Assessing temperature regimes and juvenile Chinook Salmon growth in Trinity River off-channel and mainstem habitats

September 2022

Emily J. Cooper-Hertel[1], Kenneth T. Lindke[2], Taylor Daley[3], Kyle DeJuilio[1], Kyle Hopkins[1]

1. Yurok Tribe Fisheries Department, 190 Klamath Blvd, Klamath, California 95548; (530) 430-1350

2. California Department of Fish and Wildlife, 5341 Ericson Way, Arcata, CA 95521; (707) 822-4230

3. U.S. Fish and Wildlife Service, 1655 Heindon Rd., Arcata, CA 95521; (707) 825-5124

CONTENTS

LIST OF FIGURES

downstream near Junction City. The number of flow events ≥2,500 or ≥3,500 cfs is noted for each water year in each plot.

LIST OF TABLES

ABSTRACT

The Trinity River Restoration Program has made efforts to improve juvenile salmonid rearing habitat degraded by legacy hydraulic mining and dam operations through habitat restoration and adaptive flow management. We assessed how restored off-channel habitats benefit the growth of juvenile Chinook Salmon compared to mainstem habitats in locations just downstream of Lewiston Dam and locations farther downstream affected by accretionary flows near Junction City. We hypothesized that 1) juvenile Chinook Salmon growth is greater in off-channel features during spring rearing so much that 2) those off-channel benefits would persist through the summer and fall for greater survival upon historical timing of November through December flow events that reconnect off-channel features to the mainstem and its resources. We compared temperature and juvenile growth in off-channel sites paired with mainstem sites with continuous temperature data collection and four sequential fish length and weight measurements from May to mid-June. Temperature regimes in the mainstem Trinity River are influenced by dam releases and were mostly below the optimal range (13.0–16.5°C) for juvenile growth. Temperatures in off-channel features offered warmer, more thermally diverse conditions into late spring during 2019, with some features maintaining optimal ranges, but some becoming lethally warm for extended durations (>24°C) in spring of 2020. Greater fish growth was observed in mainstem habitats compared to off-channel habitats. Greater fish growth was observed in warmer mainstem sites in downstream locations compared to cooler upstream mainstem locations. However, insufficiently sealed enclosures allowed fish to escape some experimental enclosures, compromising our study design. The loss of data at several sites did not allow for a formal analysis, resulting in a presentation of results as largely descriptive and qualitative. We recommend this study be repeated in a wetter water year to provide contrast to the findings presented herein, particularly with respect to the unexpected lower growth in thermally optimal conditions in off-channel features.

INTRODUCTION

Due to years of intense dredge and hydraulic mining, the Trinity River has been left severely disconnected from its floodplains. Valleys on the Trinity River have aggraded as much as 16 ft (Andreas Krause personal communication) from sediments washed off hillsides by mining activities. The Trinity River Restoration Program's (TRRP) goal to restore anadromous fisheries is rooted in restoration of fluvial processes. Physical rehabilitation of the channel is a primary tool used by TRRP for river restoration, which has reduced confinement in some areas and renewed river access to floodplains, creating valuable juvenile rearing habitat for salmonids. Off-channel features such as side channels, backwater alcoves and other intermittently connected features have been constructed to mimic naturally occurring conditions common to floodplains. Studies have found that off-channel features provide diverse habitat, such as thermal variability through stratification, diverse food availability, and protection from predation during vulnerable life stages (Jeffres et al. 2008, Sommer et al. 2001).

Pilot studies were conducted in 2017 and 2019 in a subset of intermittently connected off-channel features in the Lewiston and Junction City areas of the Trinity River. Temperature was monitored in both years and presence/absence snorkel dive surveys for juvenile salmonids were also conducted in 2019. Chinook Salmon were observed in nearly every off-channel feature surveyed in 2019, and thermally diverse conditions including the range of optimal growth for salmonids (Lusardi et al. 2020) were documented. The TRRP identifies an optimal juvenile growth temperature range between 13.0°C and 16.5°C. Juvenile Chinook Salmon rear in the Trinity River restoration reach beginning in the winter. In recent years, 80% of natural and hatchery juvenile Chinook Salmon emigrate from the study reach at the Pear Tree rotary screw trap by mid-May and late July, respectively (Davids et al. 2013, Petros et al. 2014, Harris et al. 2016, Petros et al. 2017), thus we define their critical rearing period from January through July. Mainstem temperatures from February 1 to May 15, 2019 ranged from 3.3°C to 13.8°C, providing suboptimal temperatures throughout the critical rearing period (Lindke and De Juilio unpublished data). Many off-channel features, particularly those in the TRRP restoration reach, have very limited access during rearing periods of juvenile salmonids due to regulated flow management. Understanding the benefits to juvenile salmonids provided by these off-channel features is a critical step toward flow management that can leverage habitat improvements to increase growth and survival. We hypothesized that fish would experience higher growth rates during the critical rearing period in intermittently connected off-channel features compared to the mainstem river.

