The Upper Sacramento River Anadromous Fish Habitat Restoration Project: Monitoring of Habitat Restoration Sites in the Upper Sacramento River in 2021-2022

Report prepared by:
Amanda I. Banet, California State University, Chico
Steve Tussing, Tussing Ecological Sciences
Greyson Doolittle, California State University, Chico

Project Partners (in alphabetical order):
California Department of Fish and Wildlife
California Department of Water Resources
California State University, Chico
NOAA Fisheries
Pacific States Marine Fisheries Commission
Resource Conservation District of Tehama County
River Partners
Sacramento River Forum
Sacramento Valley Water Districts
Tussing Ecological Sciences
U.S. Bureau of Reclamation
U.S. Fish and Wildlife
Yurok Tribe

Acknowledgement:
Pacific States Marine Fisheries Commission (Red Bluff) significantly contributed to the collection and preparation of the monitoring data presented in this report.

The CSU, Chico monitoring and analysis effort has been funded under the Central Valley Project Improvement Act via two awards (R21AC10420 and R16AC00099) to Chico State Enterprises (formerly CSU, Chico Research Foundation). The awards are jointly implemented by the US Bureau of Reclamation and the US Fish and Wildlife Service. The effort was proposed to establish efficacy of the habitat restoration projects associated with the Reclamation awards; restoration projects are designed and implemented by a collaborative inter-agency group and led by staff at CSU, Chico, Geographical Information Center.

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Note: *Some sections of this report are derived from the Monitoring Plan (Tussing and Banet, 2017) and previous annual reports (Banet et al., 2018, 2020, 2021, 2022). Information that has remained consistent between years (such as background information or methodology) may be excerpted from these earlier reports without alteration.*

SUMMARY

The Upper Sacramento River Anadromous Fish Habitat Restoration Project restores spawning and juvenile rearing habitat in the Upper Sacramento River. The project approach assumes that restoring or creating side channels that are connected at a range of flows will recreate the historical biological and geologic characteristics that support anadromous salmonid populations, leading to increased survival and condition. Each year, the monitoring team provides updates on monitoring results in an annual report. This year, the report presents several updated or new analyses, summarizes project contributions, and gives recommendations for future restoration and monitoring.

The new or updated analyses presented in this report address four questions using monitoring data collected between December 2015 and December 2022:

Q1. Does restoration impact the counts and/or density of fish in sites with paired before-after-control-impact (BACI) data?
Q2. Does data from the full suite of sites, including surveys without BACI data, show trends similar to those of the BACI data?
Q3. What is the relationship between upstream snorkel indices and downstream snorkel indices, and do upstream snorkel surveys result in fewer zero observations in the dataset?
Q4. Do side channel width and depth impact fish numbers?

At the time of reporting, nine sites have been restored (Painter's Riffle, North Cypress, Nur-Pon Open Space (also known as South Cypress), Kapusta, Anderson River Park, Reading Island, Lake California, Rio Vista, and East Sand Slough). Control sites near the restorations were chosen from historical side channels, which are thought to be the highest quality habitat nearest the restoration sites. When side channel controls were not available, mainstem controls were chosen from nearby areas that exhibited characteristics that could support juvenile salmon. The monitoring team aimed to collect data from project and control sites before and after restoration. However, due to logistical constraints (e.g. timing of restoration relative to availability of monitoring funding and resources), before data is limited to a subset of data types and sites.

To answer question one, we used a BACI (before-after-control-impact) approach to analyze total observed fish number from the restoration sites and their nearby controls that had adequate before data (restoration sites: Anderson River Park, Lake California, and Rio Vista; control sites: Bourbon Island, Mainstem North, and Mainstem South). Linear-mixed effects models show that side-channel restoration significantly increased overall counts of juvenile salmonids when species were pooled, as well as counts of Chinook Salmon and Rainbow Trout/steelhead juveniles when examined separately. It also had a significant, positive impact on the density (fish-per-acre) of juvenile salmonids (species pooled) and Rainbow Trout/steelhead juveniles. Density of Chinook Salmon juveniles showed a similar trend, but this trend was only significant when seasonal run was included in the model. Restoration did not significantly impact counts or density of non-salmonid juvenile fishes or adult piscivorous fishes.

Fish counts are difficult to analyze and interpret without adequate before data for comparison, so for question two, we only analyzed fish density (fish-per-acre). These models focused

exclusively on salmonids. Linear models of the full dataset showed similar positive trends to the BACI analyses, but the results were only statistically significant for winter run Chinook salmon and Rainbow Trout/Steelhead.

To answer question three, we used linear regression to generate the relationship between fish counts obtained from upstream snorkel surveys and those from downstream snorkel surveys. Data from mainstem sites and side channels were separated for analysis because different collection approaches were used at each site type. We did this analysis first with all values included, and again with outliers removed. Both models generated with side channel data showed a significant relationship between upstream and downstream snorkel surveys, but mainstem sites showed no such relationship. The prediction intervals generated for these models were large; because of this, using these equations as a conversion factor between upstream and downstream surveys should be done with caution. Additional data collection could help increase confidence with the use of these conversion factors. Upstream surveys had fewer zero observations than downstream surveys (13.46% vs 17.31% when salmonid species were pooled, 17.31% vs 28.85% for Rainbow Trout/steelhead, 46.5% vs 56.65% for fall run Chinook salmon, 67.31% vs 78.85% for spring run Chinook salmon, 65.38% vs 80.77% for winter run Chinook salmon, and 55.77% vs 76.92% for late-fall run Chinook salmon).

To answer question four, we used a zero-inflated linear mixed model to examine the impact of channel width and average channel depth on fish number. Side channel ID was included as a random effect to account for site specific effects. Our results showed no significant impact of either factor, which supports the idea that fish congregate in the margins. Wider, deeper channels do not appear to be holding more fish per unit length. This information could be used to inform future channel design.

Over the last five years monitoring efforts have contributed to meeting four of the five fisheries related objectives outlined in the Monitoring Plan (Tussing and Banet 2017, objectives 1-5). The datasets used in the analyses reported here and in previous annual reports vary in quality and size. Results obtained from the highest quality datasets all suggest that the Upper Sacramento River Anadromous Fish Habitat Restoration Project has effectively produced additional high quality juvenile salmonid habitat (objective 2) that supports higher numbers of fish (objective 3) in the upper Sacramento River. The effects of restoration on fish size and condition (objective 4) varied between runs when looking at seining data. The seining data was likely confounded by several other factors, and data collection of enclosure study growth rates were unfortunately not completed due to COVID-19 shutdowns. The higher number of macroinvertebrates (determined by sampling rate) observed in restored side channels as compared to baseline channels suggests that there may be a positive effect of restoration on food availability (objective 5), but without biomass and diet information, firm conclusions can’t be drawn. Addressing the logistical challenges of collecting data for objectives 4 and 5 can help paint a clearer picture of how side channel restoration affects salmonid growth.

Monitoring results have enabled the refinement of more efficient and cost-effective data collection methods that increases the quality of data being collected and retain long-term data set continuity. Results have also identified the need for data collection before restoration occurs and the monitoring of control sites, to increase our ability to detect the effects of restoration.

Additionally, monitoring efforts have also enabled us to test our assumptions and create an adaptive management feedback loop with the restoration design team to inform future restoration.

Continued monitoring of completed and future restorations will provide additional insight into the effectiveness of side channel restoration, as well as adaptive management feedback to the restoration design team. Analyses in progress include cover use preferences that additionally explore unembedded cobble and aquatic vegetation by sub-type, and the comparative fish use of placed vs. naturally recruited woody cover. Future analyses and reporting will evaluate whether we can demonstrate project effectiveness with a single year of pre- and post-project monitoring data within a BACI framework. We also anticipate providing monitoring results for objective 1 of the Monitoring Plan which is to increase the areal extent of spawning habitat meeting suitability criteria and the use of spawning habitat. Additionally, in the coming year we would like to evaluate potential day vs. night differences in fish use of habitat as this is a significant monitoring assumption that was identified in the Monitoring Plan.

INTRODUCTION

Project Overview

Central Valley anadromous salmonid populations have seen dramatic declines in the past century, largely due to anthropogenic habitat alterations (Katz et al. 2013). In the upper Sacramento River, the largest impacts have been attributed to loss of floodplains, riparian habitat, and instream cover; increased competition and predation; and alterations to morphologic function (NMFS 2014). Historic off-channel habitat has largely been lost due to flood control and associated geologic processes; the Central Valley Project Improvement Act Science Integration model (CVPIA SIT) estimates in-stream habitat to be 26 acres at median flows (8311 cfs), far below the number needed to aid in recovery of threatened and endangered populations of Central Valley salmonids (Gill n.d.).

The Upper Sacramento River Anadromous Fish Habitat Restoration Project (hereafter, the Project) restores spawning and juvenile rearing habitat in the Upper Sacramento River. The project approach assumes that restoring or creating side channels that are connected at a range of flows will recreate the historical biological and geologic characteristics that support salmon populations, leading to increased survival and condition. The conceptual model underlying this hypothesis, which forms the basis for the monitoring plan approach, is provided below (Figure 1). An in-depth discussion of this conceptual model is available in the Upper Sacramento River Anadromous Fish Habitat Restoration Project Monitoring Plan and Protocols (Tussing and Banet 2017), hereafter referred to as the Monitoring Plan.

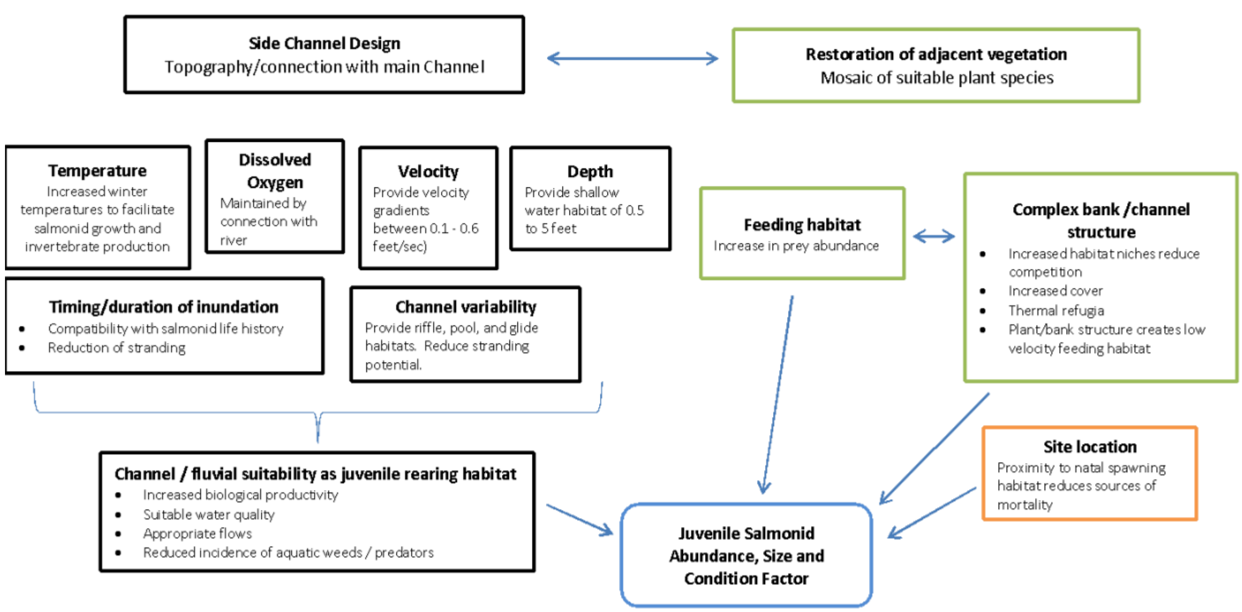

Figure 1. Conceptual model of design-related elements and their influence on biotic and abiotic juvenile salmonid habitat elements, from Banet and Tussing (2017).

