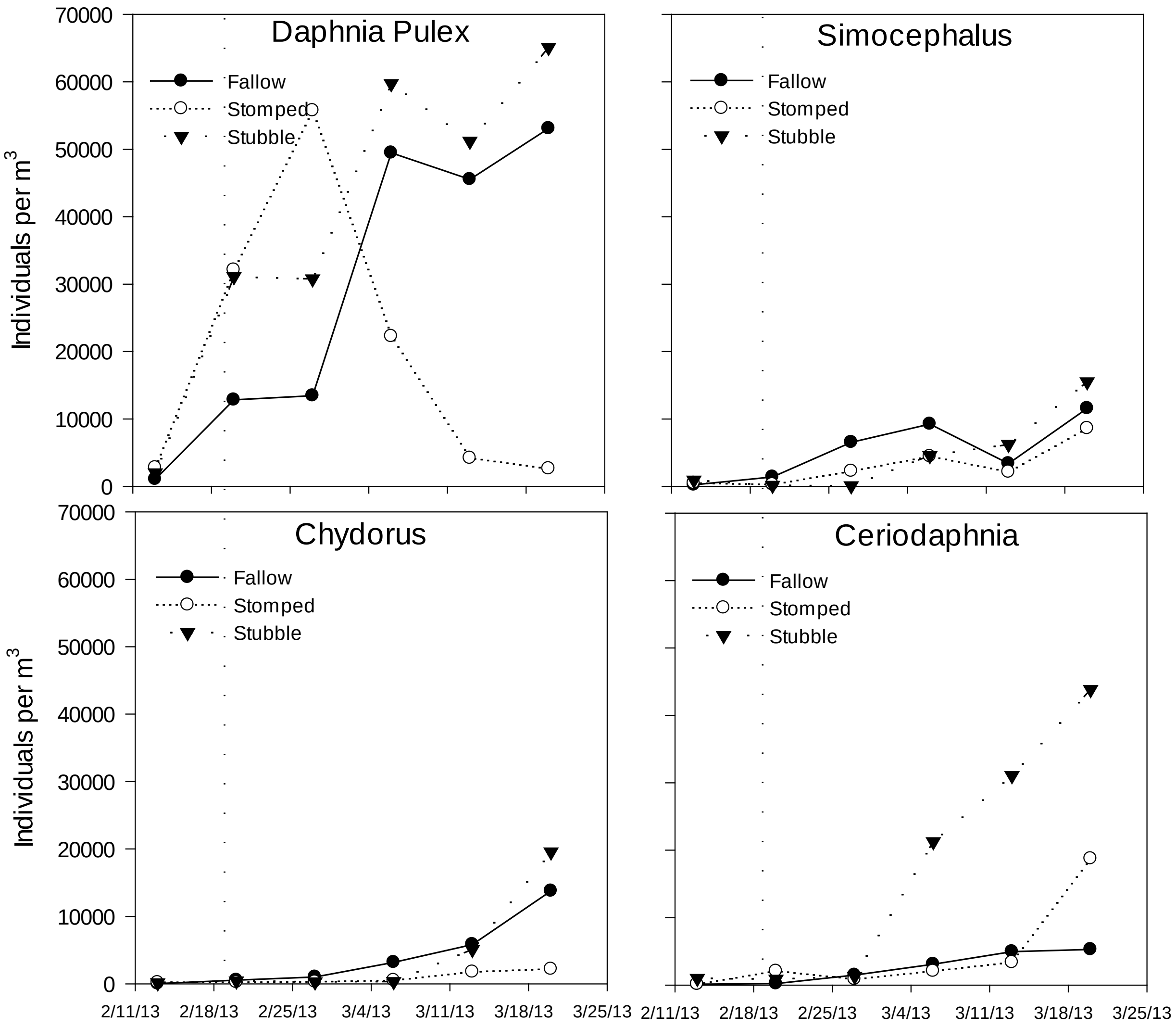

Figure 9: Abundance of cladoceran taxa within the three habitat treatments. Date of fish stocking represented by dashed line.

Macroinvertebrates: The fallow field had chironomid densities of 540.5/m^2 during the first sample period, four to thirteen times greater than the stomped and stubble fields, respectively (Figure 10). However, by the second sampling period the stomped and stubble fields had increased chironomid densities and density in the fallow field had declined. Oligocheates exhibited a similar trend, with the fallow field initially having greater oligocheate density than the other two treatments, but by the second sampling period oligocheate density was greatest in the disked and stubble fields.

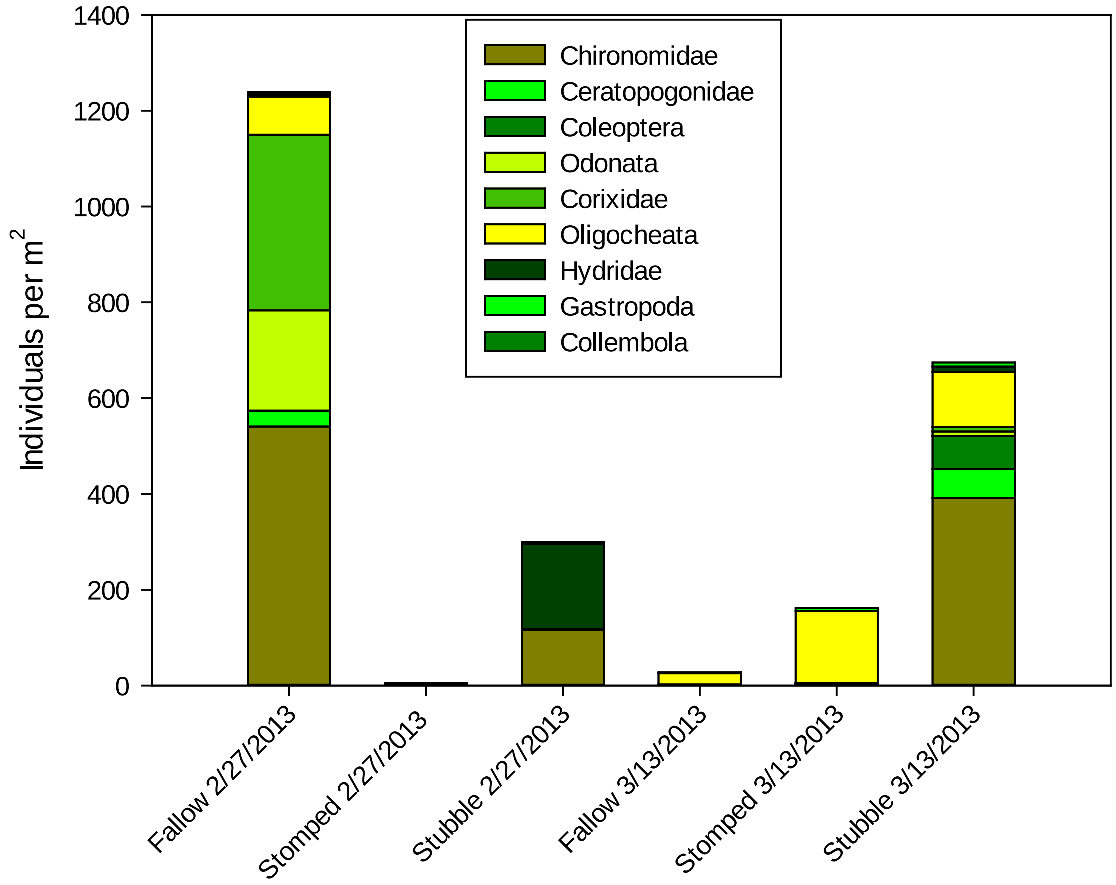

Figure 10: Abundance of macroinvertebrates from fields expressed as individuals/m^2.

Fish Gut Contents: Gut contents of the juvenile salmon consisted primarily (99.2 %) of large bodied cladocerons (Figure 11). Zooplankton samples from the fields averaged 57.0 % cladocerons (Figure 11). The remaining 0.8 % of the stomach contents consisted of ostracods, copeopds, dipterans, arachnids, and hemipterans. A total of 24 dipterans were discovered in all stomachs analyzed.

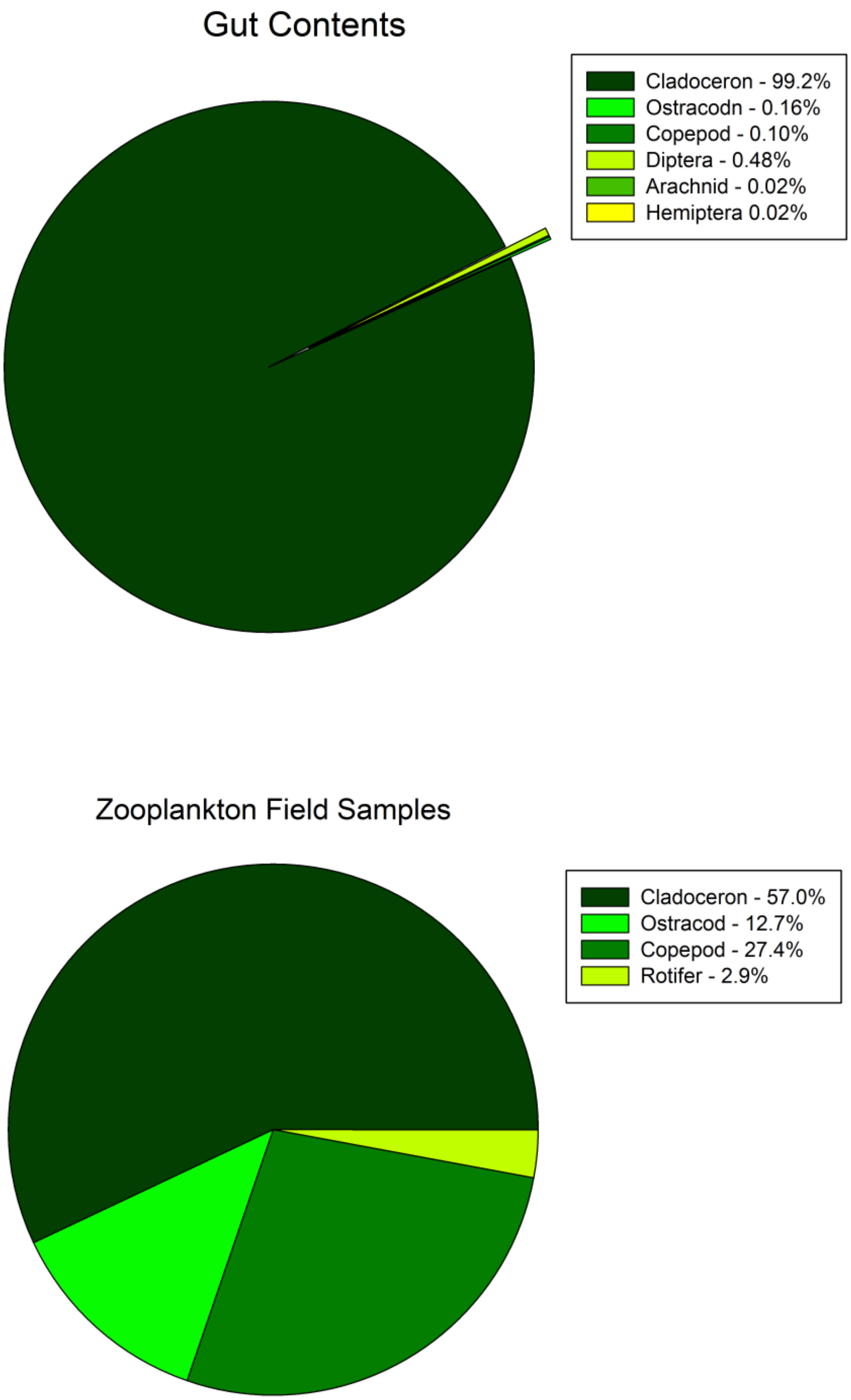

Figure 11: Gut contents from fish reared within the replicate fields. All guts were averaged across time and substrate type. Zooplankton collected within the replicate fields. All zooplankton was averaged across time and substrate type.

Fish Growth and Survival: *Free-swimming fish*: At the time of release into replicate rice fields (time 0) fish averaged (fork length ± standard error) 53.6 ± 0.15mm and 1.5 ± 0.01g (Table 5). At the study's completion (days 37-41 depending on date of field drainage) fish from all fields averaged 90.3 ± 0.34mm and 8.8 ± 0.10g (Table 5). Mean fork length was similar across all habitats until week five ($\alpha<.05$; time 0: p=0.9792, week 3: p=0.1351, and week 4: p=0.3528). At week 5, fish in the fallow fields had fallen behind fish in both the stomped and stubble habitats ($\alpha<.05$; p=0.1834). At week 6, the average length across all three habitat types had significantly deviated; stomped field 92.0 ± 0.55; stubble 90.2 ± 0.60; and fallow 88.4 ± 0.55. ($\alpha<.05$; p=0.0001) (Figure 12).

Table 5: Mean fork length, weight, and condition factor (± standard error) for free-swimming fish from all fields

	Time 0	**Week 3**	**Week 4**	**Week 5**	**Week 6**
Fork Length (mm)	53.6 ± 0.15	70.3 ± 0.23	78.6 ± 0.25	83.3 ± 0.31	90.3 ± 0.34
Weight (g)	1.5 ± 0.01	4.4 ± 0.05	5.96 ± 0.06	7.1 ± 0.08	8.8 ± 0.10
Condition Factor	0.96 ± 0.00	1.25 ± 0.01	1.22 ± 0.01	1.21 ± 0.01	1.19 ± 0.01

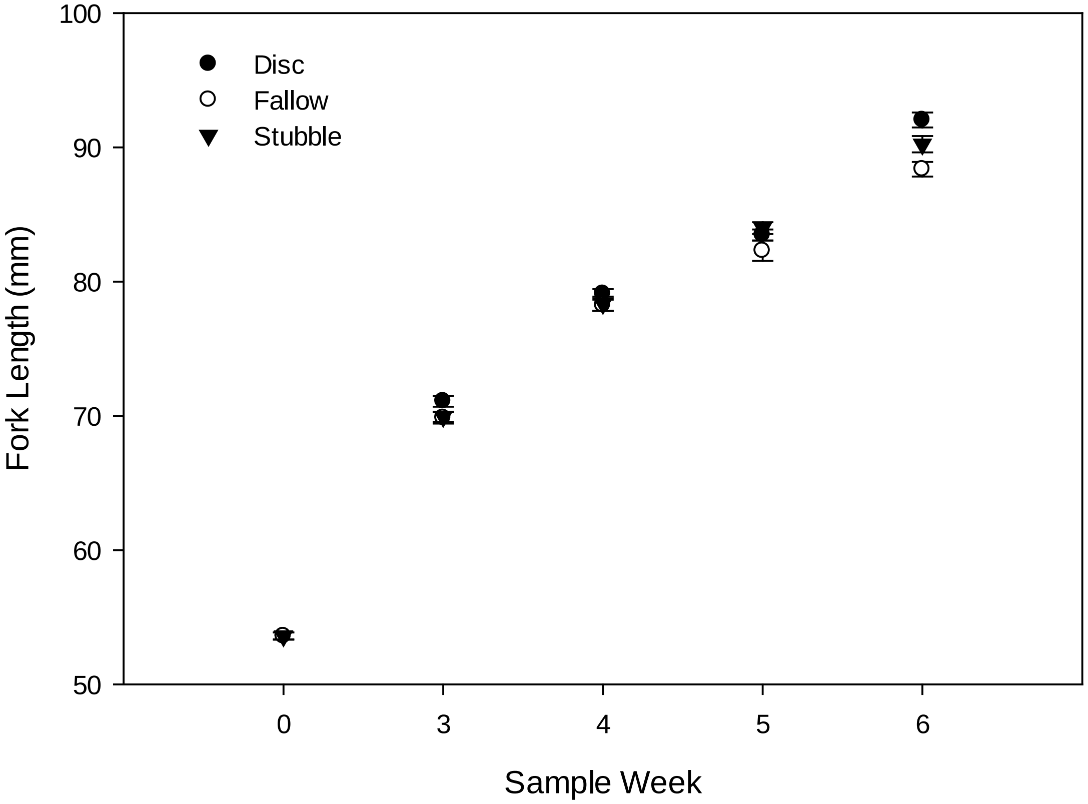

Figure 12: Mean fork length (± standard error) of free-swimming fish across substrate types

Apparent growth rate ([mean Fork length at T_x- mean Fork length at T_{x-1}]/# of days) was measured between each sampling interval and ranged from 0.32 to 1.55mm/day for weekly growth rates, for an average of 0.93mm/day across all six weeks and all nine fields (Figure 13). At the start of the study average Fulton's condition factor, a measure of body condition (K = weight (g) x 100,000/Fork Length (mm)^3) was 0.96 and upon study's completion was 1.19 (Figure 14).

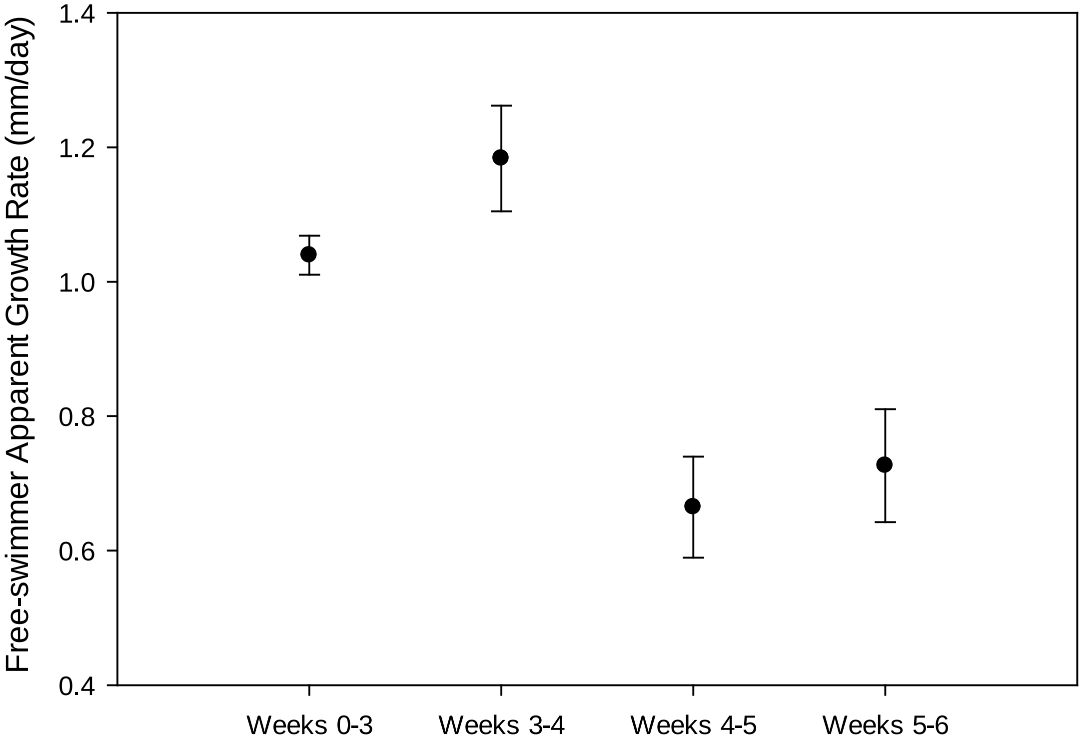

Figure 13: Mean apparent growth rate (mm/day ± standard error) across all fields sampled throughout the study.