Timing and frequency of surface water connectivity between mainstem and intermittent features is an important factor in potential resource availability and exploitation for fish growth and survival (Huntsman and Falke 2018). Potential growth advantages that fish may incur from use of intermittent off-channel features are not meaningful if fish are unable to survive and thrive until their next opportunity to access the mainstem river and its resources. This may be of particular concern under current management constraints, and of increasing concern closer to Lewiston Dam, which limits off-channel connectivity to releases above baseflow from April 15 to mid-June each year, unless necessary for flood control. Unregulated flow conditions would connect these features to the mainstem river during regular winter storm events beginning in November or December in most years. Consequently, under current management constraints, fish remaining in some off-channel features must survive from late spring/early summer until the following April. Natural flow patterns would have intermittently connected off-channel features from October through June, and fish would have many opportunities to enter or exit these types of features over that period. Hydrograph recommendations in the Record of Decision (DOI 2000) only offered one instance each year for access to these features between mid-April and mid-June. More recent modified ROD hydrographs have offered 3-5 instances of connection during the same time period. This shift in frequency of access opportunities from many to few and the duration and timing of access from nine months in fall through spring to two months in spring impacts the relative value and function of these types of features.

Project Implications

Flow releases from Lewiston Dam are recommended to the U.S. Bureau of Reclamation by TRRP and have been implemented as recommended, in addition to tribal ceremonial, safety of dam, and fish health releases. Flow scheduling under the Record of Decision (DOI 2000) does not permit flow releases greater than baseflow from August 15^{th} to April 15^{th}, thus limiting access to intermittently connected habitat features. Flows that allow off-channel features to reconnect to the mainstem and allow fish access to rear or recruit back to the mainstem would be expected from October through June under a natural flow regime. It is currently unknown whether over-wintering in disconnected off-channel features provides a benefit to rearing juvenile salmonids, and it is possible that preventing connectivity in fall/early winter is detrimental. Temperatures observed in the mainstem during the spring flow release period are nearly always below optimal for juvenile salmonid growth, while off-channel features with limited or no connection to the mainstem offer warmer temperatures and thus potentially increased growth opportunities. If off-channel features are shown to provide increased growth opportunity for juvenile salmonids as compared to the mainstem, providing access to those habitats could increase growth and survival of juveniles, which would presumably translate to increased adult production.

The results of this study were intended to provide important information about potential effects of flow management that may inform changes to flow management. Results may provide information on the importance of connection between off-channel and mainstem habitats for juvenile fish growth and survival. Better understanding of the benefits of off-channel habitats to juvenile fish may contribute to better managed flows.

Objectives

The proximate goal of this study was to improve our understanding of potential differences in short-term and seasonal growth patterns of fish using intermittently connected off-channel features in comparison to fish using the mainstem river, with an ultimate goal of informing adaptive management of flow releases from Lewiston Dam. The objectives of the study were to test for differences in growth rates and seasonal growth trajectories of juvenile Chinook Salmon between off-channel features and the mainstem Trinity River.

We hypothesized that 1) juvenile Chinook Salmon growth is greater in off-channel features during the spring rearing period so much that 2) those off-channel benefits would persist through the summer and fall for greater survival upon historical timing of November through December flow events typically high enough to reconnect off-channel features to the mainstem and its resources. We tested our first hypothesis by conducting an enclosed fish study measuring individual fish growth and water temperature during spring rearing in six locations of paired off-channel versus mainstem habitats throughout the Trinity River restoration reach. To test our second hypothesis, we intended to use otolith analysis to describe fish growth trajectories in off-channel features during the fall season as historical fall to winter timing of hydrologic conditions transition to reconnecting intermittent features to the mainstem. With these observations, we expected greater insight on the quality of off-channel features for rearing juvenile salmonids during the critical rearing period and improved understanding of the consequences of connection timing due to flow management. These data were intended to inform flow management as it pertains to the Trinity River's ability to produce salmonids of adequate outmigration size.

METHODS

Study Area

The Trinity River is the largest tributary to the Klamath River and supports anadromous fish populations in tributary and mainstem habitats downstream of Lewiston Dam at river kilometer (rkm) 180.1. Construction of Lewiston Dam was completed by the U.S. Bureau of Reclamation (USBR) in 1964 and is a complete barrier to anadromy. Trinity River hatchery was constructed to mitigate for habitat loss upstream of Lewiston Dam and produces steelhead, Coho Salmon, and spring and fall Chinook Salmon. The 40 miles of mainstem Trinity River from Lewiston dam to the confluence with the North Fork Trinity River (restoration reach), has been the focus of restoration efforts by the TRRP, including physical reconstruction of the river channel and construction of off-channel habitat to support rearing juvenile salmonids.

Site Selection

Off-channel features were identified using the 2016 SRH-2D model of the restoration reach (Bradley 2016) with modifications of surface elevations based on post-construction surveys at the Sheridan Creek site constructed since that time (Pryor 2018). Hereafter, we refer to collective surface elevations used in this study as the SRH-2D model. We identified that the vast majority of intermittently connected off-channel habitat in the restoration reach becomes connected to the mainstem at flows between 2,500 and 5,000 cfs. Off-channel features were randomly sampled after a multi-step identification process. First, we used SRH-2D to identify all features that were connected to the mainstem river via surface flow between 2,500 and 5,000 cfs. This list of features was examined at various flows between 2,000 and 5,000 cfs to roughly determine the flow at which each site became connected. The list was further refined to include only sites that connected to the mainstem river at 3,500 cfs or lower because we wanted sites that would have been connected to the mainstem river before the study began, and water year projections at the time of planning indicated Dry or Critically Dry were the most likely water year types. Second, we applied the criteria in Table 1 to further reduce the number of candidate features, some of which were evaluated based on ground-based evaluation at each site as opposed to using model outputs. Qualified sites in the Lewiston area (between river miles 111.9 (rkm 180.1) and 95.4 (rkm 153.5)) and Junction City area (between river miles 85.0 (rkm 136.8) and 74.5 (rkm 119.9)) were randomly ordered, and each qualified site was visited in that order for on the ground verification of site suitability. From their randomized ordering, the first three verified suitable sites were selected as study sites. Field visits and alternative sites were necessary because conditions such as vegetation cover, depth and connection flow level may differ from model conditions or since the last field visits for a variety of reasons.