Restoration Goals and Objectives

The primary goals of the Project, as stated in the Monitoring Plan (Tussing and Banet 2017), are to:

1. Increase the availability, quality and quantity of spawning and rearing habitat for Sacramento River Basin Chinook Salmon and steelhead/Rainbow Trout
2. Restore, maintain or enhance natural system processes whenever possible
3. Determine project effectiveness, including cost, project longevity and maintenance requirements, with an efficient and scientifically-robust monitoring program
4. Demonstrate a positive, detectable salmonid population response to habitat enhancement activities
5. Contribute to the long-term health of the river ecosystem (water quality, invertebrate and fish assemblages, riparian and floodplain habitat function, etc.)
6. Incorporate information learned to improve future projects (adaptive management)
7. Contribute to scientific understanding of aquatic ecology
8. Work collaboratively with partners to identify and implement projects that are cost effective and benefit aquatic resources, emphasizing anadromous salmonids, in the short and long term

The primary objectives of the Project, as stated in the Monitoring Plan (Tussing and Banet 2017) are to provide:

1. An increase in the areal extent of spawning habitat meeting suitability criteria and the use of spawning habitat
2. An increase in the areal extent of rearing habitat meeting juvenile salmonid rearing habitat suitability criteria
3. An increase in salmonid juvenile abundance/density at restoration sites after implementation, as compared to before implementation
4. Improved size and average condition of salmonids using the side channels, as compared to those that have not been documented using the side channels
5. An increase in available prey abundance, including both drift and benthic macroinvertebrates
6. Increased extent and quality of riparian habitat at Sand Slough

Purpose of this Report

The purpose of annual reporting, as described in the Monitoring Plan (Tussing and Banet 2017), is to determine if monitoring data collection methods are effective at achieving data objectives; to modify field protocols as needed to effectively meet those objectives; to perform preliminary tests of hypotheses as data allows; and, to inform restoration efforts where a biological response to restoration can be established.

For this report, data collection continued through December 2022, meaning that the timeline between the delivery of processed data and the target completion data of the report (i.e. the end of the award period) was much shorter than in previous years. Because of this, we narrowed the focus of our data analyses to address four questions:

Q1. Does restoration impact the counts and/or density of fish in sites with paired before-after-control-impact (BACI) data?
Q2. Does data from the full suite of sites, including surveys without BACI data, show trends similar to those of the BACI data?
Q3. What is the relationship between upstream snorkel indices (which have been proposed for future monitoring) and downstream snorkel indices (which have been used in past monitoring), and do upstream snorkel surveys result in fewer zero observations in the dataset? If this relationship is strong, then it will more easily allow comparison of data collected in the future with past data from this project. Fewer zero observations could make it easier to detect impacts of restoration.
Q4. Do channel width and depth impact fish numbers? This topic came up during a design team meeting. Anecdotally, fish at our sites tend to aggregate in the relatively shallow margins of the channels, meaning that wider or deeper channels may not hold more fish per unit length. Data related to this question is being provided to help inform future design.

Further analyses of data collected from this project may be included in reports from the next iteration of this project. In addition to addressing these questions, the discussion of this report also includes a brief summary of project contributions, as well as recommendations going forward.

Monitoring Site Selection

Project sites (Figure 2, Table 1) were identified and prioritized for construction through the CVPIA habitat restoration process. Restoration sites are side channels that were either previously connected to the river and have since been cut off to fish due to increased channelization, or side channels that are only available to juvenile fish during certain times of year (i.e. during high flow releases from Keswick dam). The Project prioritized sites for construction based on a multitude of factors which may include but are not limited to: stranding potential at lower Keswick releases, feasibility of construction, land-owner cooperation, site longevity and maintenance requirements, and overall perceived benefit to juvenile salmonids, with emphasis on benefits to listed species. Baseline snorkel data was taken from restoration sites when possible, but this data is limited, either due to logistical constraints, or because many restored sites were not consistently connected to the mainstem prior to restoration.

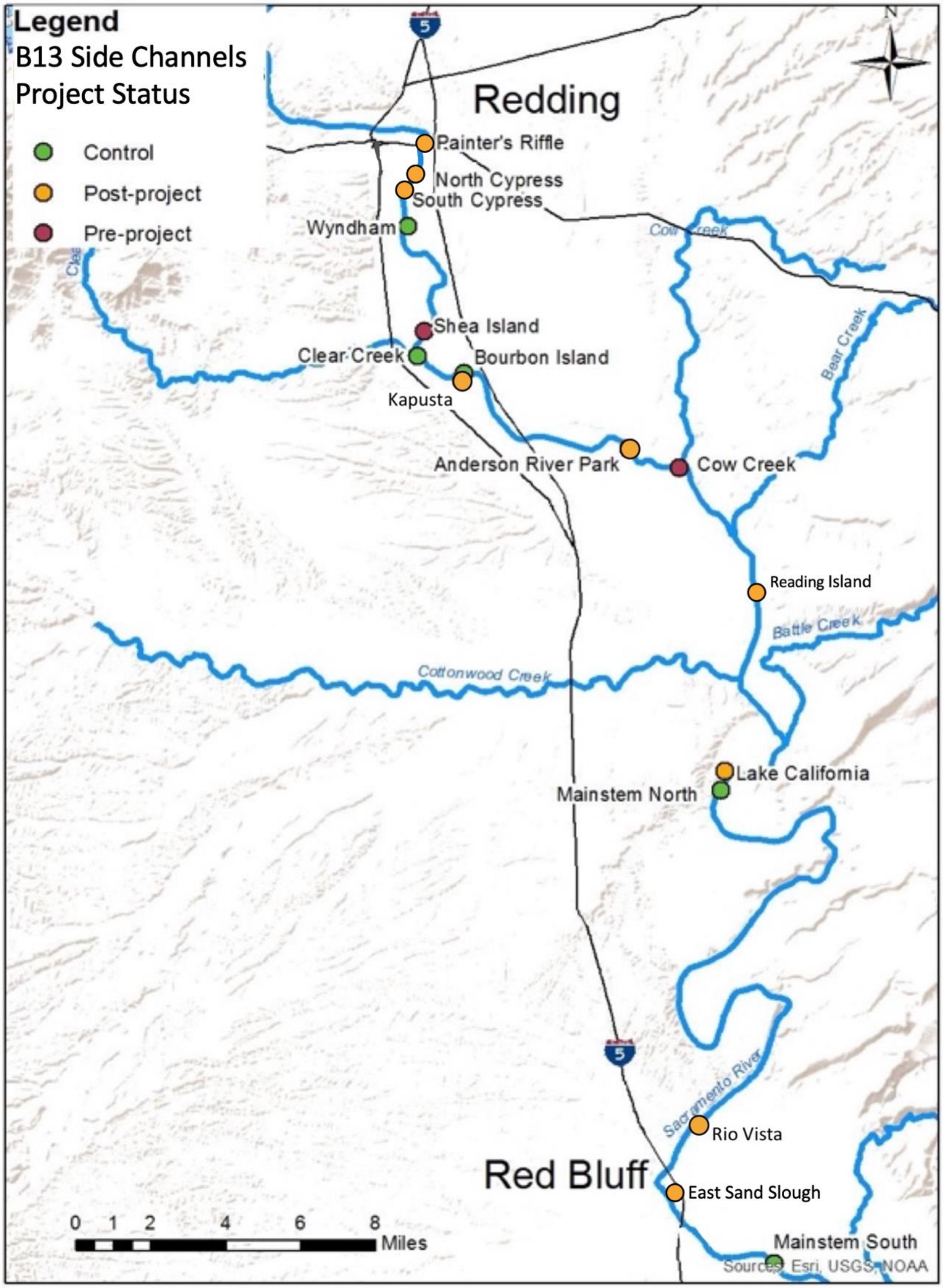

Figure 2. Map of control, pre-project (pre-restoration) and post-project (restored) side channels surveyed as part of the Project.

Table 1. Name, status (as of April 2021), and approximate river mile (RM) of Project Sites. *Note that Kutras Lake is not a side channel, and is thus not addressed in this report. Pre-project status refers to project sites that are slated for restoration, but were not restored at the end of this reporting period. Post-project status refers to sites that have been restored. Control status refers to existing habitat that is not scheduled for restoration.*

Site Name	**Status**	**Restoration Date(s)**	**RM**
Painter's Riffle	Post-project	2014	296
North Cypress	Post-project	December 2016	295.5
South Cypress *(Nur Pon Open Space)*	Post-project	May 2021	294
Wyndham	Control	N/A	293.5
Shea Island	Pre-project	N/A	290
Clear Creek	Control	N/A	289
Bourbon Island	Control	N/A	287.5
Kapusta	Post-project	May 2018 (Kapusta 1A only)	287.5
Anderson River Park	Post-project	December 2019 (Phase I) February 2021 (Phase II/III)	282
Cow Creek	Pre-project	N/A	280
Reading Island	Post-project	August 2019 (Phase I) December 2019 (Phase II)	274
Lake California	Post-project	January 2018	269.5
Mainstem North	Control	N/A	268.5
Rio Vista	Post-project	October 2019	247
East Sand Slough	Post-project	January 2022	244
Mainstem South	Control	N/A	242

In order to examine the performance of the restored side channels, the monitoring team identified five control sites. To select control sites, we consulted with experts from the project team to identify habitat geographically located near restoration (or future restoration) sites that was thought to be the highest quality nearby habitat (based on estimated depth, velocity, cover, and prior fish observations). When possible, currently functioning side channels with flow year-round were selected as controls. In areas of the river where functioning side channels were not available to use as controls, mainstem control sites were selected. This process resulted in three side channel controls, and two mainstem controls (Figure 2, Table 1).

METHODS

The methods detailed in this section are not an exhaustive description of monitoring approaches used in this project. Instead, they focus on the methods used to collect data for the suite of questions addressed in this report.

Downstream Snorkel Index

An index of fish abundance was collected via snorkel surveys when conditions permitted. Surveys were conducted at each site between 9AM and 3PM, generally every two weeks. Data was classified as control, baseline (pre-restoration), or impact (restored). The order in which control, impact, and baseline sites were surveyed were randomized whenever possible, in order to reduce the likelihood that fish abundance was confounded with time of day. We recorded several physical variables each time a site was surveyed (Table 2). Visibility, weather, and water temperature were recorded on site. Flow was calculated in the office using data from nearby gauging stations.

Table 2. Physical variables collected in conjunction with snorkel counts.

Variable	Description
Visibility	Visibility is measured using a secchi disk. A member of the crew submerges his or her face into the water and extends the pole upstream along the plane of their eye level until the disc can no longer be seen. The distance from the disc to the swimmer's eye is recorded in feet.
Weather	Weather is measured on a numeric scale as follows: 1- Clear, 2 - Partly Cloudy, 3 - Cloudy, 4 - Rain, 5 - Snow, 6 - Fog. For this report, monthly weather scores are reported both as mean and mode numeric values.
Water Temperature	Water temperature is measured in Fahrenheit during each survey.
Calculated Flow	Flow is determined using data from nearby gauging stations. Lake California, Mainstem North, Mainstem South, and Rio Vista use data from the Bend Bridge (BND) gauging station in Red Bluff, CA. All other sites use data from the Keswick (KWK) gauging station in Keswick, CA.

Each swimmer calibrated his or her vision prior to commencing a snorkel survey in order to account for the visual distortion that occurs in water. To do this, the swimmer submerged their face and mask in the water, and another crew member held a calibration tool equipped with a model fish of known length in front of the swimmer for a short period of time. This process was repeated until the swimmer was comfortable with the calibration.

Flows and conditions at some sites were not amenable to snorkeling upstream. Because of this, all surveys were conducted downstream to maintain consistency. Swimmers formed a line perpendicular to flow prior to the start of the survey and recorded the start time of the survey. At most sites, two snorkelers surveyed edge habitat along each bank of a side channel. For mainstem sites, one snorkeler surveyed the edge of the main river bank. Swimmers maintained their line in order to reduce the likelihood of double counting fish. Juvenile salmonids were identified to species, classified by size, and counted as they passed by each snorkeler. In order to gather information on species richness and the presence of predators, other fish species were noted and counted as well. After the survey was completed, an end time was recorded.