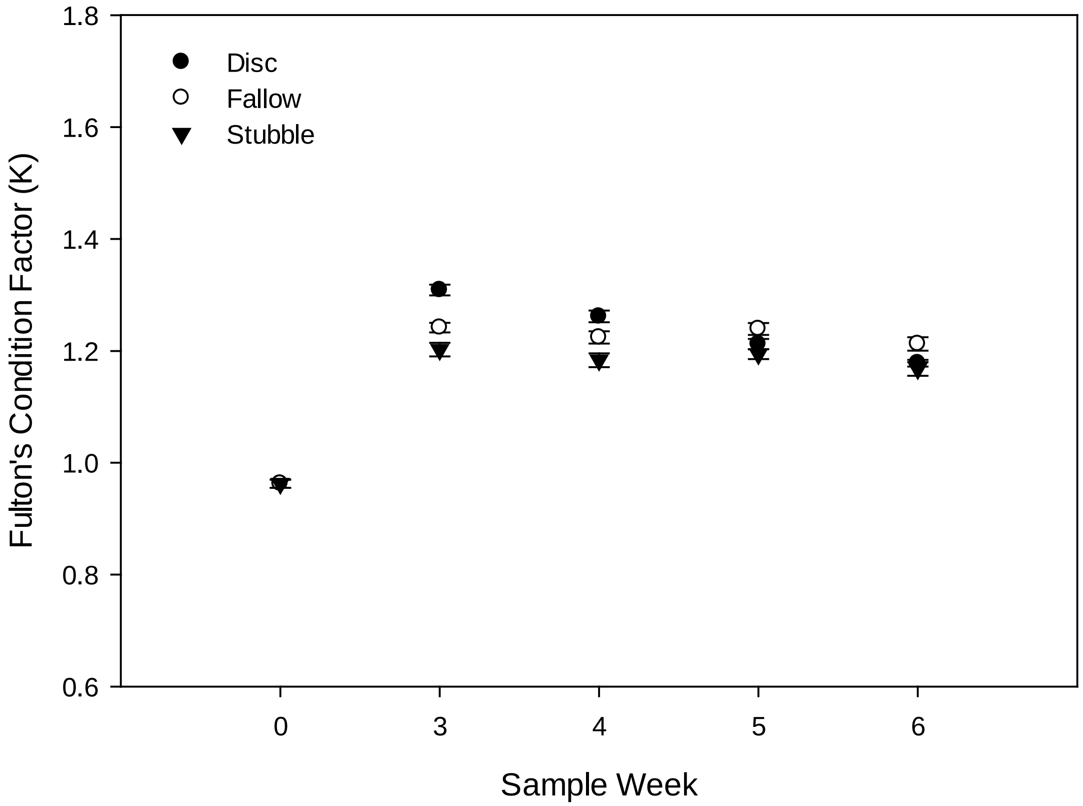

Figure 14: Fulton's condition factor (K) for free-swimming fish across substrate types.

Survival: *Free swimming fish in replicated fields* – Survival varied substantially across fields from 2 survivors in field five (stubble) to 29% in field one (stubble; Table 6). Survival of free swimming fish averaged 7.4% across all fields. Fifty fish were PIT tagged and released to swim freely in field 1 concurrent with the tagging of the enclosure fish on March 11. Of these PIT tagged fish, 44% (22 of 50) survived until draining of the field.

Table 6: Survival of free-swimming fish from the start to the end of the experiment.

Field	Treatment	% Recapture
1	stubble	29.3%
2	fallow	0.5%
3	stomped	8.4%
4	fallow	7.8%
5	stubble	0.0%
6	stomped	4.8%
7	stubble	2.4%
8	stomped	2.9%
9	fallow	10.2%

Fish Reared in Enclosures: Throughout the study period and, across all substrate types, no statistical difference in fork length (α<.05; p=0.0684) or weight (α<.05; p=0.6220) between the hatchery and natural origin fish within the enclosures was detected. On February 20, (time zero) when the fish were VIE tagged and placed into the enclosures, hatchery fish averaged (± standard error) 36.0 ± 0.1mm fork length, weighed 0.4 ± 0.00g, and had mean condition factor of 0.76 ± 0.01, while natural origin fish averaged 40.8 ± 0.2mm fork length, weighed 0.6 ± 0.01g, and had mean condition factor of 0.81 ± 0.01. At time of PIT tagging, hatchery fish averaged 52.4 ± 0.4mm, weight 1.6 ± .03g, and condition factor 1.13 ± .01, while natural origin fish averaged 52.4 ± .04mm, weight 1.7 ± .05g, and condition factor 1.13 ± .01.

Table 7: Mean fork-length, weight, and condition factor (± standard error) for the individually marked hatchery and natural origin fish VIE tagged on February 19, 2013 and placed into enclosures in the replicated fields.

	Time 0		Time 1		Time 2		Time 3	
	Hatchery	Natural	Hatchery	Natural	Hatchery	Natural	Hatchery	Natural
Fork Length (mm)	36.0 ± 0.1	40.8 ± 0.2	52.2 ± 0.3	52.4 ± 0.4	55.3 ± 0.4	56.6 ± 0.7	63.9 ± 0.5	65.9 ± 0.9
Weight (g)	0.4 ± 0.00	0.6 ± 0.01	1.6 ± 0.03	1.7 ± 0.05	2.2 ± 0.05	2.4 ± 0.10	3.3 ± 0.08	3.5 ± 0.14
Condition Factor	0.76 ± 0.01	0.82 ± 0.01	1.13 ± 0.01	1.13 ± 0.01	1.30 ± 0.01	1.23 ± 0.02	1.24 ± 0.01	1.16 ± 0.01

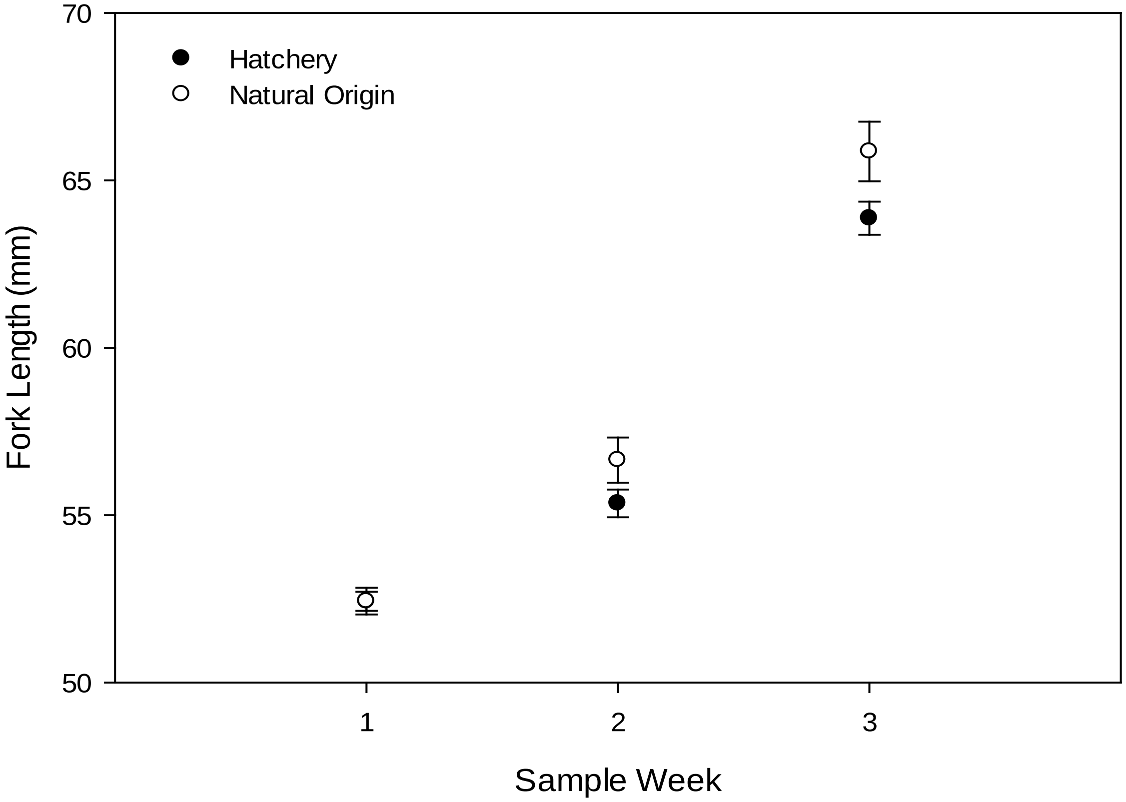

Figure 15: Mean fork length (± standard error) of hatchery and natural origin fish individually marked and placed within the enclosures.

Survival rates for enclosure fish varied across fields and substrates and ranged from 35% to 98% (Table 8). The stubble substrate had the lowest survival rate (average 52%) at the end of the experiment, while both the fallow and stomped had similar survival rates of 82% and 84 % respectively. The majority of the mortality in the stubble habitat occurred within enclosures 10 and 14, fields 5 and 7 respectively, where 54 fish died during the first week following PIT tagging.

Table 8: Number of fish stocked to and recaptured from enclosures by field

Field (Treatment)	Start	End	Survival
1 (Stubble)	60	47	78%
2 (Fallow)	60	46	77%
3 (Stomped)	60	49	82%
4 (Fallow)	60	52	87%
5 (Stubble)	60	25	42%
6 (Stomped)	60	46	77%
7 (Stubble)	60	21	35%
8 (Stomped)	60	59	98%
9 (Fallow)	60	59	98%

Pen effects: There was no apparent difference in growth between free swimming and penned groups across any substrate or time interval. Although it must be noted that sampling was not conducted on identical dates such that, only graphical analysis was possible for comparing apparent growth of free-swimming fish seined from the fields versus three groups of free-swimming fish captured from fields and placed into enclosures 2, 8 and 16 on March 11 (Figure 16).

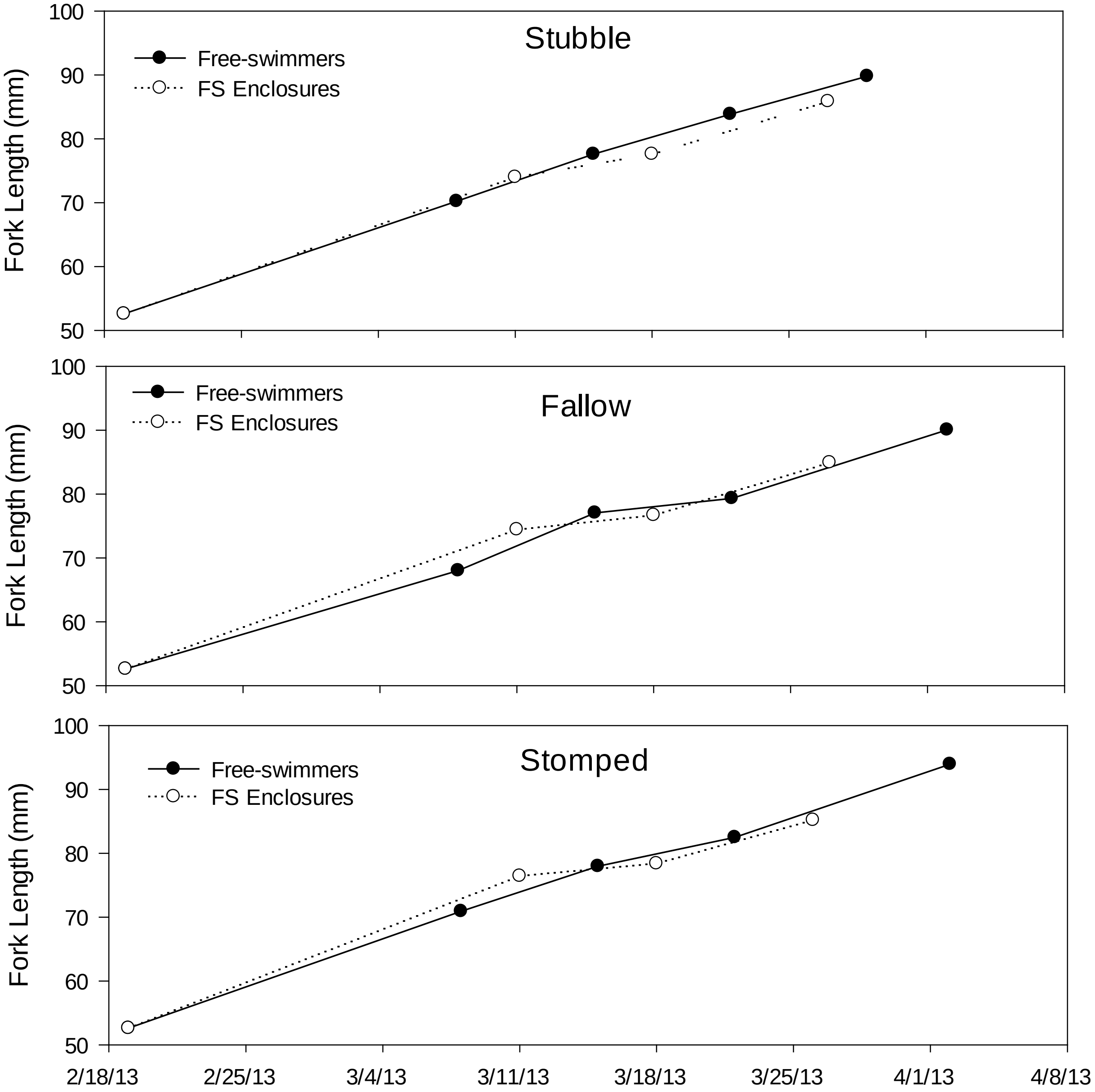

Figure 16: Visual analysis length of free-swimming fish seined from the fields versus three groups of free-swimming fish captured from fields on March 11 and placed into enclosures 2 (stubble), 8 (fallow) and 16 (stomped).

DISCUSSION

This study demonstrated that experimental inundation of Yolo Bypass rice fields during winter can create productive aquatic food webs. High densities of zooplankton were observed across all substrate treatments providing a robust food resource exploited by juvenile Chinook salmon. Growth of juvenile Chinook averaged 0.93mm per day for the six-week experiment, with growth of 1.5mm per day observed during specific two-week intervals. Fish condition was also excellent, with an average Fulton's condition factor of 1.19 at the end of the study (Figure 17). These are the fastest growth rates and highest condition factors ever documented in freshwater in California. Mortality was greater than in the previous year's study, apparently due to increased avian predation pressure, potential reasons for which are discussed below.

Zooplankton: Observed zooplankton abundances across substrate treatments were inversely proportional to macrophyte stem density and were likely driven by a combination of bottom-up (primary productivity) and top-down (fish predation) forcing (Figure 8; Table 1). Designed to approximate alternative agricultural practices for vegetation and soil management, experimental treatments physically differed primarily in vegetative cover and soil surface disturbance. Accordingly observed differences in zooplankton abundances, assemblage diversity and population cycling were likely driven by the interface of physical and biological processes involving macrophytes and soil, such as substrate integrity and refuge structure.

Turbidity: Suspended sediment has several negative effects on zooplankton. In the water column it increases light attenuation thus decreasing potential for photosynthesis and limiting potential phytoplankton production (Soeken-Gittinger et al. 2009), which in turn may limit zooplankton production. Suspended sediment also fouls zooplankton feeding appendages and decreases their food assimilation rates (McCabe and Obrien 1983, Kirk and Gilbert 1990, Dzialowski et al. 2013). Vegetative structure dissipates wind energy within the water column and shields dirt substrates from wind-driven disturbance (Horppila et al. 2013). These factors result in less sediment suspension in the water column near vegetated areas. During periods of strong wind, fallow and rice stubble treatments remained clear, relative to the stomped fields which rapidly grew highly turbid (personal observation). Small areas of exposed bare dirt within the stubble fields caused by tractors during harvest were also associated with localized high turbidity relative to adjacent areas of intact stubble cover. Substrate integrity in stomped fields was dimnished during the stomping process liberating fine sediment that was easily suspended. Greater amounts of suspended sediment in the stomped field therefore may have contributed to lower zooplankton abundances. Conversely, high turbidity has the potential to limit Chinook predation efficiency upon zooplankton (Gregory and Northcote 1993).

Refuge Structure: In water without obstructions, juvenile Chinook salmon effectively forage on large *zooplankton* species within the water column. Macrophytes can serve as refuge structure for zooplankton limiting fish predation on large bodied zooplankton such as various *Daphnia* species (Dzialowski et al. 2013, Liu et al. 2013). Relative to the fallow and stubble fields, the stomped treatments experienced a precipitous decline in *D. pulex* densities subsequent to Chinook salmon being stocked. This rapid drop may be the result of more efficient predation rates by salmon in the open water column of fields unencumbered by standing macrophyte stems. Upon completion of samples analysis we will find out if the other stomped fields follow a similar pattern. After *D. pulex* densities dropped, small-bodied cladoceran densities increased. Fallow and stubble fields did not show this trend, possibly indicating that selective predation on large bodied cladocerans was more efficient within the stomped field. Cladocerans of the genus *Simocephalus* are littoral species strongly associated with macrophytes which they use for attachment (Orlova-Bienkowskaja 2001). Fallow and stubble treatments both supported high numbers of *Simocephalus mixtus* relative to the stomped treatment.

Soil Colonization: Observed differences in zooplankton communities were likely affected by differences in soil disturbance across treatments. Ostracods (benthic microcrustaceans which deposit highly recalcitrant desiccation resistant eggs on submerged substrates) were most abundant in fallow fields where the upper soil horizon was undisturbed by planting, stomping or discing. Fallow sites may also have had more soil surface detritus environmental conditions that favor ostracod egg survival (Stenert et al. 2010). In soil samples taken previous to inundation, fallow fields had high numbers of emergent ostracods, while stomped soils had the lowest abundances of total invertebrates (unpublished data). Mixing of the top soil in stomped fields may also interrupt light and hydrologic cues needed to trigger emergence from reaching the dormant stages of soil-resting invertebrates (Gleason et al. 2003). Ostracods and copepods were the most abundant crustaceans to emerge from inundated soil sediments from fallow fields, with greater densities than rice stubble (Stenert et al. 2010).