Table 1. Off-channel site selection criteria for pairing with mainstem sites and conducting a comparison in juvenile Chinook Salmon growth in the Trinity River restoration reach.

Number	Criteria
1	The feature maintained suitable temperatures throughout the full monitoring period of 2017 and 2019 pilot studies
2	The feature is at least 100 m^2 in total area at 2,000 cfs[1]
3	The feature is not so deep that constructing enclosures or sampling fish during revisits will be logistically infeasible
4	There is suitable habitat in the mainstem in close proximity where paired enclosures can be constructed
5	The feature connected at least one time during the water year prior to this study

[1] This criterion was relaxed for Sawmill side channel (90 m^2 at 2,000 cfs) due to the limited number of sites meeting other criteria.

Each off-channel feature was paired with a mainstem river site in close proximity and occurring in an area containing suitable juvenile salmonid habitat across the range of scheduled flows based on the 2016 SRH-2D model. Suitable off-channel habitat was considered habitat expected to provide low velocities and remain wetted as spring flows receded. The study occurred during the spring critical rearing period when flows were expected to remain relatively stable (but may include snow melt or riparian recession components of the hydrograph) and below 2,500 cfs for at least six weeks. Features that did not connect at some point during the water year prior to the study were excluded from this study.

For purposes of this report, we define three spatial scales to aid the reader. Areas refer to the Lewiston (upstream) area and Junction City (downstream) area generally. Locations refer to the combined off-channel feature and paired mainstem site. Finally, sites refer to individual off-channel features or a paired mainstem site. We focused on the Lewiston and Junction City areas because they offer different temperature conditions due to differences in proximity, and thus influence from, hypolimnic cold water releases from Lewiston Dam. Furthermore, flow conditions also differ in these two areas due to tributary accretions downstream of Lewiston Dam. Off-channel features in these areas interact similarly with the mainstem river but the timing and duration of interactions differ due to tributary accretion adding to dam releases. In both areas off-channel features include constructed and natural off-channel ponds, depressions, and high-flow side channels. These off-channel features provide thermally diverse habitat compared to the mainstem river because of their intermittent connectivity.

Site Construction

Two enclosures were constructed at each off-channel or mainstem site to act as replicates for each site. The enclosed study was timed to coincide with timing of optimal growth temperatures based on temperature data collected in off-channel features in 2017 and 2019, to the degree possible, given scheduled flow releases from Lewiston Dam. Conducting the study when temperatures are optimal for growth was intended to demonstrate the maximum contrast in growth potential of these features given available conditions in the study year. Enclosures spanned the depth of the water column and breeched the surface to provide access to a range of temperatures and prey species. Enclosures were sized to minimize effects of density dependent growth, provide sufficient sample sizes of fish within each enclosure (30 fish per enclosure), and accommodate site-specific considerations. Fish density was standardized to area of enclosures using methods similar to Zeug et al. (2019).

Enclosures were constructed using metal t-posts, ¼ inch mesh netting, sandbags, and various hardware. T-posts were pounded into the stream bottom at four corners of each enclosure, which were then wrapped with mesh netting to form sides of enclosures. Zip ties were used to close the seam where ends of mesh netting overlapped. The inside perimeters of enclosures were lined with sandbags set end-to-end on the bottom edge of mesh netting walls. Finally, raptor netting was draped over the top of enclosures and secured along each side with zip ties or sticks woven through the top netting and side mesh to exclude predators, particularly birds (Figure 1).