For analysis, steelhead and Rainbow Trout juveniles were classified together, and Chinook Salmon were categorized into runs using the Central Valley length-to-date chart (Harvey 2011). Some analyses broke fish down into size classes of juveniles (>50 mm) and fry (≤ 50 mm).

Microhabitat Use and Upstream Snorkel Index

Microhabitat-use snorkel surveys were conducted across a range of flows. The entire side channel area was surveyed with a sufficient number of snorkelers to cover the cross-sectional width of the channel.

Snorkelers worked in an upstream direction and at a slow pace to observe the point locations of undisturbed fish. The location of fish observed was marked with a weighted tag on the stream bottom. The species, run, size, and number of fishes were recorded on tags for any observed salmonids less than 201mm in fork length. Estimates of fish size and selection of the appropriate size class bin was aided by the use of a dive cuff with photographs of salmonids at class bin lengths. Size class bins included fork lengths of <41mm, 41-50mm, 51-60mm, and then by 20mm bin widths up to a maximum of 200mm. For the analyses presented in this report, all size classes were pooled together.

After the habitat unit was surveyed, flagged locations were revisited, and data was collected on fish attributes, GPS point location, habitat type, depth (total water column), distance to bank, distance to cover, cover type, mean water column velocity, and substrate. Due to safety concerns, snorkeling surveys were restricted to flows below 13,000 CFS. This resulted in a shortage of late-fall run observations, as they are typically most abundant at high flows. In some cases, for the purpose of building the upstream vs. downstream index relationship, an upstream index of fish abundance was performed following the observational methods of microhabitat use surveys but without the dropping and processing of tagged fish locations.

Macrohabitat Mapping

At each site, cross sections for discharge measurement were established following the Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California (CDFW 2013). Cross sections were benchmarked for future use. Habitat typing and mapping followed methods from the California Stream Habitat Restoration Manual (CDFW 2010). Surveys began at the downstream end of side channels, and proceeded upstream to the side channel inlet. Habitats were classified to level III using the habitat types hierarchy provided in CDFW (2010) (Figure 3, below).

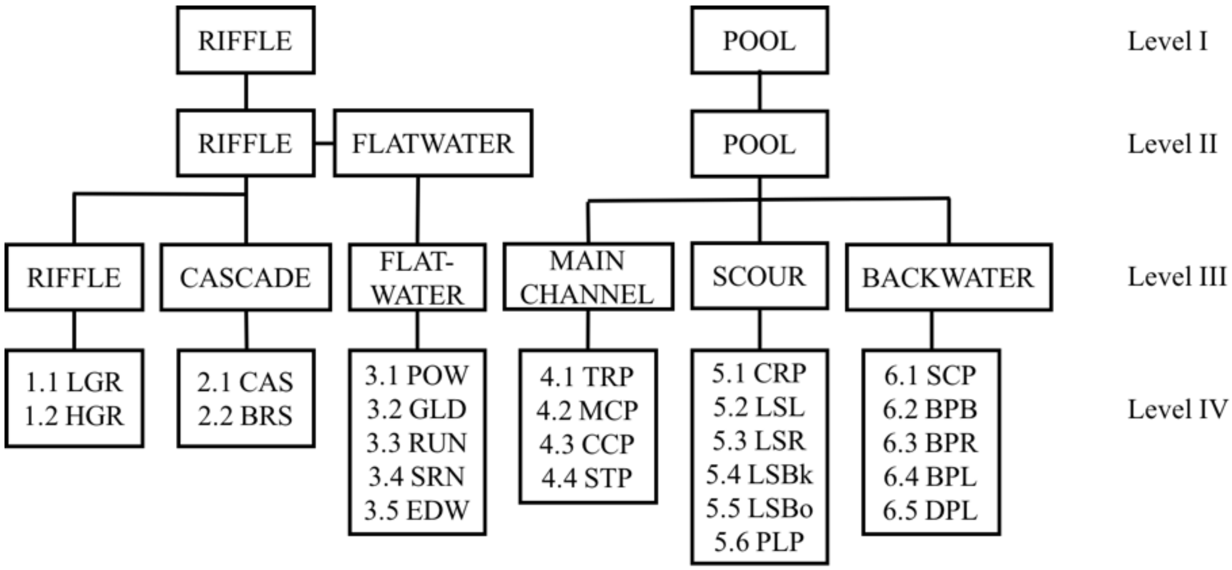

Figure 3. Habitat hierarchy from California Stream Habitat Restoration Manual (CDFW 2010).

The wetted perimeter and breaks between habitat types were mapped for the entire length of the channel using a Trimble GPS. The maximum depth was recorded for each habitat type (habitat unit), and average depth was calculated using data taken by a stadia rod across several transects. Channel width was collected within each habitat unit. Three channel width measurements were taken for units less than 300 feet in length. For units over 300 feet, an additional transect was taken for every additional 100 feet in length. These widths were averaged to provide a single value per unit. Dominant and codominant substrate within the wetted area was identified following classification of CDFW (2010), shown in Table 4. Tree canopy cover was measured as percent stream area covered with a spherical densiometer.

Table 3. Substrate Size Classification

Particle Size	Diameter (Inches)
Boulder	>10
Cobble	2.5-10
Gravel	0.08-2.5
Sand	<0.08
Silt/Clay	N/A
Bedrock	N/A

DATA ANALYSIS AND RESULTS

Fish Abundance in Habitats with Before-After-Control-Impact (BACI) Data

Data Analysis

To analyze the impact of restoration on fish counts, we used linear mixed models to examine the effects of site classification (restoration/control), restoration timeline (before/after), visibility, quarter (January-March, April-June, July-September, and October-December), and the interaction between site classification and restoration timeline on fish counts. Because geographic location may influence fish count, we paired restoration sites with their nearest control (Anderson River Park with Bourbon Island, Lake California with Mainstem North, and Rio Vista with Mainstem South) and used these pairs as a random effect in the model. ARP and Bourbon Island each had 10 before surveys and 13 after surveys. Lake California and Mainstem North each had 10 before surveys and 56 after surveys. Rio Vista and Mainstem South each had 20 before surveys and 21 after surveys.

We used a type I negative binomial distribution in the model, because it had the lowest corrected Akaike Information Criterion (AICc) score compared to the other distributions considered: normal, Tweedie, and type II negative binomial. The interaction term in this model (Restoration Timeline x Site Classification) is the key output for understanding the effect of restoration. A greater increase in fish count in the restored side channels after restoration, relative to the control sites, would indicate that the restoration was successful in increasing the number of fish. Separate models were run for five groups of interest: All salmonid juveniles pooled into a single dataset, Chinook Salmon juveniles, Rainbow Trout/steelhead juveniles, non-salmonid juvenile fishes, and adult piscivorous fishes. Because sampling effort was not identical at all sites before and after restoration, we initially included an offset based on the number of days sampled; however, the offset had no impact on the significance, overall magnitude, or trends of the variables of interest, and was dropped from the final models. We also examined the need for zero-inflation in the models, since these types of fish surveys often have large numbers of zero observations. Zero-inflation was significant in the model for counts of non-salmonid juvenile fishes. For consistency, we included zero-inflation in all count models. We note that the output for models where zero-inflation was not significant had Chi-square values identical to two rounded decimal places, both with and without zero-inflation (here and in all models described below). The emmeans package in R was used to calculate the estimated marginal means reported below (Lenth 2021). The alpha level was set at 0.05.

We used similar models to examine fish density with the following modifications. The dependent variable of fish-per-acre was estimated by the following equation:

$$Fish\text{-}per\text{-}acre = N \div \frac{L * V * S}{43{,}560}$$

where *N* was total fish count during the survey, *L* was the length of the survey in feet, *V* was the visibility surveyed in feet (a proxy for survey width, since snorkelers looked toward the stream margins when counting), and *S* was the number of snorkelers. Fish-per-acre is used rather than metric units because acres are used in the Central Valley Project Improvement Act (CVPIA) salmon populations models, as developed by the CVPIA Science Integration Team (SIT). Using this unit of measurement should make interpretations of our results more intuitive for fisheries managers in the Central Valley. Because visibility was included in the calculation of fish density, it was removed as a factor from the density models. The density models used a Tweedie distribution because it had the lowest AICc score of all distributions considered. Offset was not considered in the density models because it is more appropriate for count data. Zero-inflation was not significant for any model and was thus not included in the final set of density models.

Because Chinook Salmon runs differ in migration timing and are classified differently in terms of conservation status, we wanted to know whether restoration affected the runs differently. To do this, we used similar count and density models as described above with minor additions. Spring run Chinook salmon were excluded from this model because they were not observed at any of the sites prior to restoration. Because runs vary in terms of when they can be found in the river, we included the interaction of quarter and run in the models. To determine whether runs responded differently to restoration, we included a three-way interaction between restoration timeline, site classification, and run. As described for the previous models, the two-way interaction in this model (Restoration Timeline x Site Classification) is the key output for understanding the overall effect of restoration. The three-way interaction added to the Chinook Salmon run models (Restoration Timeline x Site Classification x Run) indicates whether the runs respond differently to restoration. The Chinook Salmon run count model used a type I negative binomial distribution and included zero-inflation. An offset based on sampling days was not needed and was excluded from the final model. The Chinook Salmon run density model used a Tweedie distribution. Zero-inflation was not significant in this model, and is not included in the results reported below.

Results

Fish counts: Restoration significantly increased counts of all salmonid juveniles (species pooled), Chinook Salmon juveniles, and Rainbow Trout/steelhead juveniles in restored sites relative to control sites (Timeline x Site Classification interaction in Table 4, Figure 4). It did not significantly impact counts of adult piscivorous fishes or non-salmonid juvenile fishes, though these groups did show a similar, non-significant trend (Timeline x Site Classification interaction in Table 4, Figure 4). Quarter of the year had a significant influence in all models, with trends varying between groups (Table 4, Figure 5). Counts were significantly or near significantly higher for all groups when visibility was higher (Table 4, slope coefficients: All salmonid juveniles = 0.707, Chinook Salmon juveniles = 0.874, Rainbow Trout/steelhead juveniles, 0.426, non-salmonid juvenile fishes = 0.286, adult piscivorous fishes = 0.530).

Fish density: Restoration significantly increased the density of all salmonid juveniles (species pooled) and Rainbow Trout/steelhead juveniles in restored sites relative to control sites (Timeline x Site Classification interaction in Table 5, Figure 4). It did not significantly impact the density of Chinook Salmon juveniles, adult piscivorous fishes, or non-salmonid juvenile fishes (Timeline x Site Classification interaction in Table 5, Figure 4). Quarter of the year had a significant influence in all models, with trends varying between groups (Table 4, Figure 5).