Zooplankton Sources: While differences in diversity and zooplankton population dynamics were detected across substrates, extremely high densities of zooplankton were documented in all experimental fields (> 100,000 individual zooplankton/m^3). Preliminary samples taken from the inlet canal at the time of field inundation contained high densities of cladocerans and cyclopoid copepods, which became extremely abundant within the experimental fields. Increased cladoceran abundance is a feature of longer residence time of water in off-channel habitats. None of the soil samples taken prior to inundation at Knaggs Ranch contained cladocerans (unpublished data). Instead, rehydrated samples produced high numbers of ostracods. We therefore conclude that the main zooplankton colonization source in this study was drift from initial inundation of the treatment fields with water from Knights Landing Ridge Cut.

Fish Foraging: High densities of high value invertebrate prey found in floodplain habitats may be an especially important resource for young fall-run Chinook salmon. Comparison of in-field invertebrate assemblage (mean 57.0 % cladocerans) to gut contents (99.2 % cladocerans) suggests that fish were selectively foraging on large-bodied cladocerans for the entire duration of the study (Figure 11). Large bodied *D. pulex* may be particularly nutritious food items as they can contain high levels of fatty acids, such as polyunsaturated fatty acids (PUFAs) (Brett et al. 2009). PUFAs have been identified as important nutrients for fish growth and development (Sargent et al. 1999). The stomped field had the lowest total abundance of large bodied cladocerans at study’s end and the highest salmon growth rates. These results are consistent with a top down predation mechanism limiting zooplankton abundance. This finding is similar to results from Grosholz and Gallo (2006), in which as juvenile fish densities increased, large-bodied cladoceran abundance decreased, resulting in increased relative proportions of small-bodied cladocerans.

Fish Growth: For both free-swimming and enclosure fish, growth rates were highest in the first weeks of the study (Figure 16), a finding that is consistent with non-linearity of length increase in salmon (Ostrovsky 1995). No statistical difference in the growth rate between hatchery and river origin fish was detected. Exceptionally high abundance of food resources and little to no predation within enclosures may have contributed to this finding. Without competition for resources or exposure to predation threat, little discrepancy in performance would be expected even if considerable behavioral differences existed.

Figure 17: Frozen juvenile salmon (left) from 40 days previous are tiny compared to fish that have spent 40 days on the Knaggs Ranch rice fields (right).

Fish Survival: Overall survival was variable between fields and experiments. Free-swimming survival ranged within fields from 0% to 29.3% while fish in the enclosures survived at a much higher rate ranging from 35% to 98% (Table 6 and Table 8). In addition 50 fish were PIT tagged and released to swim freely in field 1 concurrent with the tagging of the enclosure fish on March 11. Of these PIT tagged fish, 44% (22 of 50) survived until draining of the field. These variable survival estimates highlight the diverse conditions that the fish experienced across experiments. Perhaps the major issue in the 2013 study was that the project was started later than hoped because of delays in the availability of hatchery and wild fish, resulting in substantial differences in water quality and exposure to avian predation as compared to 2012. Each of the sources of potential mortality is discussed in more detail below.

Water Quality Related Mortality: Anomalous flow paths caused by emergency levee reinforcement actions conducted the day before fish were stocked into the fields may have contributed to insufficient water exchanging over the crown of fields 5 and 7 thereby causing degradation of water quality conditions. On March 19, all of the fish from one of the enclosures in fields 5 and 7 were found dead. The fish within the other enclosures in fields 5 and 7 had a 93% and 70% survival respectively, highlighting the diversity within a single field.

If food resources are abundant growth can still be substantial even at temperatures higher than generally considered optimal for juvenile salmonids (Bisson et al. 1988). The winter of 2013 was one of the driest and warmest on record for the Sacramento Valley, with little precipitation January first through the end of March. These unusually clear and warm weather conditions affected the experiment in several possible ways. Although the high food supply may have allowed Chinook to tolerate temperatures higher than their optimal range, the extreme heat in the final week of experiment may have resulted in retarded growth (Myrick and Cech 2004). In general however, even with the anomalous weather patterns, water conditions within the experimentally inundated rice fields during the winter months seem to provide excellent growing conditions for juvenile Chinook salmon.

Predation: Lack of precipitation resulted in very little surface area of inundated aquatic habitat on the regional landscape. The study fields, experimentally inundated via pumping during winter when little managed inundation occurs, therefore represented a large percentage of the open water habitat available to aquatic birds regionally. This relative deficit of aquatic habitat likely resulted in an unusually high concentration of piscivorous birds congregating near and foraging in the experimental fields. While a significant number of piscivorous birds were not observed at the beginning of the study, they gradually increased making it apparent that bird counts should be conducted. Each morning (March 15 – 25) an informal quantification of bird presence was carried out. As many as 51 wading birds (great blue heron, snowy and great egrets) and 23 cormorants were noted during a single survey. Detailed observations of bird foraging behavior was not conducted, but wounds consistent with bird attacks were observed on multiple fish as fields were drained. Avian predation success was also likely facilitated by a decrease in field depth compared to the 2012 pilot study. Experimentally designed to compare growth and survival across agricultural substrate treatments, the 2013 replicated fields were intentionally kept of uniform and relatively shallow depth, similar to conventional rice fields in order that differences in depth not confound growth and survival signals. Only the small “borrow” ditches made when soil was excavated to reinforce levees offered depth refuge. Because our data are insufficient to estimate survival prior to the arrival of the larger number of birds it is difficult to determine the actual bird-related mortality. Understanding how avian predation impacts juvenile salmon on flooded rice fields and how water year type affects avian predator density should be a topic of future research. The 2014 study design will be specifically tailored to examine the role of depth as a refuge for fish against avian predation.

CONCLUSION

While this experiment demonstrated that fish reared in stomped rice fields grew more rapidly than those reared over stubble or weedy vegetation, it must be emphasized that the average growth rates and body condition across all substrates for the 41 day duration of the study (Table 5 and Table 7) were the highest ever recorded within the Central Valley of California. We therefore conclude that winter inundation of rice fields creates high-quality growth opportunities for juvenile Chinook salmon. Although this study suggests that agricultural landscapes can function as rearing habitat for juvenile Chinook salmon, our results should not be interpreted to suggest that suitable natural (i.e. non-agricultural) habitats are not essential to establishing self-sustaining runs of naturally produced Central Valley Chinook. Rather, the study demonstrates the potential to reconcile management of agricultural landscapes with the management of Chinook salmon populations through use of existing agricultural infrastructure. Managed inundation of rice fields in winter and early spring appears to mimic historical floodplain processes, re-exposing salmon to an approximated version of the hydrologic selection regime under which they evolved and to which they are adapted.

Further research should focus on understanding dynamics of fish survival on and emigration from managed agricultural floodplains, as well as the timing and duration of project implementation in order to evaluate the use of managed inundated areas as a supplemental tool to restored, natural floodplain habitat.

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CHAPTER 2

Juvenile Chinook Salmon Habitat Preference Study at Knaggs Ranch on Yolo Bypass

Report prepared by: Louise Conrad[1], Naoaki Ikemiyagi[1], Lynn Takata[1], Carson Jeffres[2], Eric Holmes[2], Ted Sommer[1], and Jacob Katz[3]

[1]Department of Water Resources, Aquatic Ecology Section, Division of Environmental Services,
3500 Industrial Blvd. West Sacramento, CA 95691
[2]UC Davis Center for Watershed Sciences,
University of California, 1 Shields Avenue, Davis, CA 95616, USA
[3]California Trout, Central California Region, 930 Shiloh Rd, Bldg. 40, Suite 6
Windsor, CA 95492

INTRODUCTION

The Yolo Bypass is a major target for large-scale restoration of floodplain habitat within recovery plans for endangered runs of Chinook salmon (NMFS 2009), as well as the Bay-Delta Conservation Plan. A plethora of habitat types may be included in restored areas. Areas currently managed for wildlife, rangeland, and cultivated farmland are among those that may be available for use as seasonal rearing habitat for juvenile salmon. These habitat types are likely to differ in their vegetation assemblage composition and density (chapter 1 of this report), as well as planktonic and macroinvertebrate abundances and assemblages. It will be important, therefore, to understand how juvenile salmon will distribute themselves across such a variable environment, whether they exhibit any preference for specific habitat types, and whether their performance across habitat types varies. This information will inform design of restoration efforts in the Yolo Bypass.

Very little information on juvenile salmon habitat preference in off channel floodplain environments is available. While there is a general consensus on a substantial growth benefit of floodplain rearing to juvenile salmonids (Sommer et al. 2001; Jeffres et al. 2008; Bellmore et al. 2012; Hanson et al. 2012), past studies generalize across a broad spatial mosaic of sub-habitats that occur within floodplains, leaving open the question of how specific habitat types may influence rearing performance as measured by growth and survival rates. Many previous studies on habitat preference of juvenile salmonids come from riverine and stream environments (Quinn 2005; Pavlov et al. 2008; Railsback et al. 2013). Given that floodplains differ from stream habitats with respect to both water quality and food web aspects (Sommer et al. 2001), juvenile salmon may exhibit different habitat use and behavioral patterns than would be predicted from river and stream-based studies. Without information from floodplain-specific habitat preference studies, the design and modeling for restored floodplains will necessarily be based on juvenile salmonid behavior in riverine environments.

Recent analyses of otoliths taken from adult Chinook salmon returning to California’s Central Valley have shown that fry-sized emigrants contribute to approximately 20% of the adult population (Miller et al. 2010). In the Yolo Bypass, the major documented benefit of floodplain inundation is for fry-sized juveniles (average FL of 57mm, Sommer et al. 2001), though other, larger life stages may also benefit from increased accessibility of off-channel habitat (del Rosario et al. 2013). While habitat use is often assessed using acoustic or radio telemetry technologies, the smallest tags available are only appropriate for juvenile fish 80mm or larger (JSAT tags, www.lotek.com, Sean Hayes, NOAA Fisheries, personal communication), making this technology unavailable for fry-sized juveniles that are a major target of floodplain restoration efforts.

Passive Integrated Transponder (PIT) technology offers relatively small radio frequency identification (RFID) tags. PIT tags are available in a variety of the sizes from several manufactures, with the smallest options at 8mm and 12mm in length. Minimum juvenile salmon size for use of 8mm tags is 45mm FL, while minimum size for 12mm tags is approximately 60mm FL. The tags are inserted into the body cavity of the fish. Individual-level identification codes are detected passively at close range from handheld or fixed-station readers using electromagnetic fields (Gibbons and Andrews 2004). PIT tags are now widely used in stream environments to continuously monitor juvenile salmon habitat use (Johnston et al. 2009), fish passage into and out of streams or stream reaches (Zydlewski et al. 2006), and for estimates of abundance (O'Donnell et al. 2010). Traditional habitat use methods (e.g., snorkeling) introduce significant bias due to fish fright responses to observers. Remote recapture via RFID technology minimizes this bias resulting in more accurate habitat use data, with the added benefit of individual-level data (Ellis et al. 2013). However, PIT tracking techniques have been developed largely for linear, stream or riverine systems in which fish passage in and out of specific reaches is recorded. The broad expanses of shallow-water habitat characterized by floodplains presents a new challenge to the use of PIT technology to assess habitat use.

In the Yolo Bypass, rice agriculture is a dominant land use and holds substantial promise for seasonal use as juvenile salmon nursery habitat, given the unprecedented growth rates documented in 2012 and 2013 pilot efforts by the Knaggs Ranch Experimental Agricultural Floodplain Project (Katz 2012; chapter 1 of this report). This study is a pilot effort to examine habitat use by juvenile Chinook salmon on a managed, experimental floodplain. The pilot study was conducted in conjunction with a larger study of planktonic and invertebrate foodwebs and fish survival and growth across three agricultural substrates; bare dirt (stomped), rice stubble (stubble), and weedy vegetation (fallow). This habitat preference pilot component of the study compared habitat use by fish given free access to the three agricultural substrates used in the larger, 2-acre single habitat type experimental fields. Fallow fields had been uncultivated during the summer growing season, allowing a variety of annual and perennial vegetation to become established.

A second goal of this study was to compare the detectability, tagging effects, and habitat use results derived from 8mm and 12mm-tagged fish. As general rule, there exists a trade-off as tag size decreases: because smaller tags represent a smaller tagging burden they allowing tagging of smaller fish, but smaller tags also come with significant declines in range of detection (Dixon and Mesa 2011). Maximum tag detection distances are affected by environmental conditions and must be determined in the field.

Though not extensively studied, some previous research has examined the effects of implantation method for 12mm PIT tags. Richard et al. (2013) compared surgical incision and tag injection using a needle equipped with a plunger on age-0 brown trout, and found no difference between methods on tag retention, growth or survival, for fish >55mm in fork length (FL). A second recent study found significant increases in wound size resulting from 180° needle rotation upon tag injection, compared to a 90° rotation, two weeks after tagging (Bryson et al. 2013). As the 8mm tag size is relatively new, studies have not yet been conducted comparing potential growth, survival effects, implantation method or tag retention, between 8mm and 12mm tag sizes. Therefore, an additional objective of this study was to compare and contrast utility and performance of 8mm and 12mm tags.

METHODS

Two experiments were conducted simultaneously; the habitat preference study to test for differences in habitat use by juvenile salmonids and an auxiliary tagging methods experiment comparing the utility of 8 mm vs. 12 mm PIT tags under floodplain conditions.

Experiment 1: Habitat preference study design

- **Habitat Preference Hypothesis 1:** Juvenile Chinook salmon demonstrate no difference in *occupancy pattern* between agricultural habitat types.
- **Habitat Preference Hypothesis 2:** No difference in *inferred pattern of habitat use* from groups tagged with 8mm vs. 12mm tags.

Two 3mm-mesh circular enclosures were created in a small field (0.3 acres) equipped with a water inlet and outlet. Each enclosure measured 15.25m in diameter, and was oriented in sequence in relation to the field's flow inlet, rather than in a side-by-side fashion (Figure 1). The upstream, "multi-habitat" enclosure was divided equally into the three agricultural habitat types: fallow, rice stubble, and stomped substrates, such that each habitat section occupied approximately 60.8 m^2. The rice stubble habitat treatment consisted of the standing stalks that remained after harvest. Stubble height ranged from 23-35 cm but was uneven due to irregular harvest of rice. The stomped habitat type was created by discing the field and then using a Caterpillar D-3 track-type bulldozer to further compact rice straw into the ground to promote decomposition. The fallow habitat type was not planted to rice during the previous growing season but instead consisted of the "weedy" plants that grew naturally. Stem density was highest in stubble fields and lowest in stomped fields. Stem diameter was similar between fallow and rice stubble fields. Fallow fields had taller grasses that lodged over during the course of the study. The second, downstream control enclosure contained only the stomped (bare dirt) habitat. The rationale for this second enclosure was that any apparent preference for a single habitat in the "multi-habitat" enclosure could be confounded by a preference for a certain geographic location or orientation within the field (e.g., upstream or downstream). In this case, a random distribution within the control second, (bare dirt) enclosure, would support a habitat (rather than location) preference in the multi-habitat enclosure. In contrast, a similar distribution in the control enclosure to the fish in the multi-habitat enclosure would indicate a spatial pattern driven by factors other than habitat preference.

Fish location in the enclosures was tracked with PIT tags and an array of PIT tag antennae. Each enclosure was equipped with six antennae of dimensions 6.1m long x 0.46m high. Each antenna was nearly the length of the enclosure's radius, leaving approximately 7 m^2 of empty space in the center to avoid interference between the antennas. The height of the antennae was roughly equivalent to the water depth of approximately 0.46 m. In the multi-habitat enclosure, each habitat type contained two antennae, equally spaced from the habitat borders. Antennae in the stomped enclosure were arranged in the same orientation as the multi-habitat enclosure, with a pair of antennae in each third of the enclosure (Figure 1). Each antenna was connected to an individual reader (Allflex USA, Inc.), which communicated with a data logger where the date, time, antenna number, and individual PIT number of each detection event were stored on an 8GB SD card. Each enclosure had its own data logger, powered by a 24 volt system that was continuously charged with solar panels. Antennae were tuned to approximately 350-500 mA. Tuning was checked daily at the data loggers where tuning frequencies could be viewed individually for each antennae on the lcd screen. Antennae were re-tuned immediately if necessary. Detection data were downloaded on a daily basis and checked for obvious detection problems.

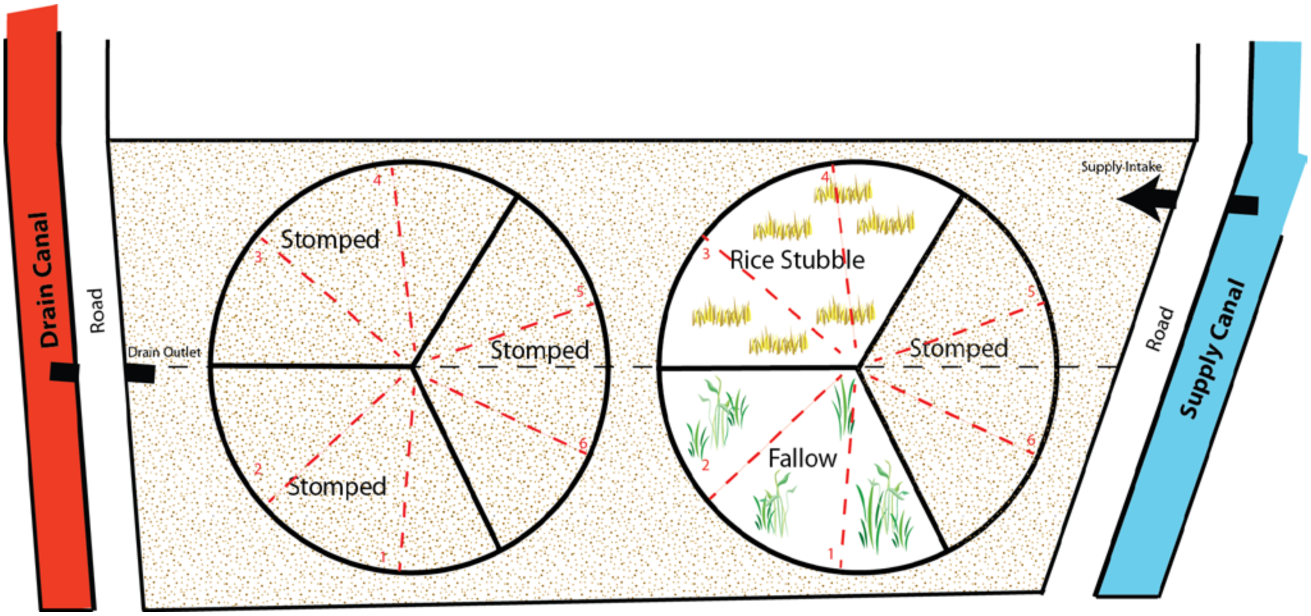

Figure 1. Layout of multi-habitat and stomped enclosures. Red dashed lines indicate PIT-tag antennae. Numbers for each antenna position are used to differentiate antennae in analyses.