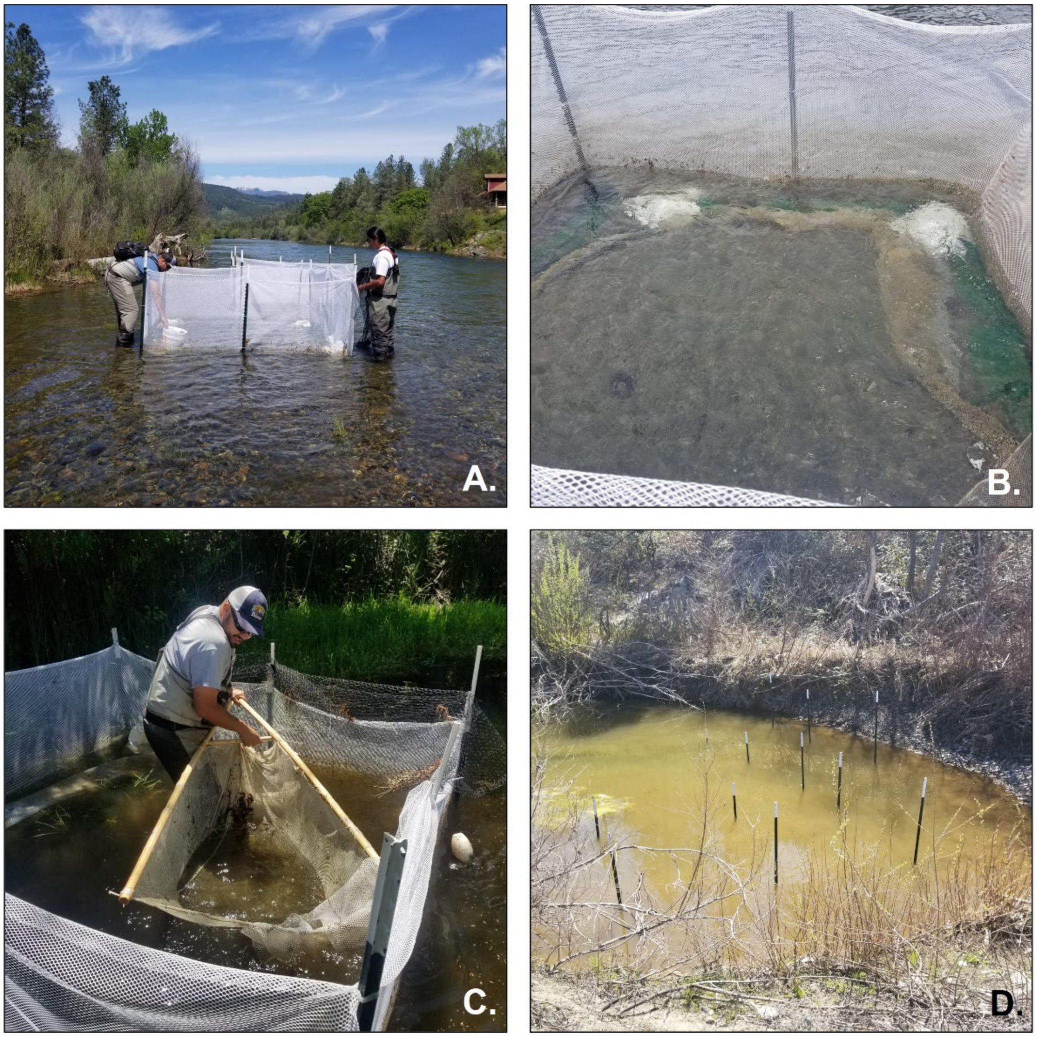

Figure 1. Photo documentation of fish enclosures used in this juvenile salmonid growth study; A depicts a mainstem enclosure with people for scale; B shows the inside of an enclosure; C depicts fish sampling within an enclosure; and D shows an off-channel enclosure before its construction was complete with netting.

Temperature

Temperature was monitored continuously every 15 minutes from early May to mid-June at all mainstem sites and from early May through October at off-channel sites. In off-channel features, a stringer of HOBO Onset water temperature loggers was placed to monitor water temperatures and potential stratification. Stringers consisted of aircraft cable strung between a bottom weight and top float with one logger at the bottom and one fixed on the stringer to consistently stay one foot below the surface. Stringers were placed adjacent to fish enclosures in off-channel features. Enclosures in the mainstem river were each fitted with a single temperature logger because temperature is well mixed (i.e., does not stratify), eliminating the need to quantify temperatures at multiple elevations in the water column. We plotted temperature at each site to evaluate conditions between off-channel and mainstem sites and between upstream and downstream areas.

Site Visits and Fish Growth

Eight hundred juvenile Chinook Salmon obtained from the Trinity River hatchery were measured, weighed, and individually identified by surgical implantation of a Passive Integrated Transponder (PIT) tag. Fish were anesthetized with a dosage of MS222 suitable for rapid anesthesia (80-100 mg/L). We then used a number 20 blade on a surgical scalpel to make a small body incision in which to insert a PIT tag. Incisions were not sutured or glued after tagging. Fish were held for one week before deployment to account for mortality and tag loss (<1% tag loss/mortality). Seven hundred twenty fish were verified for PIT tags and qualified for deployment. Thirty individuals were placed in each enclosure at selected off-channel and paired mainstem sites. The use of PIT tags was intended to allow estimation of growth rates for individual fish to avoid confounding growth and size-dependent mortality that can occur from estimating growth from changes in average size (i.e., without individual information). Study fish were observed for growth in two settings: the first in an enclosed setting to serve as a controlled environment for spring-time growth in paired off-channel and mainstem sites, and the second with fish released to swim freely throughout isolated off-channel sites for over-summer and early fall growth. Fish were captured, measured, and weighed four times over the six-week course of the enclosed study, including at initial deployment in early May and when enclosures were removed and fish were released into the features in mid-June. There were approximately two weeks between each site visit. Fish data from the six-week spring observation period were combined between enclosures at each site and plotted to evaluate growth patterns in mainstem and off-channel sites as well as between upstream and downstream areas. Combining enclosures at each site occurred in response to loss of study fish, which was considerable at some sites (see Results for further details).

After completion of the paired enclosure study, PIT-tagged fish were released into the off-channel feature in which they had been enclosed. PIT-tagged fish from mainstem enclosures were also released into their paired off-channel feature to increase sample size for the next component of the growth study. On November 4–6 2020, off-channel features that had fish released into them at the completion of the enclosed portion of the study were revisited in an attempt to collect PIT-tagged fish for otolith analysis to describe approximately 1-3 months of daily growth. We used a Smith-Root 12-B backpack electrofisher at 200 volts DC, increasing to 300 volts DC as needed in larger off-channel features and/or when fish were not attracted well by 200 volts. Specific conductivity at all sites ranged from 80-100 µS. All features were completely disconnected from the mainstem from the time fish were released into these features in June through sampling in November, thus no block nets or other exclusion devices were needed and no fish emigrated from the features (except mortality). One electofisher and two netters (three people total) passed through each feature from one end to the other in overlapping transects, covering all habitat repeatedly until no fish were captured in two successive complete passes. This sampling effort occurred approximately one month after the typical onset of storm-related flows that would connect these features to the mainstem if flows were unregulated.