Table 4. *BACI analyses of fish counts for three restoration sites and their nearby controls. Details of the zero-inflated linear mixed models used in these analyses are provided in the methods. The two-way Timeline x Site Classification interaction indicates whether restoration has a significant impact on fish count. Note that main effects of timeline and site classification cannot be interpreted directly when the interaction is significant.*

	All salmonid juveniles	Chinook Salmon juveniles	Rainbow Trout & steelhead juveniles	Piscivorous adult fishes	Non-salmonid juvenile fishes
Quarter of Year	**$\chi2 = 18.01$ df = 3 $P < 0.001$**	**$\chi2 = 37.22$ df = 3 $P < 0.001$**	**$\chi2 = 22.63$ df = 3 $P < 0.001$**	**$\chi2 = 15.80$ df = 3 $P = 0.001$**	**$\chi2 = 31.29$ df = 3 $P < 0.001$**
Visibility (m)	**$\chi2 = 29.63$ df = 1 $P < 0.001$**	**$\chi2 = 34.23$ df = 1 $P < 0.001$**	**$\chi2 = 6.49$ df = 1 $P = 0.011$**	$\chi2 = 3.29$ df = 1 $P = 0.070$	$\chi2 = 3.72$ df = 1 $P = 0.054$
Timeline (before/after)	**$\chi2 = 19.24$ df = 1 $P < 0.001$**	**$\chi2 = 27.34$ df = 1 $P < 0.001$**	**$\chi2 = 5.58$ df = 1 $P = 0.018$**	**$\chi2 = 18.79$ df = 1 $P < 0.001$**	**$\chi2 = 20.83$ df = 1 $P < 0.001$**
Site Classification (control/impact)	**$\chi2 = 34.72$ df = 1 $P < 0.001$**	**$\chi2 = 25.27$ df = 1 $P < 0.001$**	**$\chi2 = 17.24$ df = 1 $P < 0.001$**	**$\chi2 = 15.89$ df = 1 $P < 0.001$**	**$\chi2 = 82.24$ df = 1 $P < 0.001$**
Timeline x Site Classification	**$\chi2 = 19.64$ df = 1 $P < 0.001$**	**$\chi2 = 10.70$ df = 1 $P = 0.001$**	**$\chi2 = 44.91$ df = 1 $P < 0.001$**	$\chi2 = 2.02$ df = 1 $P = 0.156$	$\chi2 = 1.08$ df = 1 $P = 0.300$

Table 5. *BACI analyses of fish density (fish-per-acre) for three restoration sites and their nearby controls. Details of the zero-inflated linear mixed models used in these analyses are provided in the methods. The two-way Timeline x Site Classification interaction indicates whether restoration has a significant impact on fish density. Note that main effects of timeline and site classification cannot be interpreted directly when the interaction is significant.*

	All salmonid juveniles	**Chinook Salmon juveniles**	**Rainbow Trout & steelhead juveniles**	**Piscivorous adult fishes**	**Non-salmonid juvenile fishes**
Quarter of Year	**$\chi2$ = 10.72** **df = 3** ***P* = 0.013**	**$\chi2$ = 14.41** **df = 3** ***P* = 0.008**	**$\chi2$ = 17.76** **df = 3** ***P* < 0.001**	**$\chi2$ = 20.73** **df = 3** ***P* < 0.001**	**$\chi2$ = 60.36** **df = 3** ***P* < 0.001**
Timeline (before/after)	**$\chi2$ = 18.47** **df = 1** ***P* < 0.001**	**$\chi2$ = 22.99** **df = 1** ***P* < 0.001**	$\chi2$ = 0.35 df = 1 *P* = 0.551	**$\chi2$ = 18.30** **df = 1** ***P* < 0.001**	**$\chi2$ = 6.90** **df = 1** ***P* = 0.009**
Site Classification (control/impact)	$\chi2$ = 2.33 df = 1 *P* = 0.127	$\chi2$ = 1.61 df = 1 *P* = 0.204	$\chi2$ = 0.31 df = 1 *P* = 0.577	**$\chi2$ = 5.20** **df = 1** ***P* = 0.023**	**$\chi2$ = 30.58** **df = 1** ***P* < 0.001**
Timeline x Site Classification	**$\chi2$ = 6.77** **df = 1** ***P* = 0.009**	$\chi2$ = 3.27 df = 1 *P* = 0.070	**$\chi2$ = 16.23** **df = 1** ***P* < 0.001**	$\chi2$ = 0.32 df = 1 *P* = 0.572	$\chi2$ = 2.96 df = 1 *P* = 0.086

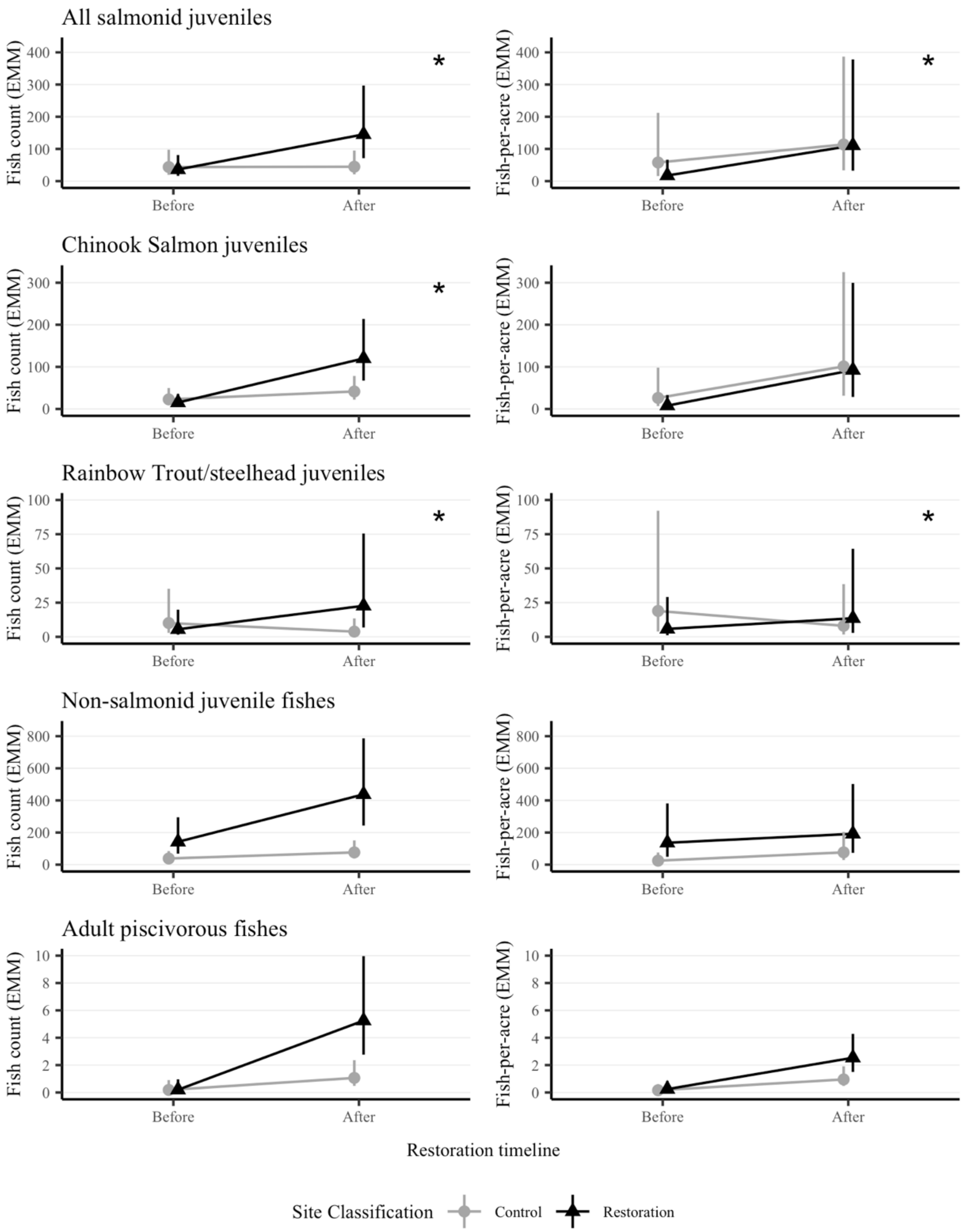

Figure 4. *Estimated marginal means of fish counts (first column) and fish-per-acre (second column) before and after restoration. Data include three restoration sites (Anderson River Park, Lake California, and Rio Vista) and nearby controls (Bourbon Island, Mainstem North, and Mainstem South). Starred panels have significant interactions terms, meaning there was a significant impact of restoration. A larger slope in restoration sites, as compared to control sites, indicates this impact is positive. Error bars are 95% confidence intervals. Note that the y-axis scale varies between panels. Details of the linear mixed models used to generate this data are provided in the methods.*

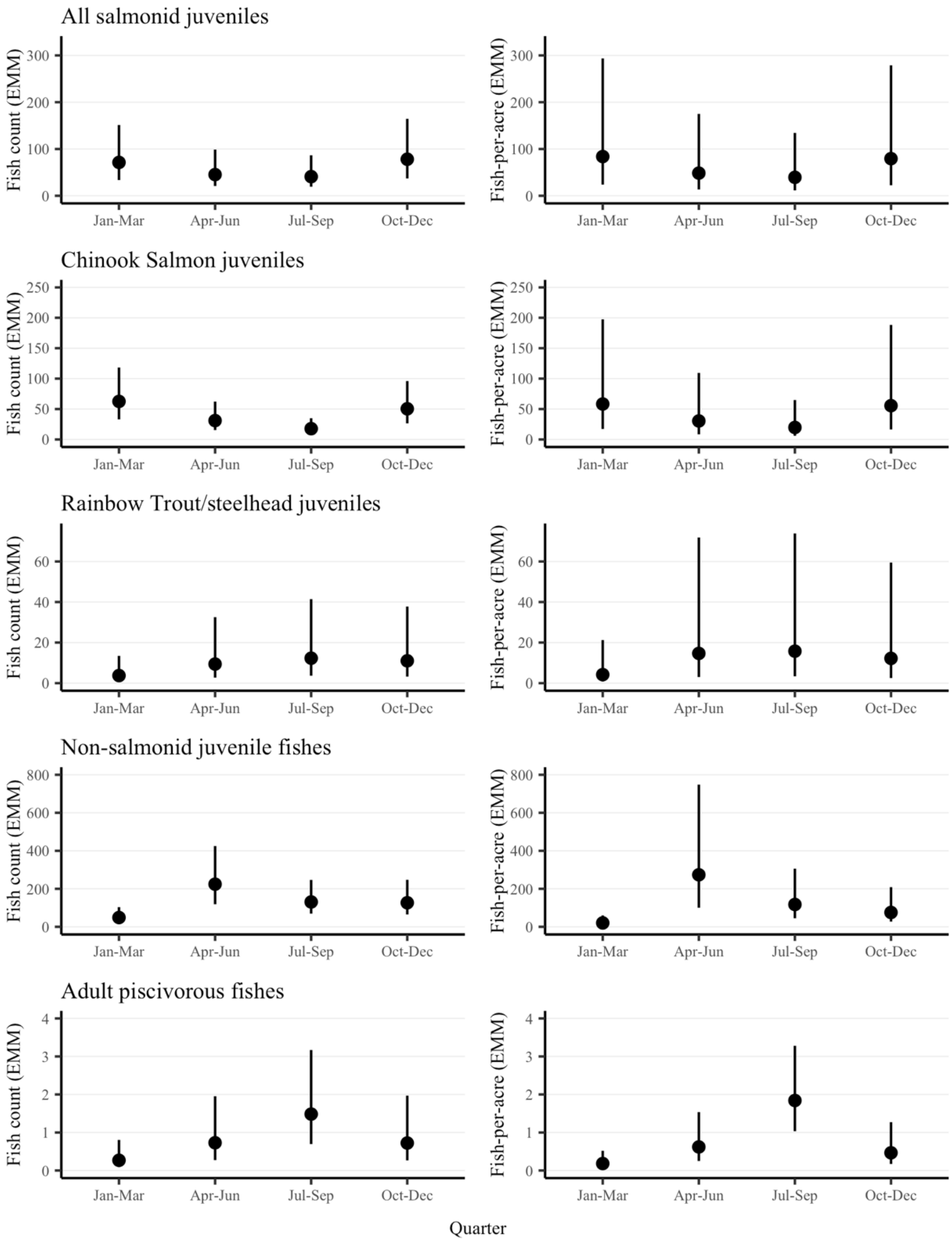

Figure 5. *Estimated marginal means of fish counts (first column) and fish-per-acre (second column) across 3-month quarters of the year. Data include three restoration sites and nearby controls. Error bars are 95% confidence intervals. Note that the y-axis scale varies between panels. Details of the linear mixed models used to generate this data are provided in the methods.*

Chinook Salmon runs: When Chinook Salmon were delineated by run, the overall trend of restoration mirrored that of the pooled Chinook Salmon model, though significance differed for density. Restoration had a significant, positive impact on both Chinook Salmon counts (Timeline x Site Classification interactions in Table 6) and density (Timeline x Site Classification interactions in Table 7). Runs did not respond significantly differently to restoration for either metric (Timeline x Site Classification x Run interactions in Tables 6 and 7, Figure 6). Counts were significantly higher when visibility was higher (Table 6, slope coefficient = 0.869). Counts and densities significantly varied over the course of the year, with runs showing different patterns of seasonality (Quarter x Run interaction in Tables 6 and 7, Figure 7).