Spatial variation in water quality: sampling methods. To characterize habitat beyond the substrate type, water quality information was also collected. Water temperature, dissolved oxygen, electrical conductivity, and pH and turbidity were measured with a YSI multi-parameter sonde on a daily basis. Turbidity samples were also collected daily and analyzed with a Hach 2100Q Portable Turbidimeter. Turbidity samples were collected separately for each habitat type within the multi-habitat enclosure (to assess whether vegetation type influenced suspension of sediments), and a separate sample was collected for the stomped enclosure. In addition to discrete water quality sampling, water temperature data was collected continuously using data loggers (HOBO Onset) set to record temperature every 15 minutes. In order to assess how water temperature conditions may have varied between the inlet and outlet, temperature loggers were deployed at the inlet, center, and outlet of the study field.

Experiment 2: Tagging methodology study design

The tagging methods experiment was designed to assess differences in 8mm and 12mm full-duplex (FDX) PIT tags by testing the following hypotheses:

- **Tagging Methods Hypothesis 1:** No difference in in-field *detection distance* across tag size.
- **Tagging Methods Hypothesis 2:** No difference in *tag retention* across tag size and implantation method.
- **Tagging Methods Hypothesis 3:** No difference in *survival* across tag size and implantation method.
- **Tagging Methods Hypothesis 4:** No difference in *growth* across tag size and implantation method.

Juvenile Chinook salmon were stocked into the enclosures on March 13, 2013. All fish were obtained from adjacent fields where a separate, concurrent and complementary experiment on the effects of habitat type on growth and survival was taking place (chapter 1). In that experiment, each 2-acre field was composed of a single agricultural habitat type (fallow, rice stubble, or stomped) and had been stocked with juvenile Chinook salmon obtained from the Feather River Hatchery located in Oroville, CA on February 19, 2013. Thus, when fish were tagged and stocked into the habitat preference study they had acclimated to floodplain environmental conditions, but individual fish were already experienced with a single agricultural habitat type. To control for any effect of prior habitat type experience on habitat preference in our enclosure experiment, fish for each tag/surgery treatment group were obtained in equal numbers from each of the three habitat types and their “habitat origin” recorded. On March 27, 2013 (two weeks after stocking), the field was drained and all surviving fish were recovered from each enclosure.

Tagging and fish data collection methods. Groups of 21 juvenile Chinook salmon (mean FL 77mm ± 3mm SD) were tagged with specific size and implant method. The 12mm tags were pre-loaded into a 12-gauge syringe and inserted into the peritoneal body cavity on the right side of the fish, with the insertion point posterior to the pectoral fin. The 8-mm sized tags were inserted into the fish manually after using a scalpel to make a small incision (3-4mm) on the left side of the body, following methods described by Gries and Letcher (2002). No sutures were used to close incisions. Because there were two surgical methods for tag insertion, it was necessary to have three comparison groups of untagged fish to evaluate effects of tag size and surgical methods on tag retention, growth, and survival: sham surgery (needle or scalpel insertion without tag injection) using a 12-gauge needle on the right side, sham surgery with just a scalpel incision on the left side, and a final group with anesthesia only (no surgery). Upon recovery at the end of the study, the treatment group of the sham surgery fish was distinguished by the location of the scar (left or right-hand side of the fish). Fifteen fish were used for each comparison group, for a total of 45 untagged fish in each enclosure. The untagged fish along with the PIT-tagged fish totaled 87 fish stocked into each enclosure. All fish were anesthetized prior to treatment in a bath of methane tricaine sulfonate (MS-222) at a concentration of approximately 60mg/L. FL to the nearest mm and weight to the nearest 1/100 of a gram were recorded for each fish prior to treatment. Upon completion of the study on March 27, 2013, FL and weight were again recorded, along with the PIT tag number (if present) or the surgery treatment group (left or right-side scar, no scar present).

Detection sensitivity tests. Before the fish were tagged and stocked in the enclosures, the detection sensitivity of the electromagnetic fields within antennae was checked manually using dead fish tagged with either 8 or 12mm tags. Tag detection was tested systematically in a gridded pattern, at 0 (touching antenna surface), 0.8, 2.8, 3.8, 5.3, and 6.1m along the length of the antenna, and 0, 7.6, 22.8, 38.1, and 45.7cm along its height (30 points total, Figure 2). Each individual antenna was tested separately after installation in the enclosures.

Data management and statistical analyses. The difference in detectability between 8 and 12mm tags was visualized graphically (Figure 2). The effect of tag size and surgery method on growth was assessed by comparing the initial and final body sizes of each treatment group with a series of ANOVA tests, or Kruskal-Wallis tests if the data were not distributed normally. It was not possible to perform an ANOVA on growth rates for each treatment group because individual growth rates were only available for the PIT-tagged fish, and only apparent growth rates based on average sizes were available for the sham surgery and no-surgery groups. However, using growth rate data from PIT-tagged fish only, a two-way ANOVA was conducted to assess effects of both enclosure and tag size. Tag retention and survival were compared for each treatment group using a table of recovery rates, because very similar results among groups did not warrant a statistical test.

Over the 2-week study period, approximately 2 million detection records were generated from both study enclosures. In order to efficiently handle this large volume of data, and to minimize the number of multiple repeated detections of a single individual that may have hovered on or near an antenna, data were condensed into unique (i.e., different PIT numbers) detections at 5min intervals. A graphical sensitivity analysis of the number of using different temporal condensing intervals revealed that the 5min interval did not alter the rank order of number of detections among antennae, while reducing the data volume to more manageable levels. In addition, periods of potential human disturbance that may have altered fish behavior (e.g., entrance into the study field for collection of water quality data) were discarded from the PIT detection record before analysis. The raw detection files for the stomped enclosure comprised a total of approximately 835,000 records, while the multi-habitat enclosure generated 1.2 million records. After condensing the data into 5min intervals and stripping the record of potential disturbance times, the stomped and multi-habitat enclosures resulted in single files of 71,492 and 62,914 detection records, respectively.

For the PIT-tagged fish, the effects of tag size, habitat origin (fallow, rice stubble, or stomped treatments in the experimental field from which fish were obtained), and daylight (day vs. night) on habitat use in each of the enclosures were assessed using a multinomial logistic regression analysis. This analysis is similar to a binomial logistic regression; however, more than two outcomes are possible. In this case, detection at each of the six antennae was included as a possible outcome. Tag size, fish origin, and daylight were included as possible predictors of antenna detection in a stepwise fashion over a series of models, which were then compared using the Akaike Information Criterion (AIC, Burnham et al. 2011). Total detections (after condensing and data cleaning) for each tag size, light condition, and fish origin, were also compared using simple bar graphs.

RESULTS

Habitat Preference Hypotheses 1 and 2: Habitat preference among agricultural substrate and influence of tag size on habitat preference results

For both multi-habitat and control enclosures, the model that included tag size, fish habitat origin (fallow, rice stubble, or stomped), and daylight (day or night) as predictors of a fish being detected at an individual PIT antennae had the lowest AIC value among the set of 7 models compared (Table 2). Model weight, defined as the probability that a given model will be the best in the set of models (Burnham et al. 2011), was negligible for the remaining 6 models for both enclosures. For the control enclosure, all models that included tag size as a predictor of probability of detection had a substantially lower AIC value than those models that did not include tag size (Table 2), suggesting tag size to be an important predictor of detection.

Table 2. Multinomial logistic model comparisons for both multi-habitat and disced-only enclosures.

Model	**AICc**	**df**	**ΔAICc**	**Model Weight**
Multi-habitat Enclosure				
Tag size + Habitat Origin + Daylight	205087.4	25	0	1
Tag size + Daylight	205450.6	15	363.2	<0.0001
Tag size + Habitat Origin	206108.9	20	1021.5	<0.0001
Daylight + Habitat Origin	206191.6	20	1104.1	<0.0001
Tag Size	206458.2	10	1370.8	<0.0001
Habitat Origin	206491.1	10	1403.7	<0.0001
Daylight	207256.0	15	2168.6	<0.0001
Stomped Enclosure				
Tag size + Habitat Origin + Daylight	236374.1	25	0.0	1
Tag size + Daylight	236432.0	15	58	<0.0001
Tag size + Habitat Origin	236609.5	20	235.5	<0.0001
Tag Size	236666.3	10	292.2	<0.0001
Daylight + Habitat Origin	238805.2	20	2431.2	<0.0001
Daylight	238866.0	10	2492.0	<0.0001
Habitat Origin	239082.0	15	2707.9	<0.0001

The condensed data from both enclosures revealed that there were approximately three times as many detections of 12mm tags as 8mm tags (multi-habitat enclosure: total detections of 8mm tags = 13,758, 12mm = 49,155; control enclosure: 8mm = 17,625, 12mm = 53,866). Interestingly, both tag sizes had more detections during the day in the multi-habitat enclosure (total day = 38,288; total night = 24,625), but this pattern was reversed in the control enclosure, with more detections in the night period (total day = 32,118; total night = 39,373). The difference in the daytime and nighttime total detections was divided roughly equally between tag sizes.

In the multi-habitat enclosure, during both the day and night, both 8mm and 12mm tag sizes had the most detections at antennae #5 and #6, which were located in the stomped habitat

(Figure 6). For the 12mm tags, the total number of detections at antennae #1-4 in the fallow and stubble habitats was fairly similar; however, 8mm tags had a slightly larger total number of detections at the antennae located in the stubble habitat (Figure 6). In the control enclosure, both tag sizes had the largest number of detections at antennae #2, 5, and 6 (Figure 6).

Multinomial logistic regression models indicated that in addition to tag size and daylight, the habitat origin of the PIT tagged fish (habitat type of the adjacent experimental fields from which the fish were obtained) also influenced probability of detection at individual antennae. To assess this effect, we calculated the average number of daily detections for individual fish of each habitat origin at each antenna (Figure 7). Bar charts were created separately for each tag size because antennae had different sensitivities for each size (Figure 2). In the multi-habitat enclosure, fish of all habitat origins had the highest average number of detections per day in the stomped portion of the enclosure. This propensity for detection in the stomped portion of the field was apparent for both tag sizes (Figure 7). However, for fish tagged with 12mm-sized tags, fish of rice stubble origin had higher average detection rates in the stubble portion of the enclosure than fish of stomped or fallow origins, and fish of fallow origin had lower average detection rates in the stomped section of the enclosure (Figure 7). Interestingly, this pattern did not hold true for 8mm-tagged fish in the same enclosure: fish of fallow origin had the highest average detection rates within the stubble section, and there was no difference between habitat origins in the stomped section.

While the multinomial logistic regression model for the stomped enclosure suggested that habitat origin explained some of the variability in the likelihood of detection at each of the antennae, the effect does not appear to have been substantial. There were no notable differences in detection rates between fish of different habitat origins at any of the individual antennae (Figure 7). In general, detection rates were highest at antennae #5 and 6, with rivaling rates at antenna #2.

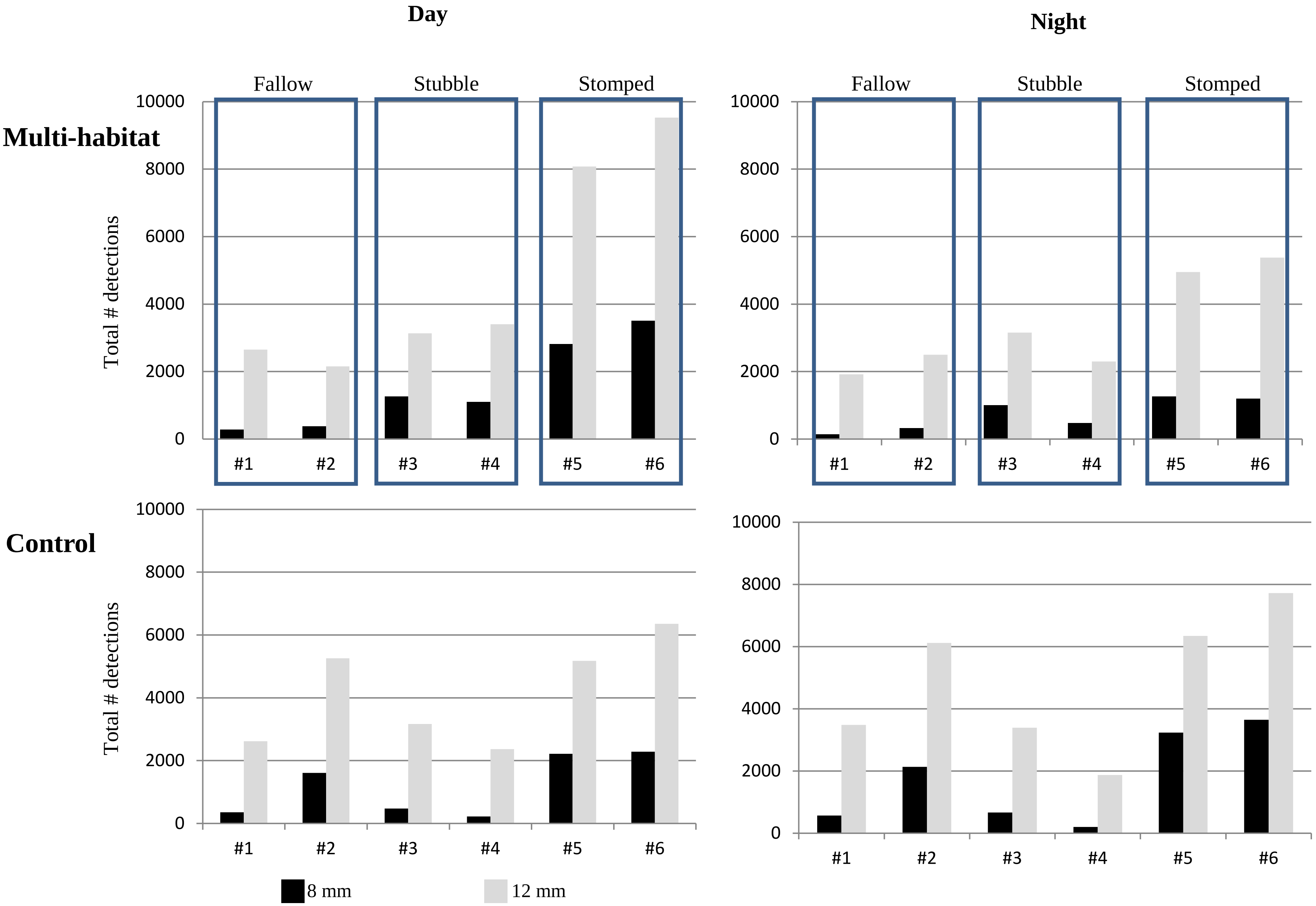

Figure 6. Total number of detections (using condensed data) for 8mm and 12mm tags at each antenna during day and night hours, for both the multi-habitat and stomped enclosures.

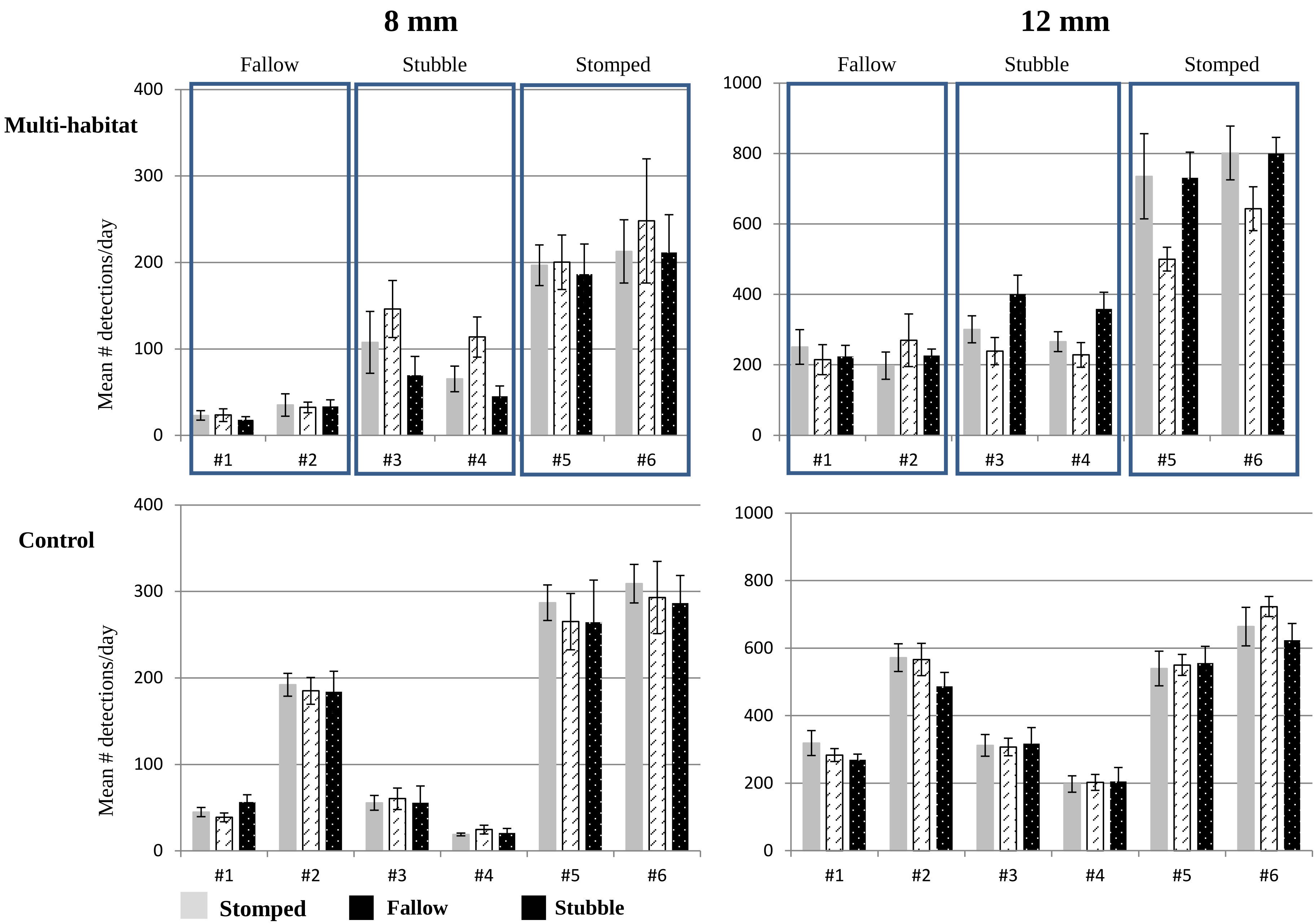

Figure 7. Mean (± SE) number of detections per day (using condensed data) for individual 8mm and 12mm PIT-tagged fish of each habitat origin at each antenna for multi-habitat and stomped enclosures.