Fish Growth and Temperature

To better understand the relationship between fish growth and temperature at our study sites, we calculated growth and temperature statistics for each period between site visits for each site, where sufficient data existed. Fish data from two enclosures at a given site were combined to increase sample size. Average fish growth per day per site was estimated as the average of individual changes in weight of PIT-tagged fish from one site visit to the next divided by the number of days between site visits. Temperature among each 15-minute observation between site visit dates was averaged. Fish growth was plotted against the average temperature over the same space and time as measured by temperature loggers deployed at each site, with three periods of growth at each of the 12 sites (six locations). Where temperature data from top and bottom loggers in off-channel features were available, data from loggers with less lethal temperatures (< 24° C, Lusardi et al. 2020) were used since fish would utilize more suitable conditions in a stratified setting. Unfortunately, due to loss of fish and temperature data at some sites, the actual number of observations for this analysis was less than 36 (12 sites * 3 periods). Growth and temperature data were plotted and symbolized by site type (off-channel vs. mainstem) and area (upstream vs. downstream). No statistical analyses were conducted due to differences in sample size across periods, site type and area. Instead, qualitative descriptions are provided. Two additional caveats for these growth data should be noted. First, estimated growth rates are not independent because the same fish were measured across successive periods at each site, commonly known as repeated measures. However, no models were fit to these data, so there are no distributional assumptions of independence inferred in plots of growth vs. temperature. Second, because a varying number of fish were lost from enclosures throughout the study, there is potential for varying density dependent effects across sites.

Off Channel Connectivity between Water Years

Fish were previously observed utilizing optimal temperatures in off-channel habitats during pilot studies in 2017 and 2019, which provided the impetus for this study. Water years 2017 and 2019 were defined by Record of Decision (DOI 2000) classification as Extremely Wet and Wet water year types, respectively. This study took place during a Critically Dry water year in 2020. To better understand off-channel habitat conditions that may contribute to fish growth between different water year types, we evaluated differences in off-channel habitat connectivity by comparing flow frequency, duration, and timing of off channel connection to the mainstem between water years 2017, 2019, and 2020. Knowing that our selected off-channel features connect to the mainstem at flows greater than or equal to 2,500 cfs or 3,500 cfs, we plotted daily time periods with flows ≥2,500 cfs or ≥3,500 cfs by the number of instances of these connection flows and the daily duration of each instance. This was done for the upstream locations with Lewiston gage data (USGS 11525500) and for the downstream locations with Junction City gage data (USGS 11526250) over water years 2017, 2019, and 2020.

RESULTS

Site Selection

Model output from SRH-2D indicated 10 off-channel sites in the Lewiston area and 12 sites in the Junction City area were connected to the mainstem between 2,500 cfs and 5,500 cfs (Figure 2 and Table 2). Among those 22 sites, four in Lewiston and ten in Junction City were connected at 3,500 cfs or lower. Lowden side channel did not meet our criteria for area, leaving only three sites in the Lewiston area to be selected. Random selection and field visits to the 10 qualified sites in the Junction City area resulted in selection of Sheridan W3, Sheridan W5, and Lime Point 2 (hereafter Lime Point) (Figure 2). All six selected sites appeared suitable at the beginning of the study based on our additional criteria and were selected for the study. Each off-channel site was paired with a nearby mainstem site.