Table 6. *BACI analysis of Chinook Salmon density (fish-per-acre, classified by run) for three restoration sites and their nearby controls. Details of the linear mixed model used in this analysis are provided in the methods. The two-way Timeline x Site Classification interaction indicates a significant impact of restoration on Chinook Salmon density. The three-way Timeline x Site Classification x Run interaction indicates that different runs are not responding differently restoration. Note that main effects cannot be interpreted directly when interactions are significant.*

	Chi-square	**df**	***P*-value**
Quarter of Year	14.57	3	0.002
Run	22.85	2	<0.001
Timeline (before/after)	21.34	1	<0.001
Site Classification (control/impact)	0.03	1	0.869
Season x Run	124.52	6	<0.001
Timeline x Site Classification	4.10	1	0.043
Timeline x Run	13.81	2	0.001
Site Classification x Run	5.87	2	0.053
Timeline x Site Classification x Run	0.84	2	0.657

Table 7. BACI analysis of Chinook Salmon density (fish-per-acre, classified by run) for three restoration sites and their nearby controls. Details of the linear mixed model used in this analysis are provided in the methods. The two-way Timeline x Site Classification interaction indicates a significant impact of restoration on Chinook Salmon density. The three-way Timeline x Site Classification x Run interaction indicates that different runs are not responding differently restoration. Note that main effects cannot be interpreted directly when interactions are significant.

	Chi-square	**df**	***P*-value**
Quarter of Year	14.57	3	0.002
Run	22.85	2	<0.001
Timeline (before/after)	21.34	1	<0.001
Site Classification (control/impact)	0.03	1	0.869
Season x Run	124.52	6	<0.001
Timeline x Site Classification	4.10	1	0.043
Timeline x Run	13.81	2	0.001
Site Classification x Run	5.87	2	0.053
Timeline x Site Classification x Run	0.84	2	0.657

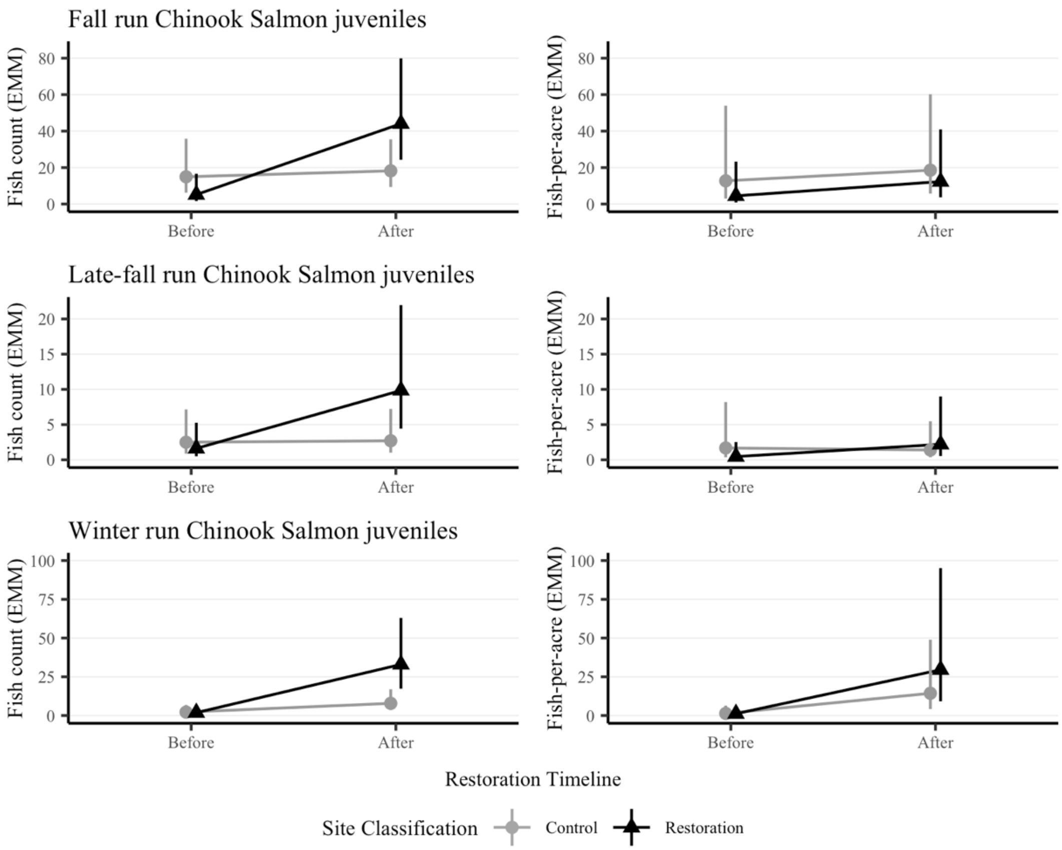

Figure 6. *Estimated marginal means of counts (left column) and fish-per-acre (right column) before and after restoration for Chinook Salmon runs. Data include three restoration sites and nearby controls. Overall, Chinook Salmon counts had a significant, positive response to restoration, with each run responding similarly (first column). Chinook Salmon density also showed a significant positive effect of restoration, and this trend was consistent across runs (second column). Note that the y-axis scale varies between panels. Details of the linear mixed models used to generate this data are provided in the methods.*

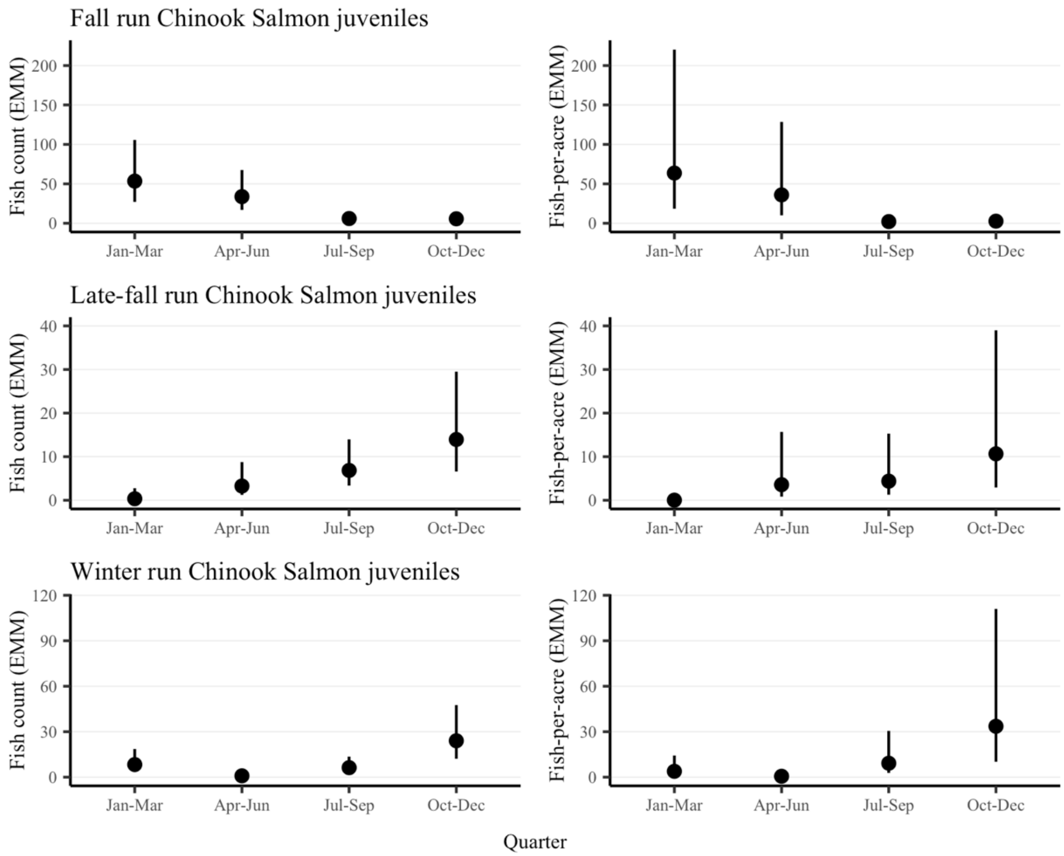

Figure 7. *Estimated marginal means of fish counts (first column) and fish-per-acre (second column) for Chinook Salmon runs across 3-month quarters of the year. Data include three restoration sites and nearby controls. Error bars are 95% confidence intervals. Note that the y-axis scale varies between panels. Details of the linear mixed models used to generate this data are provided in the methods.*

Fish Abundance in the Full Dataset

Data Analysis

The full dataset is more challenging to analyze due to lack of paired before and after data at many of the study sites. Thus, we urge extreme caution with the interpretation of the analyses described below. Fish counts, in particular, cannot be analyzed and interpreted without adequate before data for comparison. This is because the number of sites included in the dataset varies year-to-year, meaning that the areal extent of surveyed habitat may be impacted by factors other than the creating of additional habitat through restoration. Because of this, our dependent variable in these analyses is estimated fish density (fish-per-acre). This was calculated as described in the previous section.

To analyze fish density of the full dataset, we compared baseline (pre-restoration), impact (post-restoration), and control sites. This approach allows us to include more data in our analyses because we can include sites that did not have baseline data, as well as sites that have not yet been restored; however, a caveat to interpretation of the full dataset is that since the group of sites that have baseline data does not have fully overlapping membership with the group of sites that have impact data (i.e. some sites had only baseline data, while others had only impact data), it is difficult to disentangle the effects of restoration from natural variation between the sites. Additionally, data collection during earlier years of the project were biased toward control or baseline data since many restorations had not yet taken place, meaning that treatment is partially confounded with escapement. Together, this makes it more challenging to detect any effects of restoration that may be present when analyzing the full dataset.

To analyze fish density of the full dataset, a zero-inflated linear model was used to examine the effects of treatment (baseline/impact/control) on fish density. Year and quarter (October-December, January-March, April-June, and July-September) were included as fixed effects to account for temporal correlation in fish densities. Likewise, because geographic location may impact fish density, we included river mile as a fixed effect in the model. We used a Tweedie distribution in the model, which had a lower AICc score than other distributions explored.

Results from these models are presented below, and includes 1,421 surveys conducted between December 2015 through December 2022 (370 baseline surveys, 467 control surveys, and 585 impact surveys). Again, we urge extreme caution with interpretation due to the challenges described above. These results alone should not be used to make future management decisions. The BACI analyses presented in the previous section, while limited in the number of sites, provide more reliable results.

Results

Site Classification (baseline/impact/control) had a detectable effect on winter run density and Steelhead/Rainbow Trout density, but did not significantly impact the density of all salmonids (pooled) or fall-run Chinook salmon (Tables 8 and 9, Figure 8). Late-fall run models did not converge. Densities differed between quarters and years for all models (Tables 8 and 9 and Figures 9 and 10) .