Spatial variation in water quality. Mean water temperature from discrete measurements was 14.43 (±3.09 SD) °C, and varied considerably between 7.20 °C on March 23 and 18.1°C on March 25. The temperature record from the data loggers deployed at the inlet, center, and outlet of the study field provided a more complete picture of both spatial and temporal variability in temperature (Figure 3). March 13 and March 27 are excluded from the temperature record because the water was lowered during stocking and draining of the study field during initial treatment and fish recovery. The continuous record reveals a minimum temperature of 6.9 °C on March 23, and a maximum temperature of 21.0 on March 16. Over the course of the study, the temperature differential between the inlet and the outlet varied, with the inlet sometimes being warmer than the outlet, or vice versa. At maximum daily temperatures, the inlet was up to 3°C warmer than the outlet at the outset of the study, but later the pattern was reversed, with the inlet being nearly 4°C cooler than the outlet on March 24 (Figure 3). At minimum daily temperatures, the outlet was generally cooler than the inlet. This switch is likely caused by evaporative cooling on windy days acting to cool the water temperature on the field, while warm, relatively still conditions warmed the water on the study field, creating warmer temperatures at the outlet than the inlet.

Dissolved oxygen averaged 10.13 (± 1.59 SD) mg/L during the study period, ranging from 7.43 mg/L on March 21 and 12.30 mg/L on March 25. The mean pH was 8.36 (± 0.18), ranging only between 8.00 and 8.56. Electrical conductivity was on average 716 μS/cm, but exhibited a declining trend throughout the study period. The first week's average conductivity was 820 μS/cm, while the second week's average was 635 μS/cm.

Within the multi-habitat enclosure, mean turbidity over the entire study period was not notably variable between habitats (fallow = 32.2 ± 18.5 NTU; stubble = 34.6 ± 21.9 NTU; stomped = 40.0 ± 23.7 NTU). However, there was substantial variation among habitats on a daily basis, differing by as much as 40 NTUs on March 21. In addition, turbidity in the control enclosure was consistently lower than or in the lower end of the range of turbidities in the multi-habitat enclosure (Figure 4). Among all habitats and both enclosures, variation in turbidity did not seem to correlate with wind speed data gathered from the Sacramento International Airport (Figure 4).

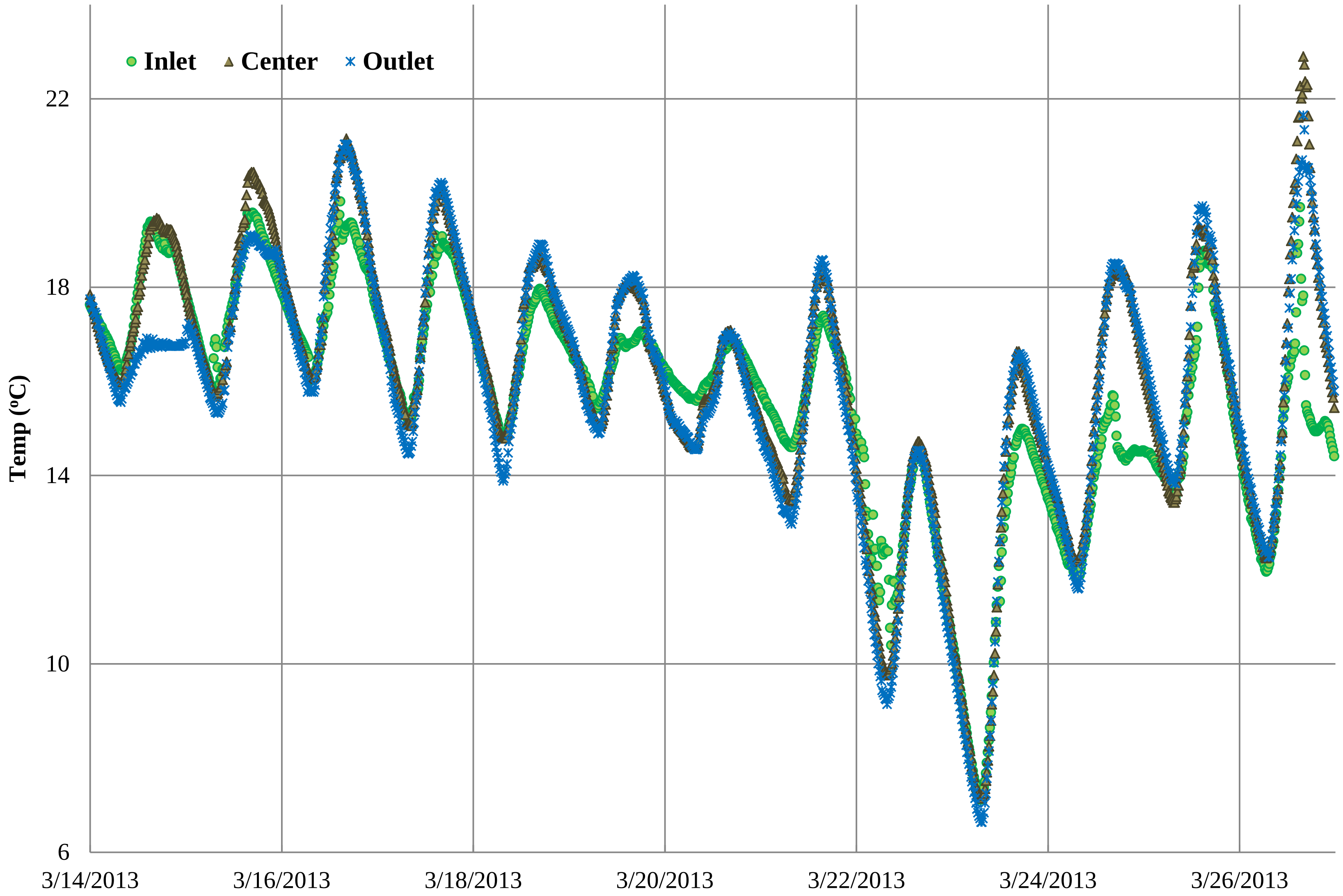

Figure 3. Water temperature (°C) recorded at 15-min intervals from continuously deployed data loggers at the inlet, center, and outlet of the study field.

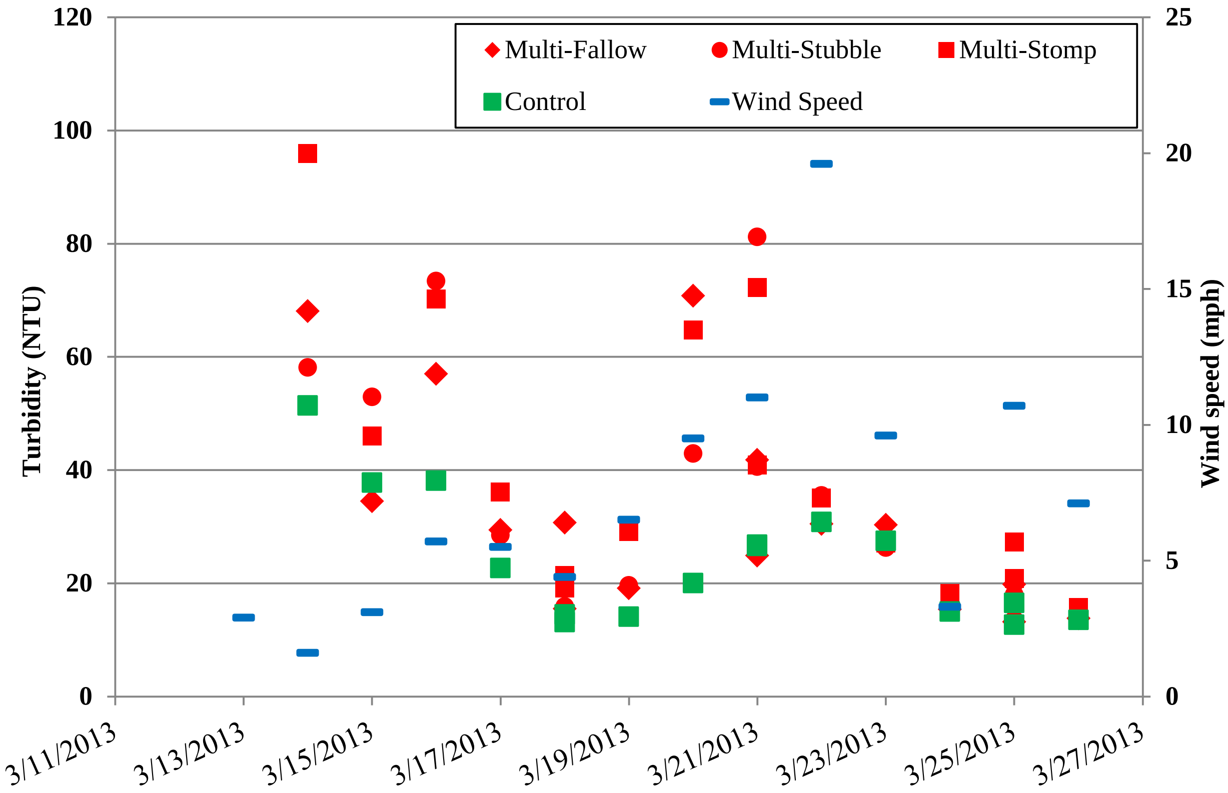

Figure 4. Daily turbidity values for each habitat in the multi-habitat enclosure, the stomped only enclosure, and daily windspeed.

Tagging Methodology Experiment Hypothesis 1: Detection sensitivity – Manual tests of detection sensitivity at each antenna revealed that 8mm tags were detectable only along the edges of the antenna, when the tagged fish was in contact or very nearly in contact with the antenna surface (Figure 2). This limited detection of 8mm tags was consistent among all antennae. Detectability of 12mm tags within the antenna field was substantially better than for 8mm tags, but varied among antennae and habitat treatments. In the multi-habitat enclosure, 12mm tags were always detected 7.6cm from the antennae (Figure 2). However, they were not consistently detected along the horizontal midline of the antenna. In the fallow substrate, the 12mm tag was detected at only 1 of the 2 antennae at 1 detection test point. In the rice stubble treatment, the 12mm tag was detected at 2 of the midline test points, and only at 1 antenna at one of these points. In the stomped portion of the multi-habitat enclosure, the 12mm tag was detected at all of the midline test points, but only at one of the antennae for two of these points.

In the stomped enclosure, the 12mm tag was detected at all 6 antennae 7.6cm above the bottom segment at 3 test points, and at 5 of the antennae at the fourth test point. Along the horizontal midline and 7.6cm below the top segment of the antennae, the 12mm tag was detected at 4-5 of the 6 antennae at each of the four test points.

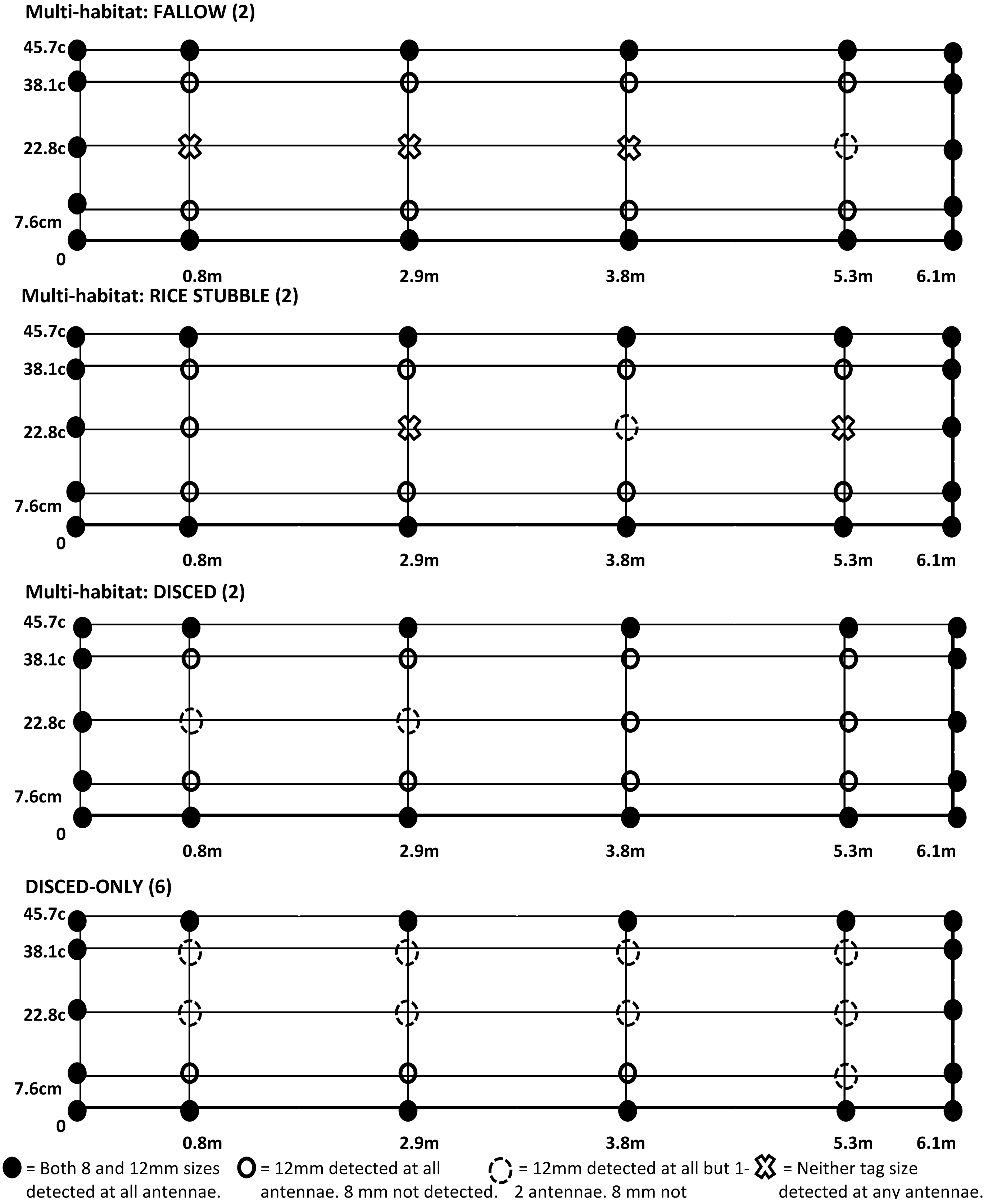

Figure 2. Results of manual detection sensitivity tests for antennae in each enclosure and habitat type. The number of antennae tested is indicated in parentheses next to the figure labels.

Tagging Methodology Experiment Hypotheses 2 and 3: Tag retention and survival.
In both enclosures and for both tag sizes, tag retention was excellent. Only 1 fish in the multi-habitat enclosure originally implanted with a 12mm-sized tag, lost its tag. Survival among tag sizes and surgery group was also roughly equivalent, with only three mortalities occurring during the study period, all in the control enclosure: one 8mm PIT tagged fish, 1 fish that received the scalpel surgery, and one fish that received anesthesia but no surgery.

Table 1. Initial numbers of fish in each tagging or surgery group, and the number of fish in each group that experienced tag loss or died during the study period.

	Initial	Tag Loss	Mortality
Multi-habitat Enclosure			
8mm	21	0	0
12mm	21	1	0
Scalpel only	15	n/a	0
Needle only	15	n/a	0
Anesthesia only	15	n/a	0
Disced-only Enclosure			
8mm	21	0	1
12mm	21	0	0
Scalpel only	15	n/a	1
Needle only	15	n/a	0
Anesthesia only	15	n/a	1

Tagging Methodology Experiment Hypothesis 4: *Effect of tag size and surgery on growth*
FL distributions were not normally distributed for all treatment groups (Shapiro-Wilk tests: Final size for 8mm-tagged fish in the stomped enclosure, $P = 0.04$; initial size for scalpel-surgery fish in the multi-habitat enclosure: $P = 0.006$, final size for needle-surgery fish in the multi-habitat enclosure, $P = 0.006$; $P > 0.05$ for all other treatment groups). Results from Kruskal-Wallis tests for differences in initial and final body sizes of each treatment group showed no differences for either enclosure (control enclosure, initial size: $P = 0.053$; control; enclosure, final size: $P = 0.062$; multi-habitat enclosure, initial size: $P = 0.18$; multi-habitat enclosure, final size = 0.36). Since the P-value for the initial size of the fish in control enclosure was borderline, a Wilcoxon-rank sums test was carried out to test for differences between individual treatment groups, but all of the resulting P-values were greater than 0.05, indicating that there were no important differences in size between groups. Box plots for initial and final fork lengths are shown in Figure 5.