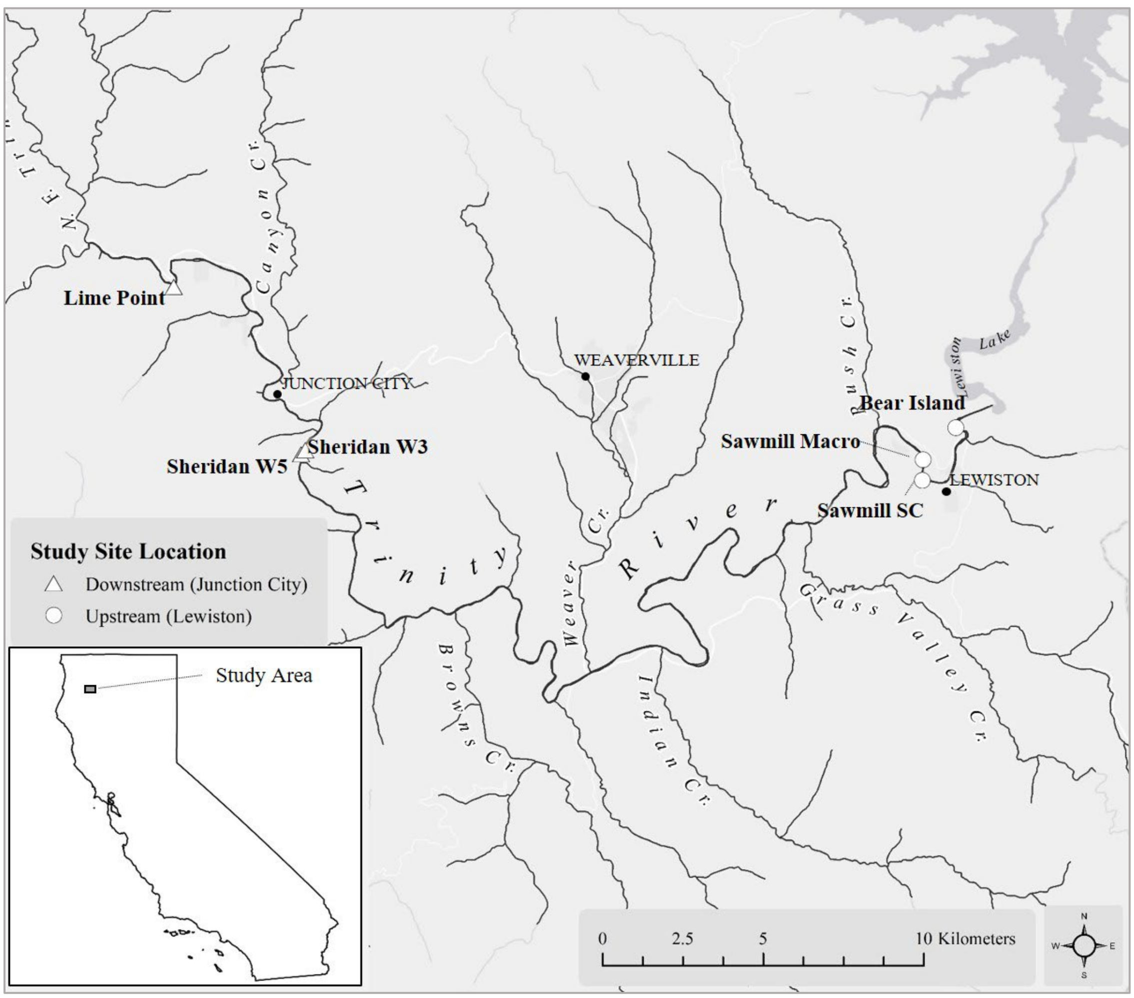

Figure 2. Study area and study site locations in upstream areas near Lewiston and downstream near Junction City in the Trinity River, CA. Source: NAD83 US State Plane California 1 (Esri, DeLorme, HERE, MapmyIndia, 2021).

Table 2. Off-channel features in the Lewiston and Junction City areas of the Trinity River that connect to the mainstem via surface flow between 2,500 and 5,500 cfs based on SRH-2D modelling. Existing temperature data from 2017 and 2019 pilot efforts are indicated by an "x". Connection (C) or disconnection (DC) are indicated for each feature at flows from 2,000-5,500 cfs. Features in bold font were selected as sites for this study.

Area	Location Description	Feature Size (m^2) at 2,000 cfs	Existing Temperature Data	Connection Flows (cfs)				
				2,000	2,500	3,500	4,500	5,500
Lewiston	**Bear Island**	**1,450**	**x**	**DC**	**DC**	**C**	**C**	**C**
	Sawmill Pond	256	x	DC	DC	DC	DC	C
	Sawmill SC	**90**		**DC**	**DC**	**C**	**C**	**C**
	Sawmill Macro	**223**		**DC**	**C**	**C**	**C**	**C**
	Upper Rush Access	236		DC	DC	DC	C	C
	Rush Creek	10,134	x	DC	DC	DC	C	C
	Salt Flat Bridge	166		DC	DC	DC	DC	C
	Bucktail	343		DC	DC	DC	C	C
	Lowden SC	73		DC	C	C	C	C
	Grass Valley Creek	115		DC	DC	DC	DC	C
Junction City	Evans Bar	231	x	DC	DC	C	C	C
	Sheridan W3	**1,102**	**x**	**DC**	**C**	**C**	**C**	**C**
	Sheridan W5	**700**	**x**	**DC**	**DC**	**C**	**C**	**C**
	Sky Ranch	175		DC	DC	C	C	C
	Upper Junction 1	1,408	x	DC	DC	DC	DC	C
	Upper Junction 2	272	x	DC	C	C	C	C
	JC CG	272		DC	C	C	C	C
	Wheel Gulch 1	535		DC	C	C	C	C
	Wheel Gulch 2	373		DC	DC	DC	C	C
	Coopers Bar	190		DC	DC	C	C	C
	Lime Point 1	349		DC	C	C	C	C
	Lime Point 2	**200**		**DC**	**DC**	**C**	**C**	**C**

Site Visits

Site visits occurred as expected, with approximately two weeks between each of the four visits (Table 3). We experienced loss of study fish at several sites, which was substantial in some cases. The decrease in individual numbers occurred for a variety of reasons including enclosure failure, predation, low water levels, lethal temperatures, and anoxic conditions. For example, a slight increase in flow on May 17 changed the direction of flow at the Lime Point mainstem site causing one enclosure to collapse and all fish to escape. Changing flow conditions at the Bear Island mainstem site also compromised enclosures there, resulting in the loss of many study fish. Insufficient sealing of the enclosures where mesh walls overlapped or sandbags were not well placed appears to have allowed fish to escape at some off-channel and mainstem sites. There was also a loss of temperature data at some sites from vandalism or wildlife interference. Mainstem loggers at Bear Island, Sawmill Macro, and Sheridan W5 were lost, so mainstem loggers from sites closest in proximity were used as surrogates for comparing off-channel conditions to mainstem conditions at those locations. We ended up with only one temperature series for Sawmill Macro off-channel site, limiting any detection of thermal stratification. Some temperature series were incomplete after data download; for example, Lime Point off-channel top logger lacked data during the spring observation period of this study. Of the three locations in the Lewiston area, Sawmill Side Channel (SW) was the only location with complete temperature data for both sites. Of the locations in the Junction City area, Sheridan W3 was the only location with complete temperature data at both mainstem and off-channel sites.