Table 8. Analysis of Deviance table produced by a zero-inflated model of fish density for the full dataset. *Run was classified using the Central Valley length-to-date chart. Details of the zero-inflated linear mixed models used in these analyses are provided in the methods.*

Run	**Site Classification**	**Year**	**Quarter**	**River Mile**
All salmonids	$\chi^2 = 2.8404$ df = 2 p = 0.2417	**$\chi^2 = 209.425$ df = 7 p < 0.001**	**$\chi^2 = 91.784$ df = 3 p < 0.001**	**$\chi^2 = 653.815$ df = 1 p < 0.001**
Fall run Chinook	$\chi^2 = 0.519$ df = 2 p = 0.0771	**$\chi^2 = 206.824$ df = 7 p < 0.001**	**$\chi^2 = 393.495$ df = 3 p < 0.001**	**$\chi^2 = 316.856$ df = 1 p < 0.001**
Late-fall run Chinook		*Model did not converge*		
Winter run Chinook	**$\chi^2 = 11.427$ df = 2 p = 0.003**	**$\chi^2 = 180.736$ df = 7 p < 0.001**	**$\chi^2 = 266.033$ df = 3 p < 0.001**	**$\chi^2 = 89.069$ df = 1 p < 0.001**
Spring run Chinook		*Model did not converge*		
Steelhead / Rainbow Trout	**$\chi^2 = 11.572$ df = 2 p = 0.0037**	**$\chi^2 = 107.067$ df = 7 p < 0.001**	**$\chi^2 = 151.100$ df = 3 p < 0.001**	**$\chi^2 = 472.081$ df = 1 p < 0.001**

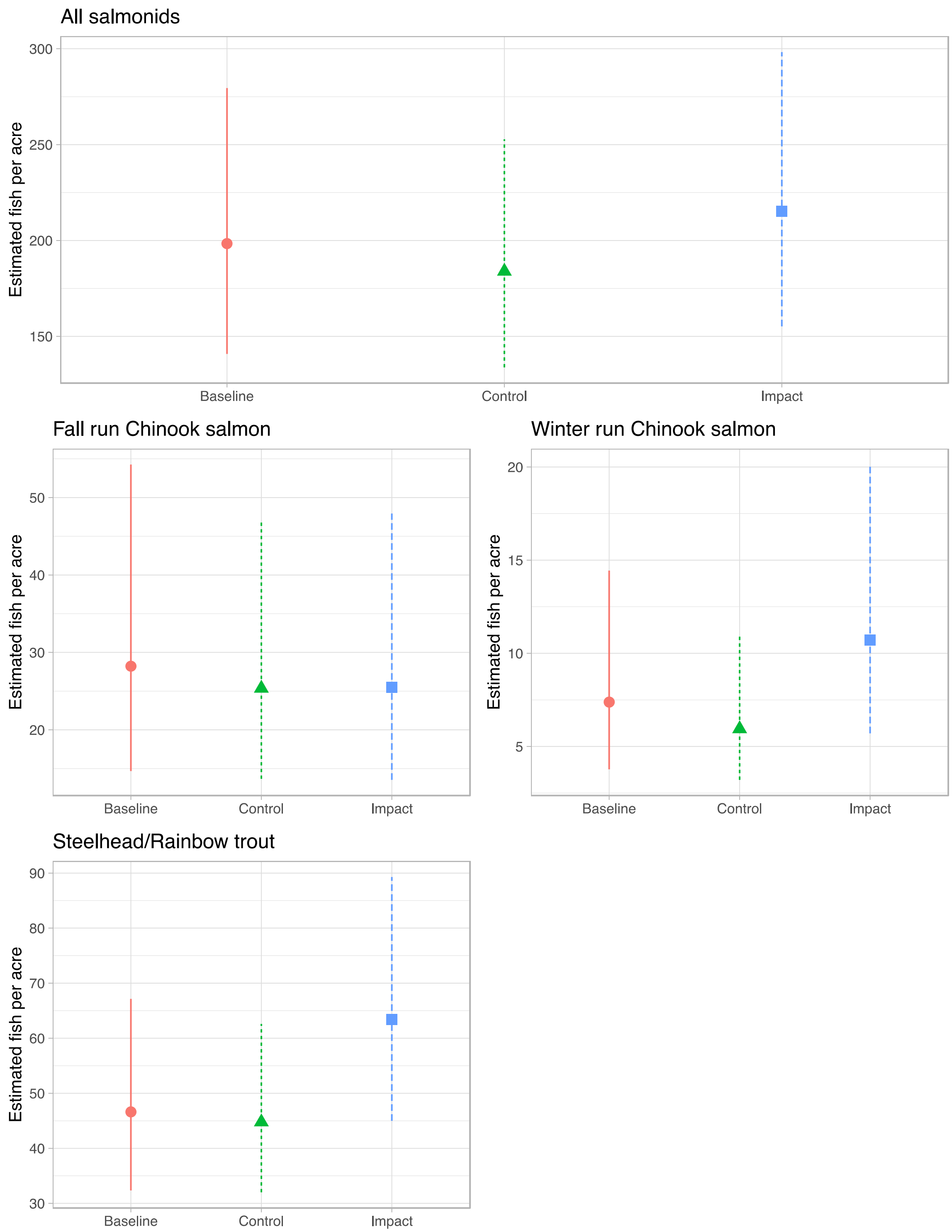

Figure 8. Estimated marginal means of fish density for the full dataset in baseline, control, and impact sites. *Run was classified using the Central Valley length-to-date chart. Details of the zero-inflated models used in these analyses, as well as caveats for the interpretation are detailed in the data analysis text.*

Table 9. Post-hoc comparisons of different site classifications for the zero-inflated model of fish density for the full dataset. *Run was classified using the Central Valley length-to-date chart. Details of the zero-inflated models used in these analyses are provided in the methods. A positive difference value indicates that the first channel status listed has a higher fish density, while a negative difference value indicates the opposite. P-values indicate whether differences in fish density are statistically significant.*

Run	**Difference**	**SE**	**z-ratio**	**p-value**
All salmonids				
Baseline - Control	14.5	21.4	0.675	0.778
Baseline - Impact	-16.8	20.8	-0.857	0.697
Control - Impact	-31.2	19.6	-1.594	0.249
Fall run Chinook				
Baseline - Control	2.9	4.6	0.618	0.811
Baseline - Impact	2.7	4.4	0.627	0.806
Control - Impact	-0.13	3.6	-0.035	0.999
Late-fall run Chinook				
Baseline - Control				
Baseline - Impact		*Model did not converge*		
Control - Impact				
Winter run Chinook				
Baseline - Control	1.44	1.61	0.896	0.643
Baseline - Impact	-3.33	1.95	-1.078	0.202
Control - Impact	-4.77	2.15	-2.233	0.067
Spring run Chinook				
Baseline - Control				
Baseline - Impact		*Model did not converge*		
Control - Impact				
Steelhead / Rainbow Trout				
Baseline - Control	1.84	6.19	0.298	0.952
Baseline - Impact	**-16.77**	**6.97**	**-2.404**	**0.043**
Control - Impact	**-18.61**	**7.03**	**-2.646**	**0.022**

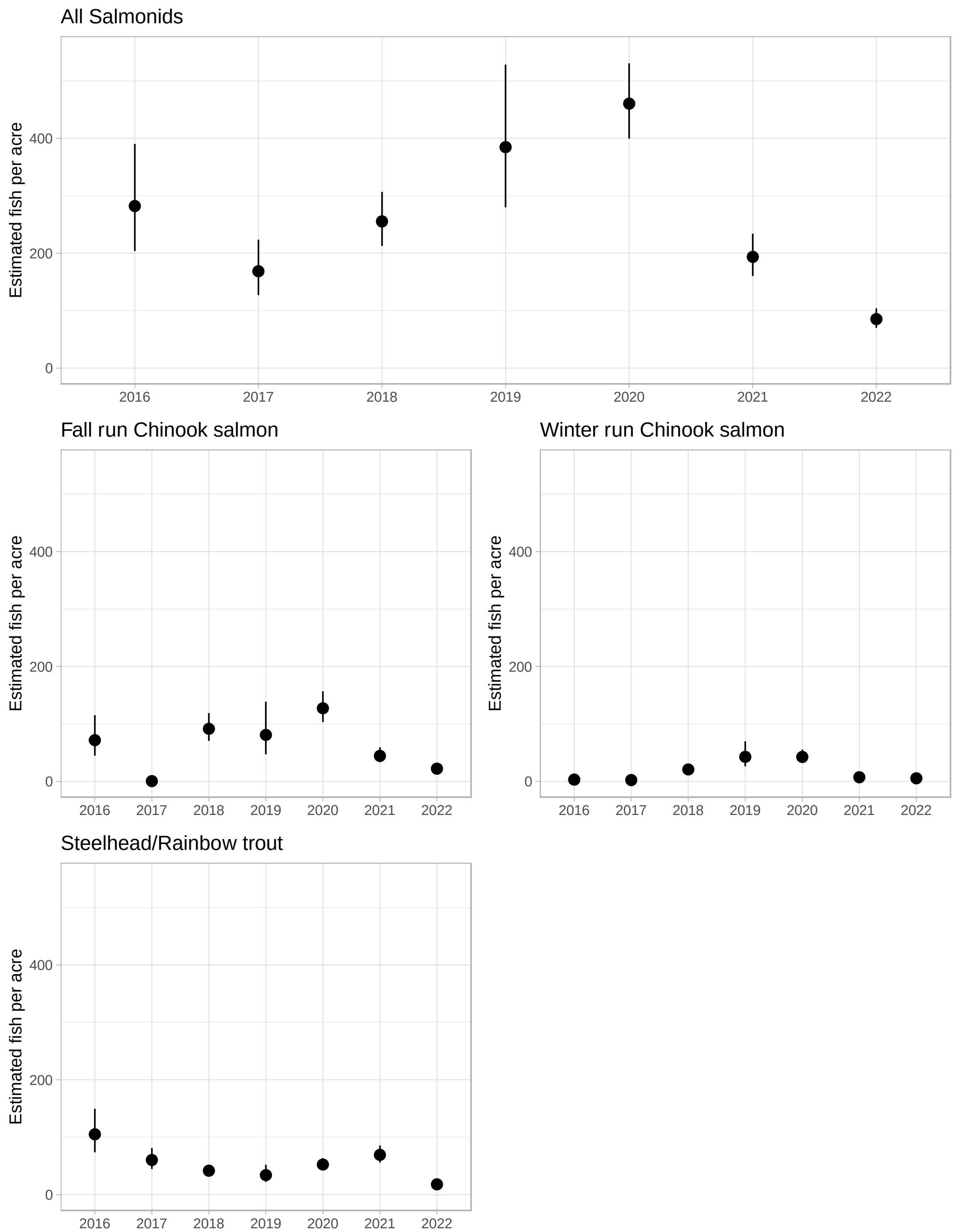

Figure 9. Estimated marginal means of fish density for the full dataset in across years. *Run was classified using the Central Valley length-to-date chart. Caveats for the interpretation of the modeling approach that these graphs are based on are detailed in the text.*

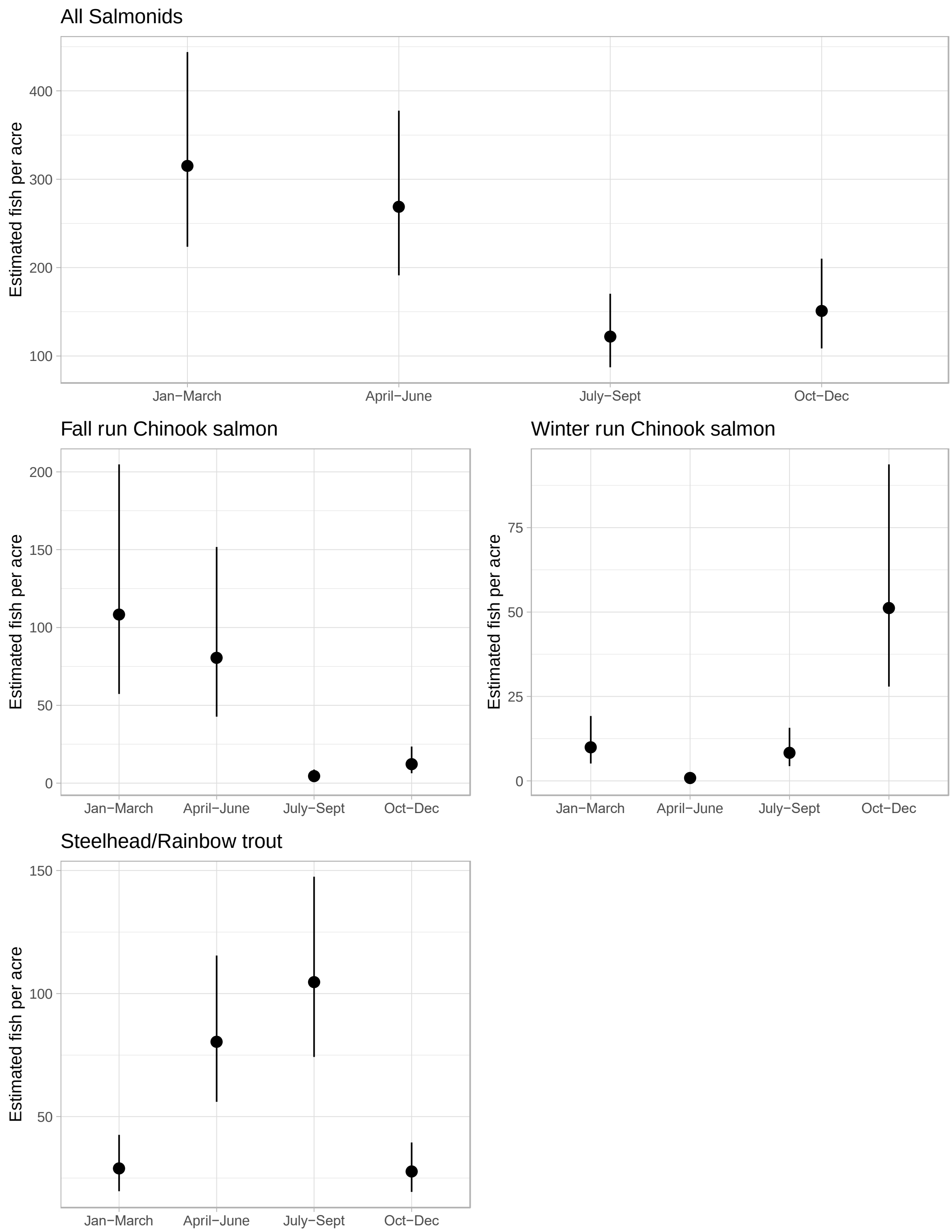

Figure 10. Estimated marginal means of fish density for the full dataset across quarters. *Data is averaged across years. Run was classified using the Central Valley length-to-date chart. Caveats for the interpretation of the modeling approach that these graphs are based on are detailed in the text.*