Individual growth rates of PIT-tagged fish were not affected by the tag size; however, growth rates were higher in the multi-habitat enclosure than the control enclosure (two-way ANOVA, FL: Enclosure: $F = 7.7$, $P = 0.007$, Tag size: $F = 1.15$, $P = 0.285$; Weight: Enclosure: $F = 6.67$, $P = 0.012$, Tag Size: $F = 0.005$, $P = 0.945$). Although statistically significant, the difference in growth rates between enclosures was small, with mean growth in length in the multi-habitat enclosure of 1.27 mm/day (± 0.15 SD), while mean growth in the control enclosure was 1.19

mm/day (± 0.12 SD). The difference in average growth in weight was similarly small (multi-habitat: 0.35 ± 0.05 g/day; control: 0.33 ± 0.04 g/day)

Initial Size

Final Size

Multi-habitat

Control

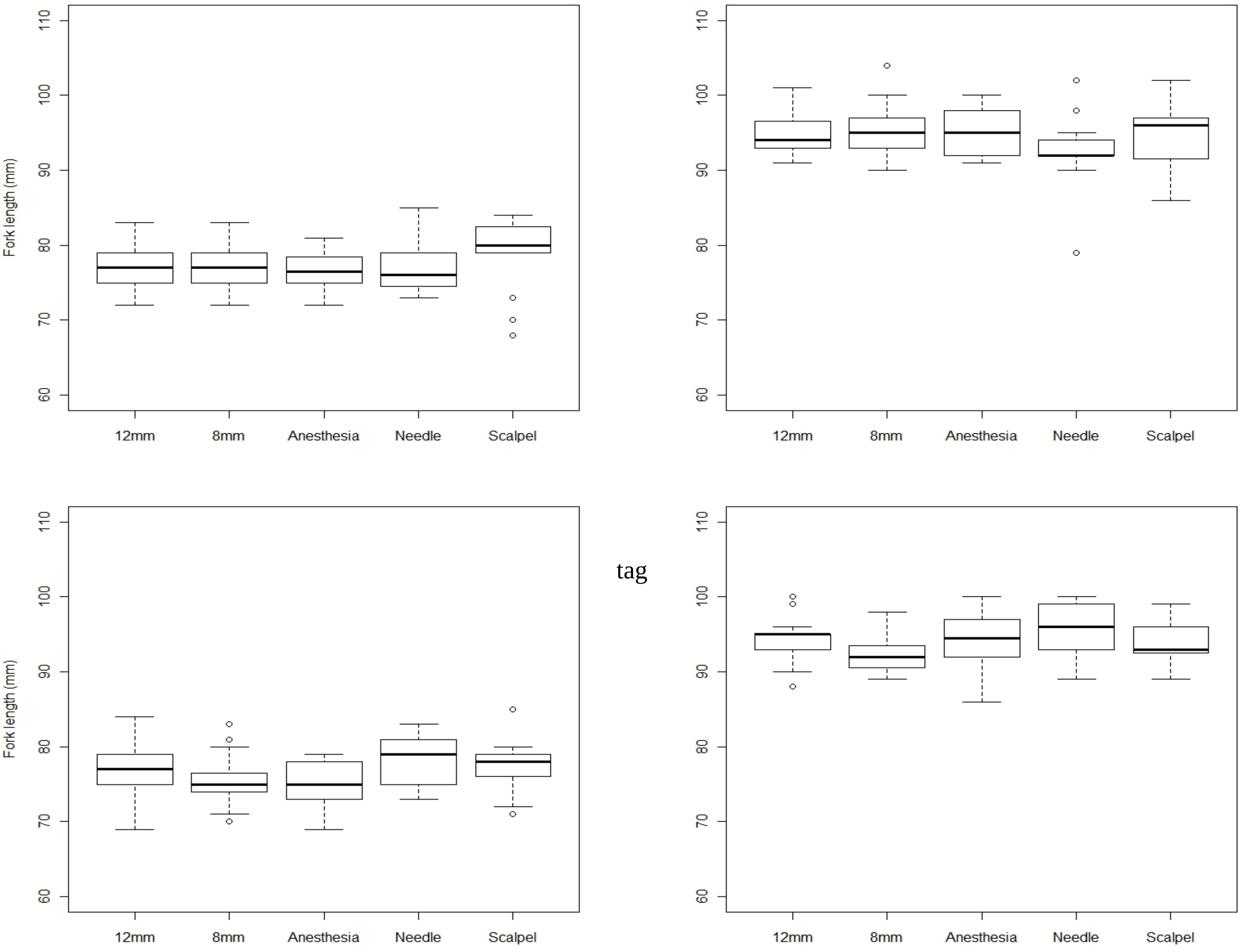

Figure 5. Bo

tag

Discussion

Habitat Preference Among Agricultural Substrates: In this study, we explored a potential method for examining micro-scale habitat use in a managed floodplain environment using PIT technology. A comparison of the relative number of detections between individual antennae shows that both tag sizes relayed a similar story regarding space use within the enclosures. For both of the enclosures, the majority of detections occurred at the upstream pair of antennae, those located in the third of the enclosure that was closest to the inlet (Antennae #5 and #6, Figure 1). These antennae contributed 58% and 52% of all detections, in the multi-habitat and control enclosures, respectively. In the multi-habitat enclosure, concentration of 12mm detections occurred in the stomped habitat where sensitivity tests indicated that tags were most likely to be detected throughout the antenna field, while substantially fewer detections occurred in the fallow and rice stubble habitats where detection gaps existed within the antenna fields (Figure 2). Fish implanted with 8mm tags were detectable at much reduced distances from the antennae, but detection patterns were consistent within the antennae fields. With this reduced yet consistent detection field with 8mm tags, the majority of detections (63%) in the multi-habitat enclosure still occurred at antennae #5 and 6. Similarly, 6% of all detections occurred at these antennae in the control enclosure. The control enclosure also had a fairly high number of detections at antenna #2, but even when combined with the detections at the other antenna in this section of the enclosure (antenna #1, Figure 1), this was only 26% of the total detections of 8mm tagged fish, indicating a propensity for detection at the upstream antennae, even in the absence of habitat (that is, substrate) variation.

Both the light status (day or night) and the habitat of the experimental fields the fish were sourced were also significant in the probability of detection at individual antennae for both enclosures. However, the patterns were not consistent between the enclosures. There were more detections during the day in the multi-habitat enclosure, but more during the night in the control enclosure. With respect to the habitat type of the source experimental fields, some differences were apparent within tag sizes and habitat types within the multi-habitat enclosure (e.g., 12mm-tagged fish from the stubble habitat were more likely than fish from stomped or fallow habitats to be detected in the stubble portion of the enclosure, Figure 7). Regardless of these fine-scale differences, the majority of all detections for all habitat origins and tag sizes were at the most upstream-oriented antennae for both enclosures. Thus, while some differences based on day/night and habitat origin were apparent, these differences were minor compared to the general preponderance of detections at upstream antennae.

Research from stream environments has demonstrated that juvenile salmonids often rely on flow for delivery of food items in the drift (Fausch 1984; Quinn 2005). The general preference for upstream positions observed here may simply be based on the same phenomenon of increased energetic gain from proximity to the food source, although the dominant food source (inflow or emergence of planktonic or invertebrate organisms from the substrate) still needs to be determined. However, flow rates often interact with other environmental parameters, such as water temperature, to influence the potential energetic gain under various flow conditions (Nislow and Armstrong 2012). Particularly when it approaches stressful levels, water temperature can be an important determinant of juvenile spatial salmonid distribution and habitat selection: for example, Sutton et al. (2007) observed fine-scale distribution of juvenile coho salmon (*Oncorhynchus kisutch),* Chinook salmon, and steelhead trout (*Oncorhynchus mykiss)* in a thermal mixing zone of the Klamath River of California, and observed juveniles moving into thermal refugia where temperatures exceeded 22° C, with each species seeking out areas specific to their own thermal tolerances. For Central Valley Chinook salmon, laboratory studies have suggested 17-20°C as a range for optimal growth, when other factors such as disease, predation, and competition for resources are not limiting (Myrick and Cech 2004). The water temperature in the enclosures used in this study never exceeded the acute stress threshold of 22°C, and particularly during the first week of the study, water temperatures were often within the optimal range for growth (Figure 3). However, the outlet temperature was often higher than the inlet temperature, and on several days (March 16, 17, and 26, Figure 3), exceeded 20°C, and was thus outside the published range for optimal growth. If other factors, not measured in this study, interfered with optimal growth, the temperature range for realizing potential growth rates may have been lower than the published range of 17-20°C. Given these possibilities, the statistically lower growth rates observed in the control (more downstream) enclosure may have been the result of higher water temperatures than in the multi-habitat enclosure. In addition, the apparent preference for upstream locations may not simply be a flow preference, but also a preference for cooler water. Interestingly, although water temperatures did not exceed an acute stress threshold at which mortality rates are expected to increase, three mortalities occurred in the warmer, more downstream enclosure, while none occurred in the more upstream, cooler enclosure.

Influence of Tagging Methodology on Detection Sensitivity, Tag Retention, and Fish Growth: Results demonstrated equivalent tag retention, survival, and growth rates between juvenile Chinook Salmon tagged with 8mm and 12mm PIT tags. While detectability of the two tag sizes was measurably different in the custom-designed antennae for this project, there were no substantial differences in habitat use results between tag sizes. These results provide a foundation for expanded research using PIT technology to understand juvenile salmon habitat use on managed and natural floodplain environments.

Tag loss and mortality was minimal for both 8 and 12mm tag sizes, and control groups that received a sham surgery or anesthesia without surgery also had excellent survival (Table 1). Only 1 PIT-tagged fish died during the entire study (8mm-tagged fish in the control enclosure). Only two other mortalities occurred, both in the control enclosure, one from the group receiving a sham scalpel surgery, and one from the group receiving anesthesia without any surgery. Surgical method and tag size also had no effect on growth rate (Figure 5). These results are consistent with previous research demonstrating excellent survival and growth and minimal tag loss with these tagging procedures (Ombredane et al. 1998; Gries and Letcher 2002; Richard et al. 2013). However, it is important to note that the initial size of the fish used in this study (mean FL 77mm ± 3mm SD) were well above the size at which the tagging procedure or the tag burden is likely to influence survival or growth. Richard et al. (2013) demonstrated no effect of tag implantation method in juvenile brown trout that were greater than 55mm FL, but significant effects of PIT-tagging with 12mm tags on fish less than 55mm FL. Thus, it is not surprising that effects of surgery method or tag size were not observed.

While the tag size had minimal effects on fish performance, there were substantial differences in detectability of the tag sizes within antennae. 8mm tags were detectable only when they were touching or within a few centimeters of the antennae, and this pattern was consistent across all habitat types and antennae. 12mm tags, in contrast, had a broader readability range, but were not reliably detected once they were 7.6cm or more separated from the antenna surface (Figure 2). In addition, there were important differences in detectability between habitat types within the multi-habitat enclosure, with more substantial gaps in detectability in the fallow and rice stubble habitats. These habitats also contained the most vegetation, which could introduce interference. This issue can be thought of as analogous to variation in sampling efficiency across habitat types for traditional, active sample methods such as seining, trawling, or electrofishing (Hayes et al. 1996). While it should not be ignored, biases in efficiency occur with nearly every sampling approach. Given the results from the manual sensitivity tests, it was not surprising that tag size had an important effect on the total number of detections. This difference in detectability was almost certainly the major factor that influenced the result that tag size was an important predictor of the probability of detection in the multinomial logistic regression models.

CONCLUSION

While typical applications of PIT technology include linear, stream-like systems, alternative systems can also be developed for shallow-water habitats that are also crucial in the salmonid life history. This study represents a pilot effort using enclosures that generated a voluminous dataset on habitat use in a small area. Given the condensing procedure that was necessary in order to effectively manage the dataset, it is likely that a reduced sampling density (lower density of antennae) would also generate a dataset that may be equally informative and possibly more manageable to the one created by the design tested in this study. A reduced sampling density may make this approach more feasible over a larger area.

In addition, despite differences in detection sensitivities, there were no important differences in habitat use results between 8 and 12mm tags. Similar patterns in habitat use between tag sizes may not always occur across study designs that differ in sampling densities, environments, and antennae designs; however, this study suggests that 8mm tags may provide adequate data even when detectability is reduced compared to 12mm tags. For many applications, the ability to tag smaller fish using smaller tags may provide an opportunity to collect individual-level habitat use, growth, and migration timing data on salmonid fry, a life stage for which this information largely not been available despite an increasing management need given the decline of Chinook Salmon and other salmon species along the Pacific coast.

Finally, juvenile Chinook salmon exhibited no strong signal of preference among fallow, rice stubble, and stomped agricultural substrates. In contrast, detection probability was heavily concentrated toward upstream areas both in the presence and absence of substrate variation. While further studies will be necessary to assess habitat preference in natural floodplain environments, results from this study indicate that post-harvest treatment of rice fields may not influence the likelihood of juvenile salmon occupancy, although there may be land treatment effects on other aspects of habitat (chapter 1 of this report). This result suggests in potential management scenarios utilizing rice fields as managed floodplains during the non-growing season, that farm managers may have some flexibility in post-harvest land treatment.

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Chapter Three:
2013 Floodplain Extension Pilot Study at Knaggs Ranch on Yolo Bypass

Prepared By:

Lynn Takata, Ted Sommer, Steve Brumbaugh, Louise Conrad,
and Naoaki Ikemiyagi
of the California Department of Water resources;

Carson Jeffres and Nick Corline
of the UC Davis Center for Watershed Sciences

and Jacob Katz of California Trout

INTRODUCTION

This chapter reports results of a pilot project designed to evaluate the feasibility of extending natural flood events on Yolo Bypass during winter/spring of 2013 using local agricultural infrastructure and water sources.

Study Location - Knaggs Ranch, Yolo Bypass: The flood extension portion of the study was conducted over approximately 20-acres (8 ha) of the southeast field of the Knaggs Ranch (Field 8: Figure 1). The year prior to the study the field was fallow and covered in herbaceous vegetation. The primary work occurred in the downstream (easternmost) cell which received drainage water from the rest of the field (Figure 2). The Knaggs property is an agricultural parcel with a total acreage of 1703.55 acres. The site is near the top of the Yolo Basin, north of Interstate 5. A drainage canal called the Knights Landing Ridge Cut enters the Knaggs property at its northwest corner. This canal was built early in the century to connect the Colusa Basin Drain with the Yolo basin to pass accumulated flood waters into the Yolo bypass while minimizing flooding of neighboring lands. Currently 1,571.6 acres of the ranch are under lease and farmed to rice, with an average yield of 88 sacks per acre. The rice is irrigated with water from the Colusa Basin Drain/Knights Landing Ridge Cut supplemented with ground water from on-site wells. The predominant soils on the property are Clear Lake, Sycamore complex and Langenour very fine sandy loam.

Primary Study Goals

1. Evaluate the potential use of managed lands to extend natural flood events and improve floodplain food web production and salmon rearing.
2. Develop recommendations and refinements for subsequent years of study.
3. Compliance with the 2008 NMFS OCAP Biological Opinion—salmon habitat.

Note that the pilot flood extension study component is not intended as a proof-of-concept for managed flooding of Yolo Bypass. Rather, it is intended as part of a continued effort to develop and refine methods, and collect important initial information about fish and food web responses.

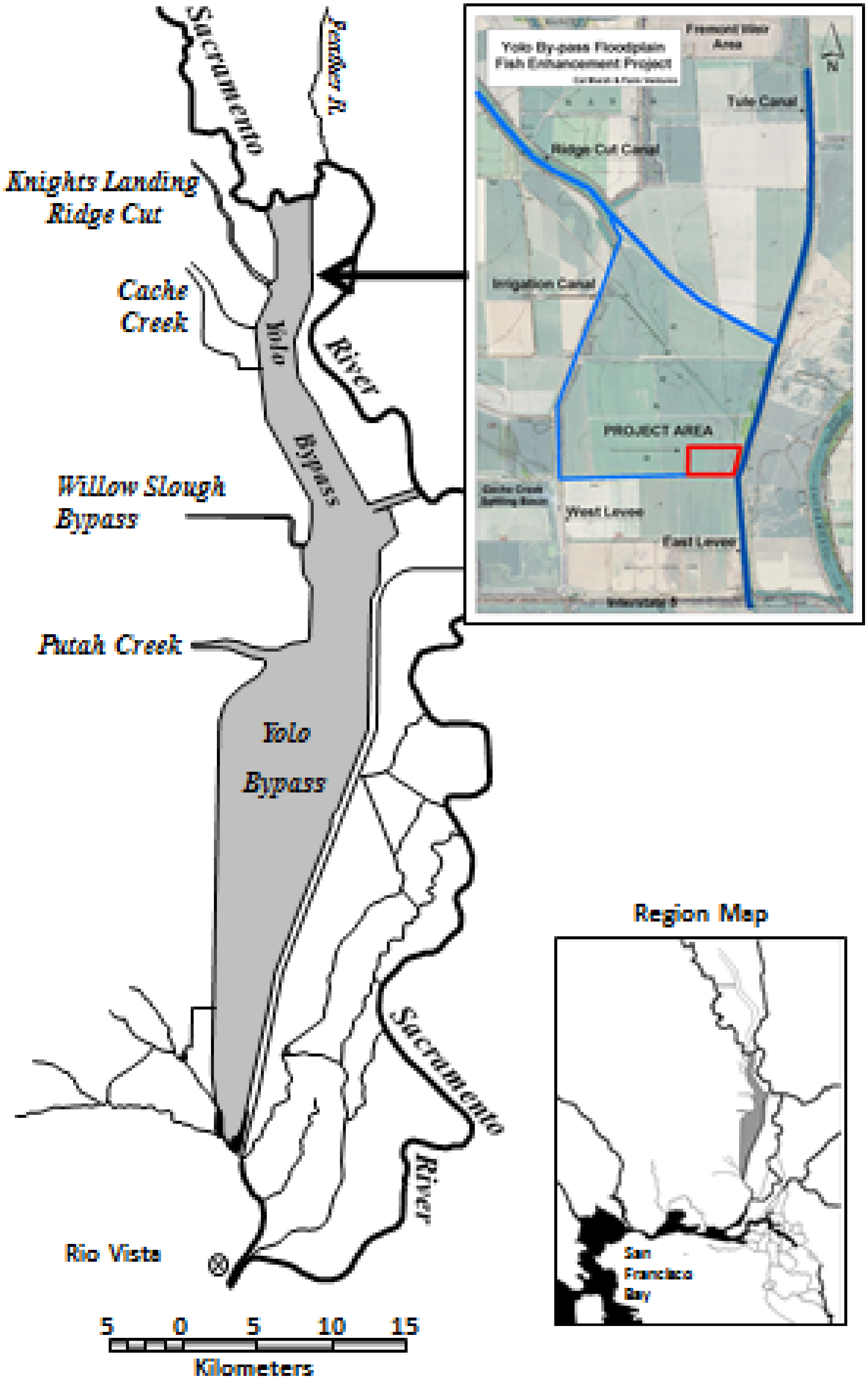

Figure 1. Location of Knaggs Ranch Study Site.

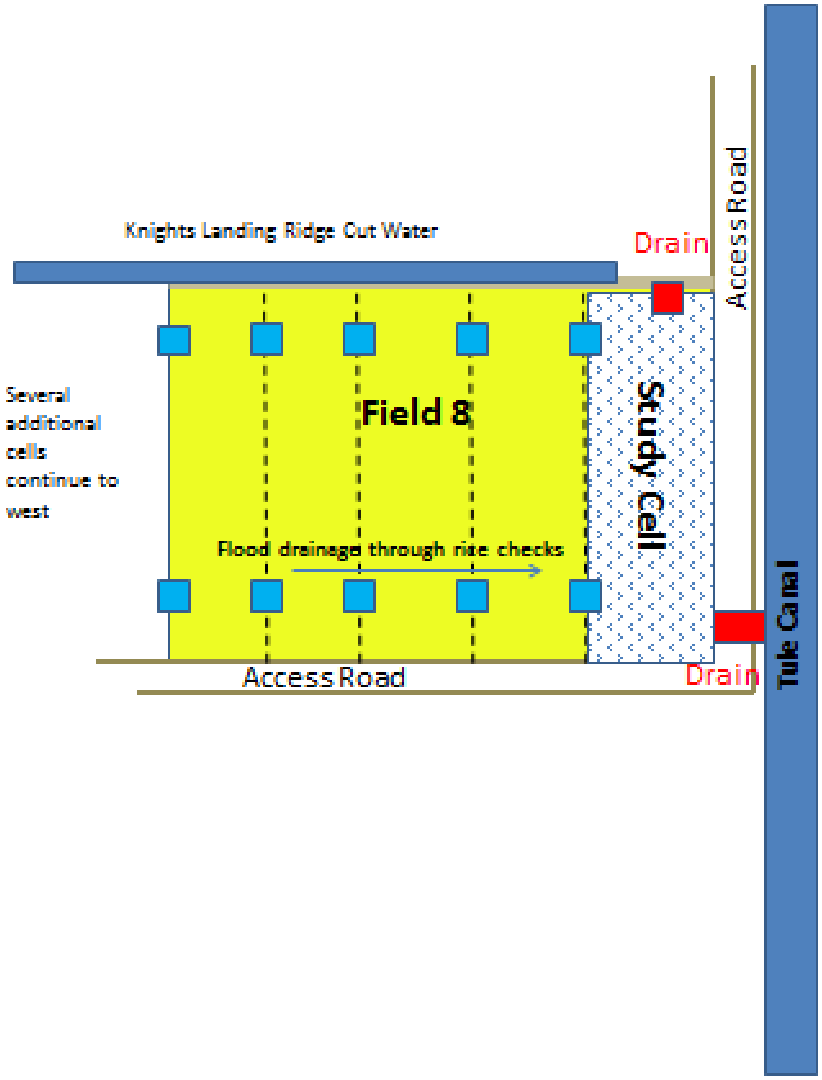

Figure 2: Conceptual design for Knaggs flood extension study component. Note that features are not to scale.