In addition, habitat conditions at two off-channel sites deteriorated considerably over the six weeks of the enclosed portion of the study. The Sawmill Macro off-channel feature became very shallow and water appeared anoxic by the second site visit. Conditions were unsuitable for fish, and none were found. The Sheridan W5 off-channel feature experienced high temperatures that resulted in considerable mortality of study fish. Although predator exclusion netting covered enclosures, predation remained a problem at some sites. On one site visit to the Sheridan W3 mainstem site an aquatic garter snake (*Thamnophis atratus hydrophilus*) was captured within an enclosure that had a PIT tag from a study fish in its stomach. On a separate visit to the same site an adult sunfish was captured in the enclosure, but no PIT tag was found in its stomach. Escape and mortality of study fish resulted in low sample sizes in many instances for data analysis. During the final site visits in mid-June, enclosures were disassembled and fish were released into off-channel features to swim freely for the remainder of the study. Sawmill Macro and Sheridan W5 off-channel features were excluded from this portion of the study due to unsuitable conditions. The few study fish captured in Sheridan W5 were released into the Sheridan W3 feature.

Table 3. Sampling dates for off-channel and mainstem enclosures to measure fish length and weight from May 4 to June 16, 2020. All enclosures were sampled at each site during each visit except where indicated. Site codes are provided in parentheses.

Site Area	Site Name	Site Visit 1	Site Visit 2	Site Visit 3	Site Visit 4
Lewiston	Bear Island (BI)	5/4/2020	5/18/2020	6/1/2020	6/15/2020
Lewiston	Sawmill Macro (SM)	5/5/2020	5/19/2020	6/1/2020[a]	6/15/2020[a]
Lewiston	Sawmill SC (SW)	5/5/2020	5/19/2020	6/1/2020	6/15/2020
Junction City	Sheridan W5 (W5)	5/6/2020	5/20/2020	6/2/2020	6/16/2020
Junction City	Sheridan W3 (W3)	5/6/2020	5/19/2020	6/2/2020	6/16/2020
Junction City	Lime Point (LP)	5/7/2020	5/20/2020	6/3/2020	6/11/2020

[a] Off-channel enclosures were disassembled and excluded from the study starting on 1 June 2020 due to unsuitable conditions.

On November 2–4, 2020, off-channel sites were visited to collect any surviving study fish using electrofishing sampling techniques. No study fish were recaptured in any off-channel feature, thus otolith analysis to describe late summer–early fall growth was excluded from this study. The Bear Island feature is quite large and was almost entirely covered in aquatic vegetation by November, making it nearly impossible to sample effectively. One juvenile Chinook Salmon and five juvenile Coho Salmon were captured, all in good condition, suggesting this feature provided suitable conditions through summer. Sheridan W3 was too deep in some areas to effectively electrofish. After several failed attempts to capture fish in areas shallow enough to electrofish, three surveyors conducted two snorkel dive passes and observed no juvenile Chinook Salmon. Coho Salmon and speckled dace (*Rhinichthys osculus*) were the only juvenile fish species identified. Three Coho Salmon in good condition were captured in the Sawmill side channel feature, suggesting this feature also provided suitable conditions through summer. Zero fish were captured in the Lime Point feature, and none were observed via snorkel diving.

Temperature

Temperatures were recorded continuously every 15 minutes in mainstem sites as well as in the top and bottom of off-channel sites, however, some data were lost due to being stolen or tampered with. Sites missing mainstem temperature data were analyzed with data from another mainstem site in proximity. Some sites resulted in adequate temperature data from only one enclosure, so data from one enclosure per site were utilized for the entire site as needed.

Temperatures in the optimal range (13.0–16.5ºC) were observed throughout the spring rearing period more often in upstream than in downstream off-channel sites, and two downstream off-channel sites reached stressful levels in late-May (Figures 3 and 4). Bear Island off-channel site maintained temperatures almost entirely within the optimal range from May to mid-June. Sawmill Macro off-channel experienced highly variable diel fluctuations where temperatures were both below and above the optimal range. The Sawmill SC off-channel site experienced cooler than optimal temperatures until mid-May, when temperatures rose to the optimal range through mid-June. In off-channel sites downstream near Junction city, temperatures were generally warmer than in sites upstream near Lewiston. The Sheridan W5 off-channel site experienced little stratification with maximum temperatures around 27ºC at the bottom of the feature in late May. The Sheridan W3 off-channel site experienced stratification with maximum temperatures around 22ºC at the bottom of the feature in early June, followed by decreases in average daily temperatures to mid June. The off-channel site farthest downstream, Lime Point, maintained maximum temperatures at the bottom of the feature below 20ºC when outside of the optimal range.

In mainstem sites, temperatures were lower than in their paired off-channel sites, and mainstem sites downstream were thermally optimal for longer than in upstream mainstem sites (Figures 3 and 4). Mainstem temperatures in upstream sites near Lewiston stayed below the optimal range throughout the entire spring rearing observation period. Mainstem sites located downstream near Junction City were below optimal until about late May, when optimal temperatures began to occur (Figure 5).

Figure 3. Temperature profiles for three locations upstream near Lewiston in the Trinity River restoration reach, where blue lines are mainstem (MC) temperatures, black/gray lines are off-channel (OC) bottom/top temperatures, the temperature range for optimal growth is shaded from 13.0 to 16.5° C, and the lethal temperature (24°C) is the red dotted line. There are no bottom temperature data for SM OC in the middle panel.