Comparison of Upstream and Downstream Surveys

Data Analysis

We used a subset of sites that had both downstream and upstream snorkel surveys on the same day in order to determine the relationship between fish counts using these two approaches. Survey order (upstream first vs. downstream first) was alternated randomly. Additionally, individual snorkelers switched sides between surveys to avoid confirmation bias in the second survey, and enough time was taken between surveys to allow survey-induced turbidity to recede. These surveys were conducted between 4/26/2022 and 12/20/2023 and included 32 paired upstream/downstream surveys from the mainstem (all conducted at Kapusta 1B), and 30 paired surveys from side channels (three pairs from ARP Phase 1, two from ARP Phase 2, two from ARP Phase 3, eight from Bourbon Island, six from Kapusta 1A, three from Kapusta Island, one from South Cypress, and five from Wyndham). Data from mainstem sites and side channels were separated for analysis because different collection approaches were used at each site type. We used a simple linear regression in order to generate the relationship between fish counts obtained from upstream snorkel surveys and those from downstream snorkel surveys. This approach was chosen over correlational analysis because it allowed us to generate the 95% prediction interval for each model. We did this analysis first with all values included, and again with outliers removed. Outliers were defined as values that fell more than 1.5 times the interquartile range below the first quartile or above the third quartile. We report the equation, R, p-value, 95% confidence interval, and 95% prediction interval for each model.

Results

Both models generated with side channel data showed a significant relationship between upstream and downstream snorkel surveys (Figure 11). Mainstem sites did not show significant relationship (Figure 11). Of the 30 paired surveys from side channels, on 35 occasions upstream surveys observed salmonid species or stocks not observed on downstream oriented surveys. On 5 occasions downstream surveys observed salmonid species or stocks not observed on upstream oriented surveys. Upstream surveys had fewer zero observations than downstream surveys (13.46% vs 17.31% when salmonid species were pooled, 17.31% vs 28.85% for Rainbow Trout/steelhead, 46.5% vs 56.65% for fall run Chinook salmon, 67.31% vs 78.85% for spring run Chinook salmon, 65.38% vs 80.77% for winter run Chinook salmon, and 55.77% vs 76.92% for late-fall run Chinook salmon).

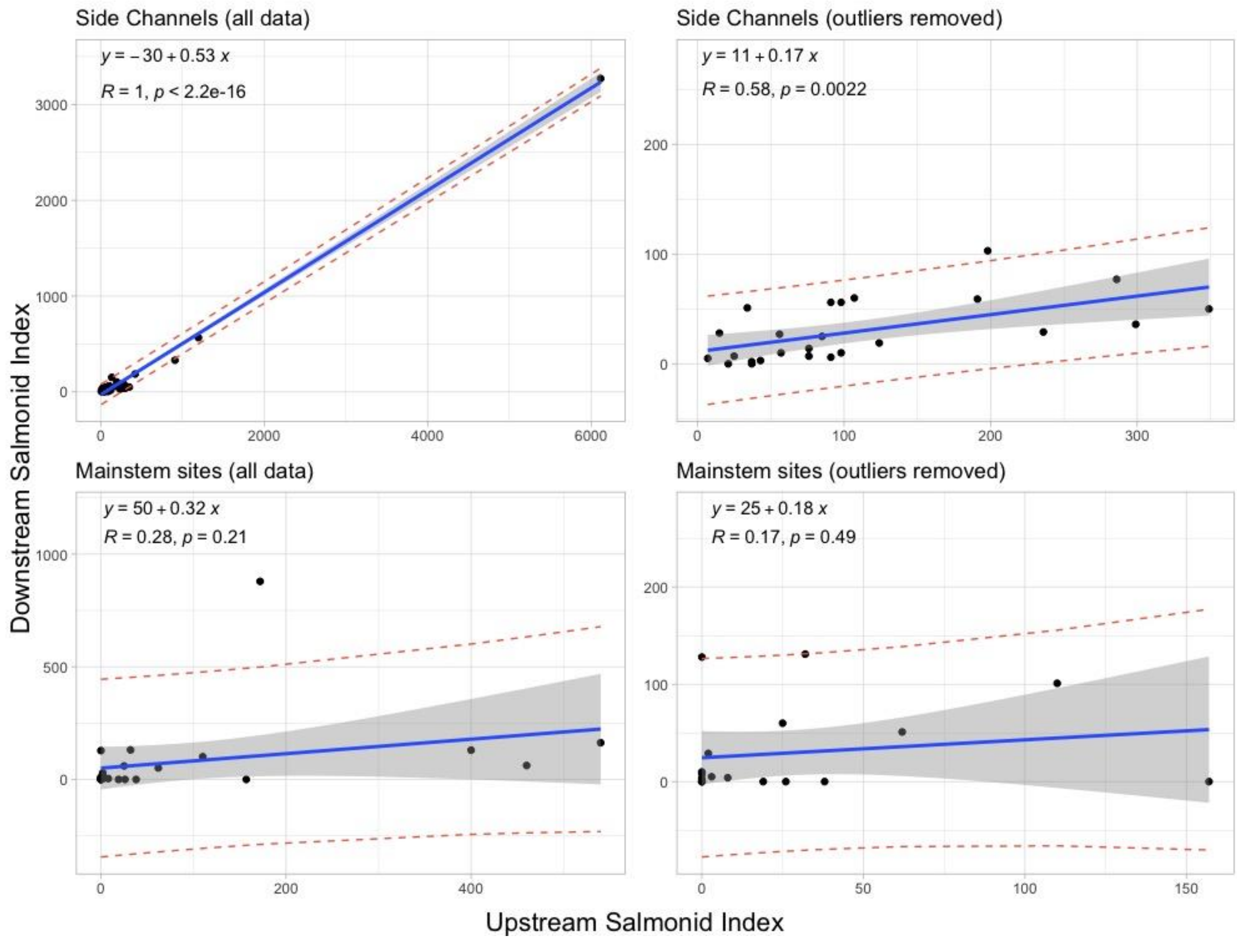

Figure 11. Relationship between upstream and downstream snorkel indices in mainstem and side channel sites. *The blue line represents a simple linear regression line, gray shading represents the 95% confidence interval of the regression, and dotted red lines represent the bounds of the prediction interval with 95% confidence.*

Impact of Channel Width and Depth on Fish Number

Data Analysis

We used a zero-inflated linear mixed model to examine the impact of channel width and average channel depth on fish number. Side channel ID was included as a random effect to account for site specific effects. For each section surveyed, fish count was standardized as fish per 100 feet. A Tweedie distribution was used in the model because it had a lower AICc score than a normal distribution.

Note that the above-described statistical approach should continue to be refined as more data is collected, as it is likely that the shape of the relationship between the main variables of interest may not be fully represented in these models. This is both because it is a zero-inflated dataset, and because there are relatively few observations with higher values. Because of this, we have visually reported both the raw data and modeled data.

Results

Channel width and average channel depth did not significantly impact the number of fish observed per unit length of the channel (Table 10, Figure 12).

Table 10. Analysis of Deviance table produced by a zero-inflated linear mixed model of fish counts in relation to channel characteristics. *Details of the model are provided in the text.*

	χ^2	df	p-value
Channel Width	1.8441	1	0.1745
Average Channel Depth	2.6975	1	0.1005

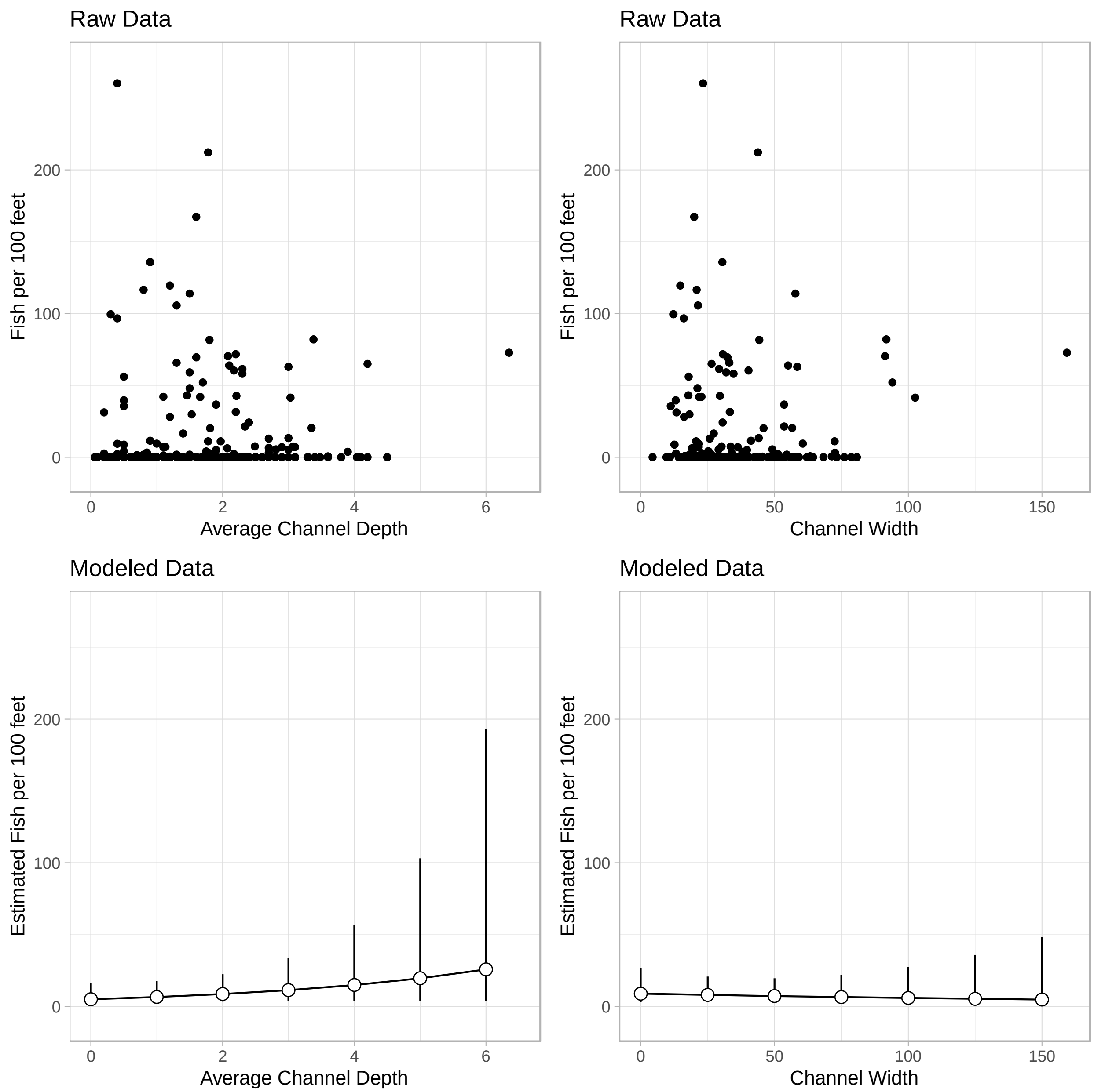

Figure 12. Raw data (top row) and estimated marginal means (bottom row) of fish counts in relation to average channel depth (left column) and channel width (right column). *Details of the zero-inflated linear mixed model used to generate the estimated marginal means are provided in the text.*

DISCUSSION

Impact of Restoration on Fish Counts – BACI and Full Dataset

BACI analyses showed a significant, positive impact of restoration on juvenile salmonid counts as a whole, as well as Chinook salmon juveniles (all runs) and Rainbow Trout/steelhead juveniles. No impact of restoration was found on piscivorous adult fishes or non-salmonid juveniles. Fish densities showed a similar result, with one exception: the impact of restoration on Chinook salmon was only significant in the model that included seasonal run. An analysis of density in the full (non-BACI) dataset showed similar trends for salmonids, but the results were only statistically significant for winter run Chinook salmon and Rainbow Trout/Steelhead.