Study Questions

1. Hydrology
    a. Can existing land structures and local water sources be used to extend natural flood events in Yolo Bypass?
2. Water quality
    a. Are water quality conditions (temperature, dissolved oxygen, pH, turbidity, conductivity) in the pilot floodplain adequate for survival and growth of juvenile Chinook salmon?
    b. How do temperatures and turbidities on the managed floodplain differ from those in the Sacramento River?
3. Food web.

    a. Does extension of a natural flood event generate higher plankton and drift invertebrate levels and communities compared to the adjacent Sacramento River and Yolo Bypass Tule Canal/Toe Drain?
    b. Does the managed extension of a natural flood event generate similar plankton and drift invertebrate levels and communities compared to historical Yolo Bypass flood events?
4. Fish
    a. Does the managed floodplain habitat support similar juvenile Chinook growth rates to those documented in past natural flood events on the Yolo Bypass?

METHODS

Study Timing: The study occurred in January and February of 2013, following a short high flow event that started in late December 2012.

Floodplain Design and Study Approach: Field 8 is approximately 200 acres and 0.3-0.65 m deep, and the easternmost cell of the field that was the focus of the flood extension study was approximately 20 acres (8 ha; Figure 2). After natural floodwaters recede, the fields drain eastward into the study cell, located closest to the Tule Canal (Figure 2). Habitat diversity was minimal since early local flooding of the study area precluded the construction of other habitat types. The field had been kept fallow during the growing season prior to the pilot study.

Fremont Weir began to spill late on Christmas Eve, 2012. Overflow ceased five days later on Dec. 29, 2012. Immediately prior to this event, flashboards topped with a perforated plate screen were placed in the southeast drain of Field 8 to retain water and limit fish emigation. The expected outcome was that any retained fish could utilize shallowly inundated habitat that would have otherwise rapidly drained. As floodwaters receded, fish would become gradually concentrated in the final cell of Field 8 (Figure 2).

A second drain in the northeast corner of Field was not noticed until January 10, when it was closed. Fish emigration may therefore have occurred during this period. Throughout the study, there were limited inputs to Field 8 from surrounding upstream fields, which helped maintain flooding in multiple cells throughout the study period. A positive aspect of this inflow was that no additional management was needed to provide inflow. A negative aspect was that excessive inflows on January 23 overtopped the study cell, flowing over the access road and into the Toe Drain.

Physical and Chemical Sampling: Water temperature, Secchi depth, turbidity, and weather were recorded on all sampling days. Onset temperature loggers were deployed at the Sacramento River Sherwood Harbor dock, the Yolo Bypass Toe Drain screw trap site, and at Lisbon Weir near the Yolo Bypass fyke trap site. The loggers were visited every two weeks throughout the sampling period to download data using an optic shuttle. Conductivity was measured periodically using a portable EC meter. Flow data for Yolo Bypass was recorded on a spreadsheet using data from California Data Exchange Center and Solano County Water Agency (Putah Creek only).

Food Web Sampling: As in 2012, invertebrate drift and zooplankton was collected weekly with nets manually towed in the field (e.g. Limm and Marchetti 2009). A DWR crew used fixed nets to collect comparative zooplankton and insect drift samples from the Yolo Bypass screw trap site and from the Sacramento River at Sherwood Harbor (methods detailed in Sommer et al. 2004). The drift net dimensions are 0.46 m x 0.3 m at the mouth, 0.91 m long, and 500-μm mesh. Zooplankton sampling was conducted with a Clarke-Bumpus net. Nets were fished for approximately 10 minutes during mid-morning and volume is recorded using a flow meter (General Oceanics Model 2030R). Yolo Bypass zooplankton, drift, and chlorophyll a grab sampling was conducted every other week on an ebb tide during dry or unflooded conditions and weekly when the Bypass is inundated. Each sample had a tag and was preserved in Formalin. Toe Drain and Sacramento River zooplankton and insect drift samples were analyzed by DWR contractors, but the Knaggs samples were analyzed by UCD.

Weekly Chlorophyll-a grab samples were collected from the pilot floodplain (inlet and outlet), lower Yolo Bypass, and Sacramento River at Sherwood Harbor (Mueller-Solger et al. 2002; Schemel et al. 2004). Chlorophyll samples were analyzed by the DWR Bryte Laboratory (lower Yolo and Sacramento River) and UC Davis (pilot floodplain).

Fish Sampling: The main tools used to sample salmon and other species throughout the study were beach seining and fyke net trapping at the outlet. All species collected were identified, counted, and measured (FL). Pilot floodplain seining was conducted using a similar approach to Sommer et al. (2005, 2008). Weekly collections took place in several locations around the project perimeter. Additional fish were collected in a fyke net at the outlet of the field starting on January 29, 2013, when field drainage was initiated. The nets were fished intermittently during drainage through February 14, 2013 with sets ranging from 1 hr to 12 hours.

Additional comparative data were taken from Yolo Bypass rotary screw trap collections of emigrating fish. A parallel beach seining effort was conducted at established stations located around the perimeter of the Yolo Bypass (outside of the study area) on a biweekly basis. Data collected from adjacent Sacramento River FWS beach seine stations also were used for comparison.

Fish Growth: Size measurements throughout the study were used to evaluate the mean growth rate in the floodplain wetland (mm FL/day). Results for wild fish were compared graphically to parallel measurements in the Sacramento River and historical Yolo Bypass flood events.

Category	Metric	Historical Yolo Comparison	Sacramento River Comparison	Inlet vs. Outlet	Comments
Physical & Chemical	Bathymetry	X			Aerial photography. Surveying.
	Inundated Area	X	X		As above
	Floodplain flow	X	X		Manual gaging
	Residence time	X	X		Calculated - area, flow estimates
	Temperature	X	X	X	Continuous loggers (2)
	Turbidity/secchi	X	X	X	Discrete sampling
	DO	X	X	X	Discrete sampling
	pH	X	X	X	Discrete sampling
Vegetation	Habitat map	X			
Fish	Salmon Growth	X	X		Initial vs. final size; seine FLs; RSTR FLs Stable isotopes; diet studies (optional)
	Fish Community: Abundance	X	X		Beach seine, fyke
	Fish Community: Percent alien and predators		X		Beach seine, fyke
Food web	Chlorophyll *a*	X	X	?	Discrete
	Zooplankton species & density	X	X		Discrete
	Drift species & density	X	X		Discrete

Table 1. Proposed metrics for pilot Yolo Bypass floodplain study.

RESULTS

Hydrology: Yolo Bypass flooding can originate from several sources. The main source is through Fremont Weir, located 7.3 km north of our experimental field. When stage at the weir exceeds 10.2 m, water begins to spill over and into the bypass. Bypass inundation is also fed by four western streams that augment Fremont Weir flows, and can cause localized inundation even before Fremont Weir reaches flood stage (Sommer et al. 2001a). Inundation at 2013 pilot study site as initially from Fremont Weir, followed by drainage flow from upstream fields. Minor overtopping at Fremont Weir occurred from December 6 through December 8, cresting at levels less than 6 inches above the top of the weir. A more significant flooding event began late in the night on December 24. This event lasted approximately 4 consecutive days with a maximum elevation of 34.98 feet, approximately 1.5 feet above the crest (Figure 3). Flooding during this event was more extensive, and marked the beginning of the flood extension study.

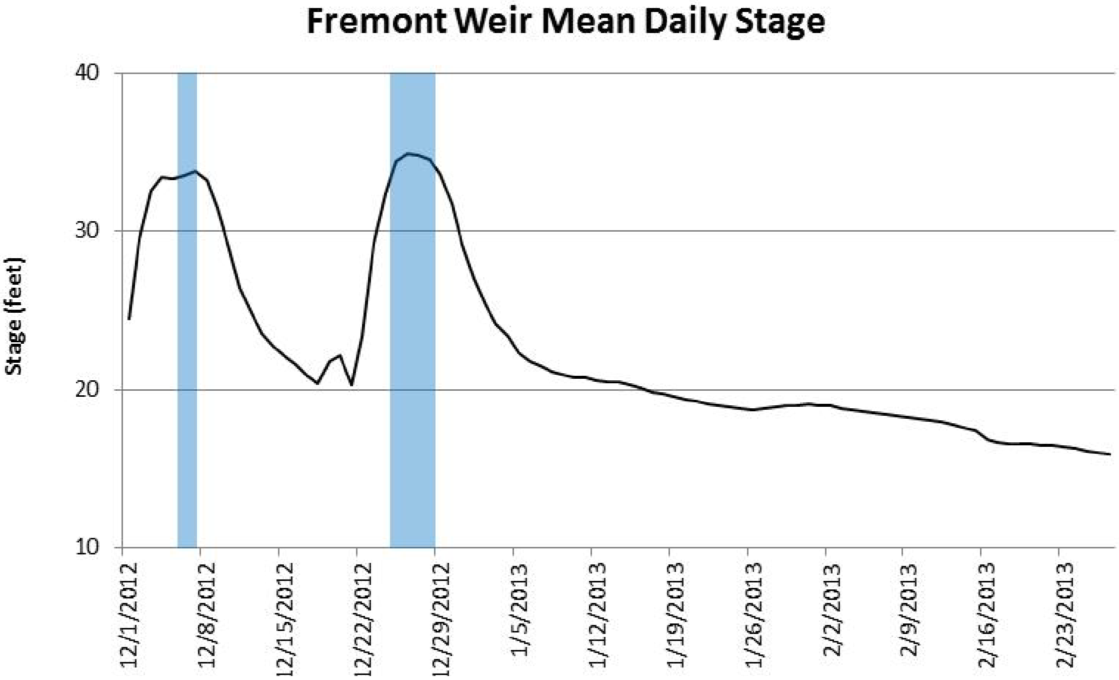

Figure 3. Mean daily stage (m) at Fremont Weir. Blue denotes periods of weir overspill.

Tributary Inputs to Flooding: Contributions from the western tributaries were examined via the combined flow inputs of South Fork of Putah Creek and Yolo Bypass as measured by the USGS gage near Woodland. Localized flooding began before and continued after both overtopping events at Fremont Weir. On December 3 inundation from the tributaries began approximately 3 days before the Weir overtopped, and continued 6 days after overspill ceased. One day before the more significant overtopping event, the tributaries began to flood (December 23) and continued for 13 days.

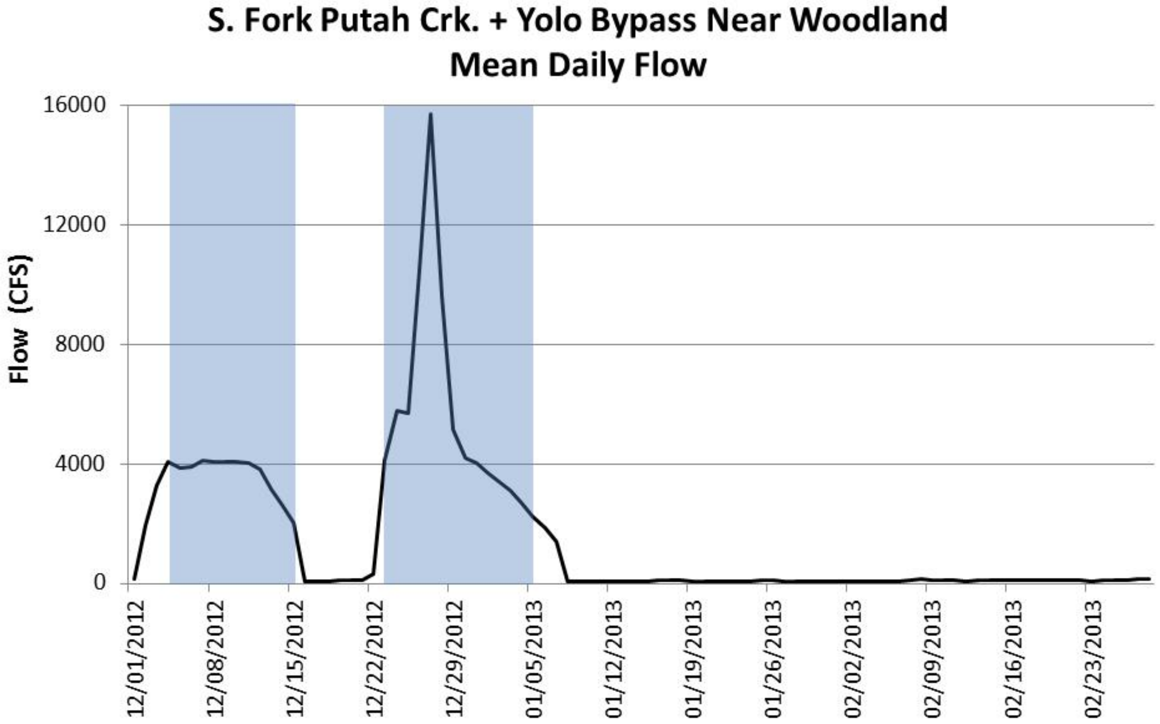

Figure 4. Flow inputs from the western tributaries to the Yolo Bypass. Blue shading denotes periods of significant flooding.

Experimental Field Water Dynamics: Flashboards and screens were placed in the southern outlet of Field 8 on December 21, prior to the Fremont Weir overtopping on Christmas Eve, in order to extend the duration of the anticipated flooding event. Subsequent floodwaters from the Sacramento River, and the western tributaries of Knights Landing Ridge Cut and Cache Creek initially filled the field. Fish sampling (seine) and water quality monitoring began on January 4 and continued until the field was drained on February 14. Once sampling and monitoring began, supplemental water flowed into Field 8 from surrounding upstream fields.

Field depths remained between 0.3 – 0.65 m during the study, with the exception of the period around January 23 when debris clogged the outlet drains, briefly raising water levels above the levee road along the eastern border of the field. Debris was cleared and input flows were reduced, returning the water to its previous levels. During this holding period, flows were extremely low.

The screen and upper flashboards were removed from the southern outlet on January 29, initiating the drainage phase. During the first week, water levels in the westernmost cells of Field 8 quickly dropped, while levels in the 4-5 easternmost cells remained at levels similar to the holding period. Due to the slow pace of the draining process, on February 4 additional boards were removed from the northern outlet and from between the cells of Field 8 in order to expedite drainage. Drainage was completed on February 14.

Temperatures and Turbidity: Water temperatures in the experimental field were generally warmer and more variable than those in the adjacent Sacramento River and bypass Toe Drain. This was especially evident when air temperatures rose significantly during the latter portion of the experimental period. Before January 18, maximum air temperatures ranged between 7.2° and 15° (C), whereas after that date they ranged from 12.8° to 20.6° (C). Water temperatures in the shallow field likewise rose over 13 ºC between January 24 and Feburary 14. Water temperatures rose in the Toe Drain and Sacramento River only 2-3 ºC during the same time period.

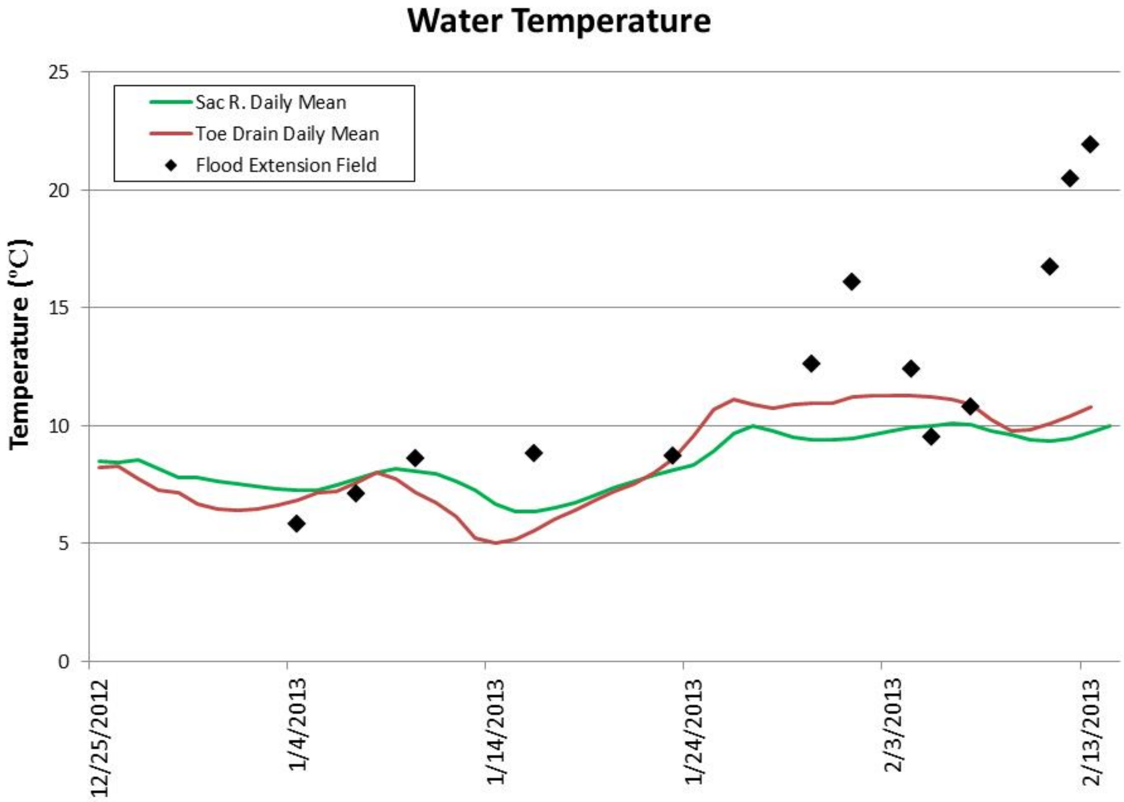

Figure 5. Daily mean water temperatures in the adjacent Sacramento River, Yolo Bypass Toe Drain, and experimental Field 8.

Turbidities were very high in both the Toe Drain and Sacramento River during the main overtopping event, but immediately dropped after December 29 when overtopping ceased. Sacramento River turbidities remained lower than those in the Toe Drain and experimental field throughout the experimental period. In the experimental field, turbidities continuously declined with time following the overtopping event.

Food Web: Food web data from this study are still being analyzed, so the results were not available for this report.

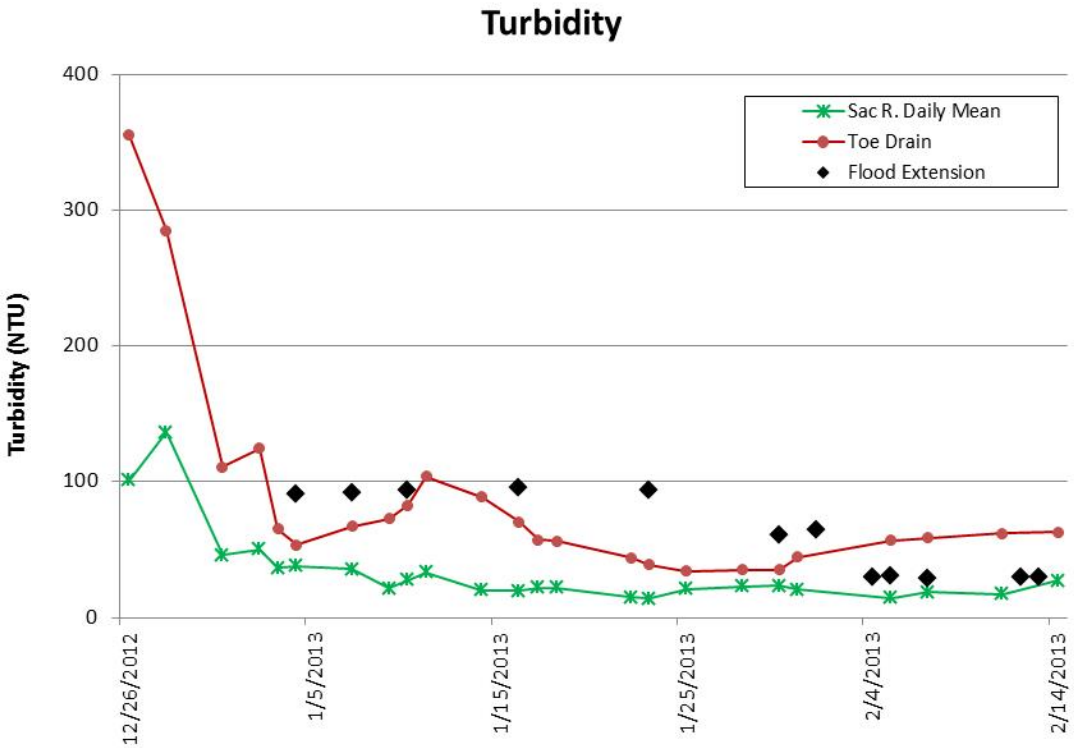

Figure 6. Turbidities during the experimental retention and drainage period.

Fish Data: A total of 7 salmon were captured during the study, with five caught in seine hauls conducted during the retention period (Table 2). Given the size of the eastern cell (8 ha), these densities were very low compared to typical levels of around 100-900 fish/ha (Sommer et al. 2005). Note that the Sommer et al. (2005) data are based on sampling during drainage events later in the winter, when there may have been more juvenile salmon moving through the Sacramento River watershed.

Species	Seine Catch (Retention)	Fyke Catch (Drainage)	Total Catch	Size Range (mm)
Mosquito Fish	6	105	111	26-45
Inland Silverside	1	50	51	47-80
Chinook	5	2	7	36-59
Bluegill	1	6	7	36-56
Threadfin Shad	5		5	62-96
Black Crappie	2	2	4	114-155
Carp		3	3	45-93
Black Bullhead		2	2	49-59
Prickly Sculpin		1	1	83
Logperch		1	1	90

Table 2. Fish catch during the holding period and drainage.

Mosquitofish dominated fish caught at drainage, with inland silverside being the second most frequent catch. Only two Chinook salmon were caught during drainage subsampling. Very few fish of large enough size to prey on the Chinook (Pelham et al. 2001) were captured in the field.

Salmon Size & Growth: Salmon captured in the experimental field appeared to be similar in size to those captured in the Toe Drain and Sacramento River during the first two weeks following inundation (Figure 7). After three weeks, however, lengths of Chinook in the experimental field and Toe Drain appear larger than those captured in the Sacramento River. Fish from both systems appear to be well above mean length of fish seined at adjacent sites in the Sacramento River. However, this is due at least in part to continual immigration of small fish from upstream reaches of the Sacramento River, which would result in a lower apparent growth rate.

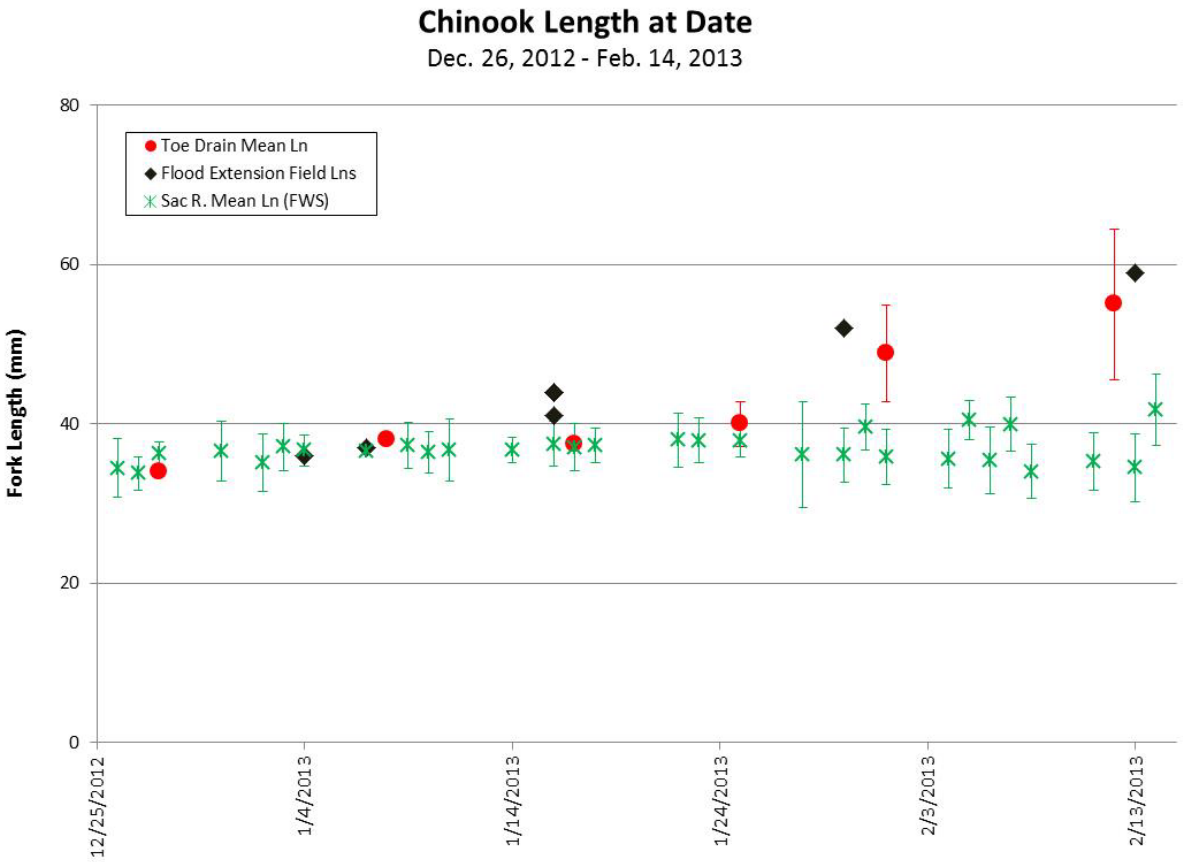

Figure 7. Wild (unmarked) juvenile Chinook length at date of capture. Means are presented for the Yolo Bypass Toe Drain and the Sacramento River. Bars denote standard deviation. For the experimental field, individual measurements are presented.

Since 1998, timing of Fremont Weir overtopping in late December through the first week in January (similar to our experimental flood extension period) occurred 5 times: 2002, 2003, 2004, 2006 and 2011. Sizes of Chinook salmon captured in the flood extension field were similar to unmarked fish captured in the Yolo Bypass during these years (Figure 8). In contrast, the fish in the 2013 flood extension study appeared larger than those captured historically in the Bypass when overtopping began after the second week in January (1998, 1999, 2000 and 2010)

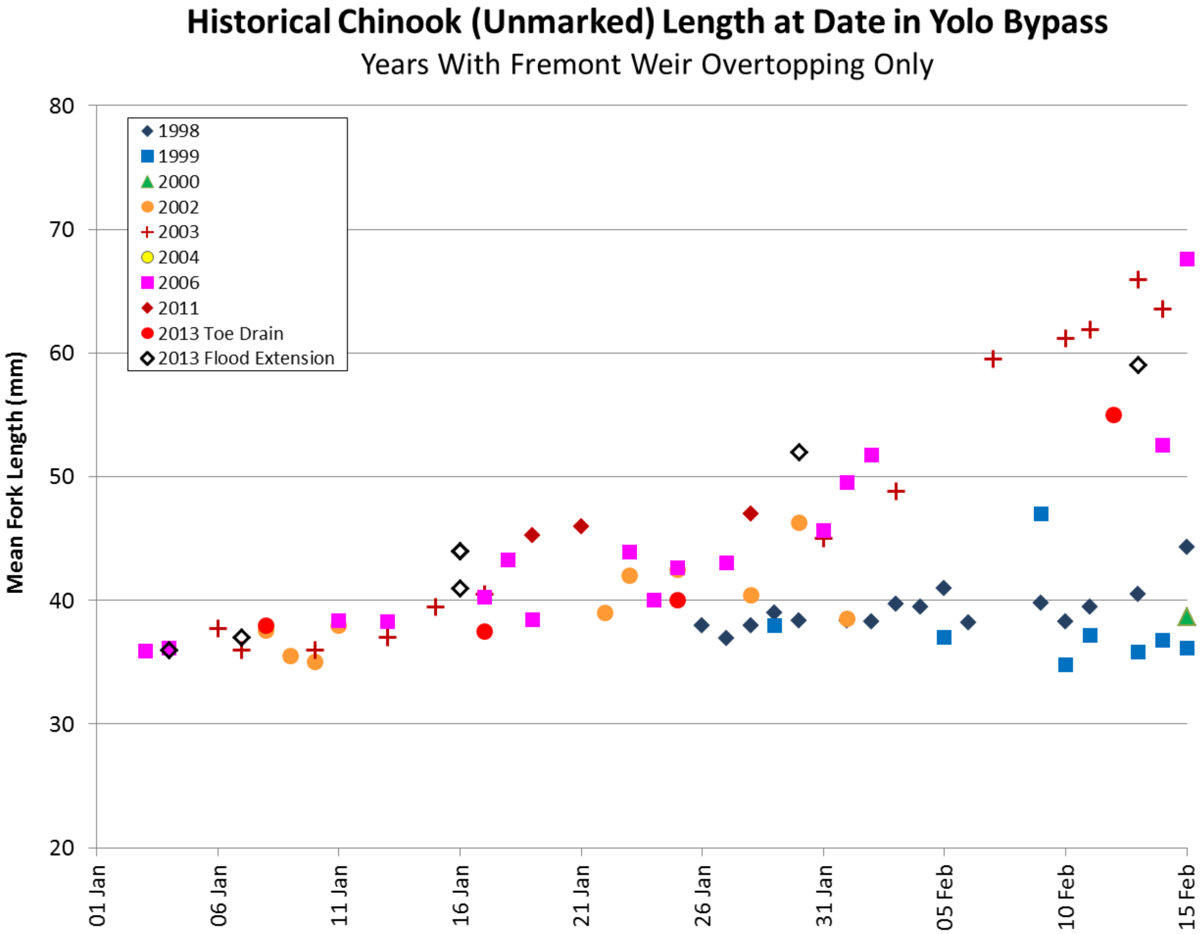

Figure 8. Mean length at date of wild (unmarked) Chinook salmon captured in the Yolo Bypass during years when overtopping occurred at Fremont Weir. Warm colors denote years where overtopping began January 4th or earlier. Cool colors denote years where overtopping occurred after the second week in January.

DISCUSSION

This study was designed as a pilot effort to examine the feasibility of using local water sources and existing agricultural infrastructure to extend inundation duration over agricultural lands in northern Yolo Bypass, thereby allowing juvenile salmon longer occupancy in these rearing habitats. Emphasis was placed on evaluating key logistical features and constraints in order to inform more intensive efforts in the future. As described below, we consider this pilot effort successful as it helped us identify some of the key physical and biological issues which will need to be addressed by future studies.

Water Management: Based on this pilot effort it appears that extending the duration of a Yolo Bypass flood event given existing agricultural infrastructure is feasible. The pilot project extended water residency for more than 1 month following inundation. By placing flash boards in the drains of rice fields prior to flooding, floodwater recession can be managed and inundation prolonged. Screening the top of the drains enables drainage while retaining fish.

Water management in the experimental field presented some challenges, however. Two relatively small drains in the primary eastern study cell provided the only drainage for the entirety of Field. Excessive drainage flow from the upslope portions of Field 8 combined with clogged outlet screens from algal buildup and other vegetative debris, resulted in water rising above the levee elevation and spilling freely in two locations; to the east into Toe Drain and on the north into a drainage ditch and from there into the Toe Drain. Final drainage of the field also took considerably longer than anticipated (nearly 3 weeks). These complications hindered our 2013 efforts to quantify potential benefit to juvenile salmon. However, relatively minor improvements to the drainage infrastructure of Field 8 planned for the 2014 field season should resolve these flow issues. Improvements could also serve to hydraulically isolate the study cell from the rest of field 8, should that be deemed desirable. In addition, improvements will be made to the fish screening methodology including use of trash racks and/or more frequent cleaning of the screen to avoid clogging. If fish density following a 2014 natural inundation event is as low as documented in 2013, it may be necessary to supplement the field with fish obtained from Feather River Hatchery in an effort to better quantify the survival and growth benefits of flood extension.

Fish: While there were a large number of non-natives captured during sampling, only one seemed to be large enough to pose potential predatory risk to the size of Chinook salmon that were captured, a 155 mm black crappie. However, black crappie of similar size studied by Pelham et al. (2001) preyed on fish to a lesser extent than other piscivores, and only to approximately 35 mm or less in length suggesting that little real predation risk. The majority of non-natives in our pilot study were inland silversides and gambusia, which is not surprising given widespread mosquito abatement efforts throughout the region.

Few salmon were caught through the course of the flood extension pilot study, likely due to some combination of the following four scenarios: 1) sampling for the salmon was inefficient, 2) fish were widely dispersed within the study field, 3) fish escaped during the short period where a screen was lacking in one of the drains, or during overtopping of the surrounding levees, 4) relatively few wild juvenile salmon entered Yolo Bypass during this early season flood event. The latter three scenarios are more likely than the first, since the methodologies employed for sampling have been used extensively and effectively in the Yolo Bypass. Our hope is that conducting a more intensive effort in future years with later (more normal) Fremont Weir overtopping will generate higher densities of salmon migrants in Yolo Bypass. Despite the small number, of fish captured, the study does provide limited evidence that flood extension may provide juvenile salmon with growth benefits similar to historical natural flooding events.

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Contacts for Project Affiliates

California Trout
Jacob Katz
Director of Salmon and Steelhead Initiative
Central California Region Manager
jvkatz@ucdavis.edu
office: (707) 836 0769

Jake Messerli
VP, Conservation Programs
1346 Blue Oaks Blvd.
Roseville, CA 95678
(916) 648-1406 ext. 141
JMesserli@calwaterfowl.org

Cal Marsh and Farm, LLC.
John Brennan
Principal
530-870-6625
pfbsons@frontiernet.net

David Katz
Principal
office: (707)578-8347
cell: 707 484-6283
davidkat@sonic.net

California Department of Fish and Game
Jason Roberts
Water Branch
830 S Street
Sacramento, CA 95811
(916) 445-0970
jdroberts@dfg.ca.gov

California Waterfowl Association
Mark Hennelly
Vice President, Legislative Affairs and Public Policy
1346 Blue Oaks Blvd.
Roseville, CA 95678
(916) 648-1406 ext 105
mhennelly@calwaterfowl.org

California Department of Water Resources
Ted Sommer, PhD
Program Manager II
3500 Industrial Blvd
West Sacramento CA 95691-6521
Mailing Address: PO Box 942836
Sacramento CA 94236-0001
Tel: 916-376-9772
tsommer@water.ca.gov

Louise Conrad, PhD
Program Manager
Aquatic Ecology Section
Division of Environmental Services
3500 Industrial Blvd.
West Sacramento, CA 95691
Ph: 916-376-9759
Fax: 916-376-9688
jlconrad@water.ca.gov

Gina Benigno
Environmental Scientist
3500 Industrial Blvd
West Sacramento, CA 95691
916-376-9767
gbenigno@water.ca.gov

Steven Brumbaugh
Environmental Scientist
Division of Environmental Services, Habitat Restoration Section
3500 Industrial Blvd.
West Sacramento, CA 95691
(916) 376-9724
sbrumbau@water.ca.gov

Joshua A. Martinez
Environmental Scientist
Division of Environmental Services
3500 Industrial Blvd.
West Sacramento, CA 95691
(916) 376-9725
jamartin@water.ca.gov

NMFS Southwest Fisheries Science Center

Joseph D. Kiernan, PhD
Research Ecologist
NOAA Fisheries
Southwest Fisheries Science Center
Fisheries Ecology Division
110 Shaffer Road
Santa Cruz, California 95060
Phone: (831) 420-3975
Fax: (831) 420-3977
Joseph.Kiernan@noaa.gov

UCD Center for Watershed Sciences

Peter Moyle, PhD
Professor
Wildlife, Fish, and Conservation Biology &
Center for Watershed Sciences
University of California
1 Shields Ave
Davis CA 95616
530-752-6355
pbmoyle@ucdavis.edu

Carson Jeffres
Staff Research Associate
Center for Watershed Sciences
University of California, Davis
1 Shields Ave.
Davis CA 95616
office (530) 754-5351
cell (530) 219-5813
cajeffres@ucdavis.edu

Nicholas Corline
Junior specialist
Center for Watershed Sciences
University of California, Davis
1 Shields Ave.
Davis CA 95616
njcorline@ucdavis.edu

Eric Holmes
Junior specialist
Center for Watershed Sciences
University of California, Davis
1 Shields Ave.
Davis CA 95616
holmes.ej@gmail.com

US Bureau of Reclamation

Joshua Israel, PhD
Fish Biologist
Bay-Delta Office, Science Division
801 I Street, Suite 140
Sacramento, CA 95814-2536
Cell: 916-296-8792
Office: 916-414-2417
Fax: 916-414-2439
JAIsrael@usbr.gov

Becky Victorine
NEPA Specialist
Bay-Delta Office
Conservation and Conveyance Division
801 I Street, Suite 140
Sacramento, CA 95814-2536
916-414-2429
RVictorine@usbr.gov