Overall, the impacts of restoration were less detectable for salmonid densities than counts. This may be explained by a number of factors. First, the areal extent of available habitat in the river was increased by restoration. Prior to restoration, a relatively small number of juvenile salmonids inhabited a smaller area; following restoration, there were greater numbers of fish in a larger habitat. This means an increase in total fish could still be reflected as lower or similar densities. Second, anadromous juvenile salmonids may leave the system due to outmigration; even short migrations to find available rearing habitat can span several kilometers (Bourret et al. 2016). Thus, observation on a local scale may mask some effects of restoration, particularly if sites were already near carrying capacity (Roni 2019). Migratory behavior may also explain why Rainbow Trout/steelhead density exhibited a more detectable positive response to restoration than Chinook Salmon; if a substantial proportion of observed *O. mykiss* were comprised of resident Rainbow Trout, fewer fish may have left the system via migration. Third, this study took place over a relatively short time period. In our dataset, post-restoration data varied from approximately one to four years, depending on the site. Prior work suggests that the full effect of stream restoration may only be evident on a longer time scale (Fuchs and Statzner 1990; Feld et al. 2011; Roni 2019). For example, Stoffers et al. (2021) analyzed 30 years of side channel restoration monitoring data from the lower river Rhine in the Netherlands, and found that the density of rheophilic fishes (a sensitive guild of particular conservation interest) peaked between 13 and 14 years after restoration.

It is possible that the increases in salmonid abundance observed in this study are a result of fish being attracted from other areas of the river, rather than a true increase in abundance. However, a review by Roni et al. (2019) concluded that there is little evidence that river restoration concentrates fish, particularly for salmonids. Näslund (1989) argued that for habitat-limited populations like those seen in our study, any redistribution in response to restoration will be followed by new recruits colonizing the vacated habitat, ultimately resulting in a stream-wide increase in fish numbers. Work by Shetter et al. (1949), Roni and Quinn (2001), and Lehane et al. (2002) all concluded that increases in salmonid numbers after restoration were not due to fish migration into restored areas. Together, these studies suggest that the increased fish abundance observed in this study could translate to greater overall numbers of juvenile salmonids in the river.

We also explored whether restoration influenced potential juvenile salmonid competitors (non-salmonid juvenile fishes) and predators (adult piscivorous fishes). We found that restoration did not significantly impact counts or density of non-salmonid juvenile fishes, nor did it significantly affect adult piscivorous fishes that may be preying on juvenile salmonids. However, both groups did show a non-significant trend for increased counts in response to restoration. Pooling of non-salmonid juvenile fish species for analysis does present a challenge for interpretation, as it could conceal variation in response among species or ecological guilds. It also does not discriminate between native and non-native fishes. Prior work has demonstrated that native fish species in California streams have substantial niche partitioning (Baltz and Moyle 1993), making it possible for native assemblages to experience relatively low levels of direct interspecific competition (Hutchinson 1959; MacArthur 1970; Chesson 2000; Finke and Snyder 2008). Additional information on species identity, niches, and distribution would increase our understanding of competition between juvenile salmonids and other juvenile fishes at our study sites.

The presence of non-salmonid juvenile fishes also has the potential to influence predation risk. Previous work found that Pacific salmon species from the Columbia River experienced lower predation rates during the transition from freshwater to marine habitat when alternative prey fishes were present in higher densities (Phillips et al. 2021). In our study, density of non-salmonid juvenile fishes was significantly higher in restored sites than control sites (both before and after restoration), making it plausible that the restoration sites may have an overall lower risk of predation, irrespective of restoration timeline. Additional work would be needed to confirm this hypothesis. Overall, the densities of adult piscivorous fishes within all study sites were low (estimated marginal mean < 3 fish-per-acre at all sites), though it may be possible for a single adult piscivorous fish to eat a substantial number of juvenile fishes. Studies that examine predator species, size, diet composition, and prey consumption rates could be used to help inform the impact of predators at our sites (Rieman et al. 1991; Vigg et al. 1991; Stompe et al. 2020)

The results of this study suggest that side channel restoration in the Sacramento River has successfully created habitat to support greater numbers of juvenile salmonids. Juvenile habitat in the Sacramento River is at critically low levels, so this type of off-channel habitat restoration could play an important role in the conservation and persistence of salmonid populations in the Central Valley of California. While this study focuses on data associated with restoration sites in Shasta and Tehama Counties, numerous similar restorations are planned or underway within the river. Individually, each restoration site has the potential to provide essential rearing habitat; together, they will form a network of stopover sites along the outmigration route of anadromous populations. Stopover habitat along migratory routes has been shown to be of critical importance for replenishing energetic reserves and increasing migration success in other taxa (Sawyer and Kauffman 2011; Gómez et al. 2017). In the Sacramento River, the addition of this valuable habitat along the migratory corridor has the potential to provide similar benefits to salmonids.

Comparison of Upstream and Downstream Surveys

A recent proposed revision to the monitoring plan was to shift from downstream snorkel index surveys at the margins of the channel to upstream surveys that covered the entire width of the channel. These types of upstream surveys were already being conducted as part of the microhabitat use surveys, which provided an opportunity to generate a relationship between these two approaches, with the goal of more easily relating future and historical data collection at project sites. Downstream snorkel indices were significantly linked to upstream indices in side channels, but not in mainstem sites. In the analysis of the full side channel dataset (including outliers), the correlation between the two approaches was nearly 1. However, this was driven primarily by one set of paired surveys where an unusually large number of fish were observed. Once outliers were removed, the correlation dropped to a moderate 0.58.

In all cases, the prediction intervals were large enough that we recommend caution with using these equations as a conversion factor between upstream and downstream surveys. Additional data could potentially refine these relationships in the future; however, the amount of additional data needed may be large, due to the inherently noisy nature of snorkel data. Upstream oriented full channel indices did outperform downstream oriented margin surveys relative to the number of different salmonid stocks and species observed within side channels. Upstream oriented surveys will improve data quality by reducing the number of zero counts for stocks actually present.

Impact of Channel Width and Depth on Fish Number

Wider and deeper channels produce a greater volume of potential habitat for fishes. However, data on salmonids in other studies have found that fish tend to concentrate around stream margins, particularly those with cover (Quiñones and Mulligan 2005). Because this may have important implications for channel design, we examined whether channel width and depth impacted the number of fish per linear distance. Our results found no significant impact of either factor, which supports the idea that fish congregate in the margins. Wider, deeper channels do not appear to be holding more fish per unit length. This information could be used to inform future channel design.

Project Contributions and Future Directions

Over the last five years monitoring efforts have contributed to meeting four of the five fisheries related objectives outlined in the Monitoring Plan (Tussing and Banet 2017, objectives 1-5). The datasets used in the analyses reported here and in previous annual reports vary in quality and size. Results obtained from the highest quality datasets all suggest that the Upper Sacramento River Anadromous Fish Habitat Restoration Project has effectively produced additional high quality juvenile salmonid habitat (objective 2) that supports higher numbers of fish (objective 3) in the upper Sacramento River. The effects of restoration on fish size and condition (objective 4) varied between runs when looking at seining data. The seining data was likely confounded by several other factors, and data collection of enclosure study growth rates were unfortunately not completed due to COVID-19 shutdowns. The higher number of macroinvertebrates (determined by sampling rate) observed in restored side channels as compared to baseline channels suggests that there may be a positive effect of restoration on food availability (objective 5), but without biomass and diet information, firm conclusions can't be drawn. Addressing the logistical challenges of collecting data for objectives 4 and 5 can help paint a clearer picture of how side channel restoration affects salmonid growth.

Monitoring results have enabled the refinement of more efficient and cost-effective data collection methods and increases in the quality or information content of data being collected (see Tussing and Banet 2022). Focused studies have been employed to relate historic and refined methods for the continuity of long-term trend monitoring (see up/down snorkel comparisons, this report). For future restorations, we emphasize the need for data collection before restoration occurs, to increase our ability to detect the effects of restoration. The use of control sites has also been instrumental in our ability to control for potential confounding environmental and fish population effects between pre- and post-project years and has enabled us to compare results from restored sites to similar and nearby naturally occurring sites.

Monitoring efforts have also enabled us to test our assumptions and create an adaptive management feedback loop with the restoration design team. We were able to provide refined habitat suitability criteria and cover preferences for juvenile salmonids found in side channels in the upper Sacramento River, which can be used to inform future restoration. However, some metrics need additional data collection to draw definitive conclusions. Additionally, the results of focused analyses such as evaluating the impact of channel width and depth on fish number (this report) should help refine restoration designs and improve cost effectiveness.

Continued monitoring of completed and future restorations will provide additional insight into the effectiveness of side channel restoration, as well as adaptive management feedback to the restoration design team. Due to the shortened analysis and reporting window for this report we have some analyses in progress that are structured to provide adaptive management feedback to the design team. The first is analyzing cover use preferences in a slightly different manner than in the past that will allow us to additionally explore fish use preference for unembedded cobble and aquatic vegetation and its subcategories (emergent, submerged, floating mats). As channel designs can influence conditions conducive to the establishment of aquatic vegetation it is important to evaluate if fish are using this cover type in proportion to its occurrence. The second is analyzing the comparative fish use of placed vs. naturally recruited woody cover (large, small, fine). These results may be released as a technical memorandum in the short term for the design team prior to its inclusion in the next annual report.

In 2022, changes were made to monitoring protocols consistent with the recommendations outlined in the Monitoring Plan Revisions for 2022-2026 (Tussing and Banet 2022). These changes were made to maximize cost effectiveness and to better meet the monitoring recommendations of the Science Integration Team (SIT). Future analyses and reporting will test the efficacy of these modifications and evaluate if we can demonstrate project effectiveness with a single year of pre- and post-project monitoring data within a BACI framework. Two sites will initially be evaluated Kapusta 1B (restored fall/winter 2022) and East Sand Slough (restored fall/winter 2021). Drought conditions and low mainstem releases in the summer of 2022 prohibited data collection of typical spring through fall flow conditions (available suitable habitat and fish use) at East Sand Slough.

We also anticipate that in the next reporting cycle we can provide monitoring results for objective 1 of the Monitoring Plan (Tussing and Banet 2017) which is to increase the areal extent of spawning habitat meeting suitability criteria and the use of spawning habitat. To date there are a total of three sites where gravel was added to increase spawning habitat areas including Rio Vista (Oct 2019), South Cypress (May 2021), and Kapusta 1B (Jan 2023).

Additionally, in the coming year we would like to evaluate potential day vs. night differences in fish use of habitat as this is a significant monitoring assumption that was identified in the Monitoring Plan (Tussing and Banet 2017). Potential fish behavioral responses to cold water temperatures would ideally be incorporated into this focused study but that will depend upon winter stream conditions including temperatures and low turbidity levels that enable direct fish observations with snorkeling methods.

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