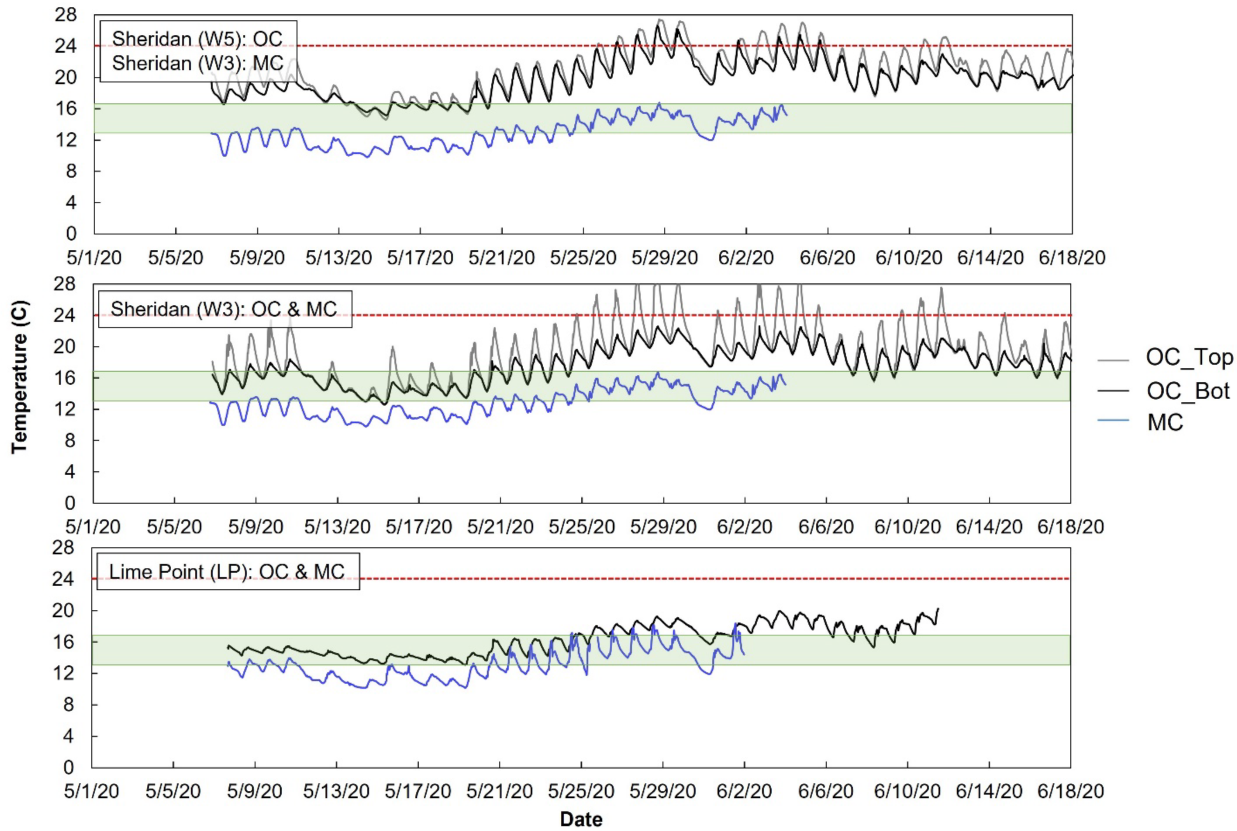

Figure 4. Temperature profiles for three locations in the Junction City area of the Trinity River restoration reach, where blue lines are mainstem (MC) temperatures, black/gray lines are off-channel (OC) bottom/top temperatures, the temperature range for optimal growth is shaded from 13.0 to 16.5° C, and the lethal temperature (24°C) is the red dotted line. There are no top temperature data for LP OC in the lower panel.

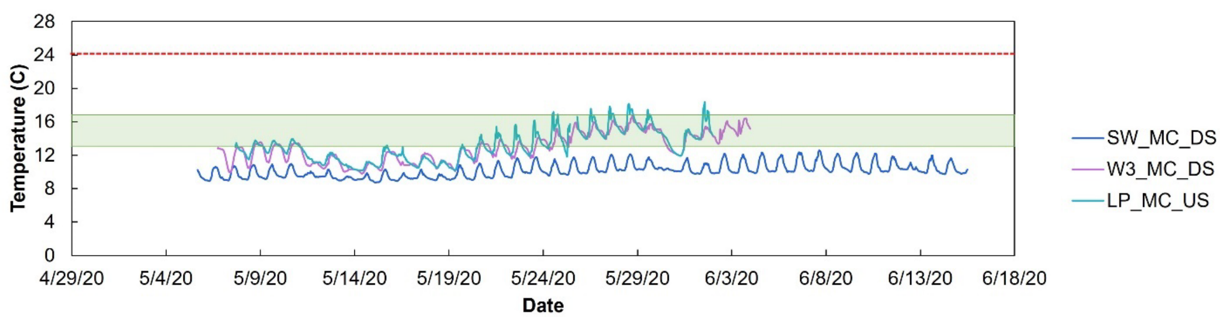

Figure 5. Temperature profiles in the mainstem Trinity River restoration reach in one upstream site near Lewiston (SW) and two downstream sites near Junction City (LP and W3. The temperature range for optimal juvenile salmonid growth is shaded from 13.0 to 16.5° C and the lethal temperature (24°C) is the red dotted line.

Fish Growth

Due to considerable loss of fish at multiple off-channel and mainstem sites, we did not conduct any statistical analysis to evaluate differences in growth between off-channel vs. mainstem or upstream vs. downstream areas. Instead, we qualitatively describe patterns of apparent growth in length and weight of PIT-tagged fish (Figures 6 and 7). Hereafter we refer to apparent growth simply as growth for brevity, recognizing changes in average size at a given site cannot be separated from possible size-dependent mortality or predation due to the loss of study fish. In addition, data from the two enclosures at each site were combined to increase sample sizes at all sites to provide some consistency of comparisons across sites due to varying amounts of loss of fish across sites and across enclosures within individual sites.

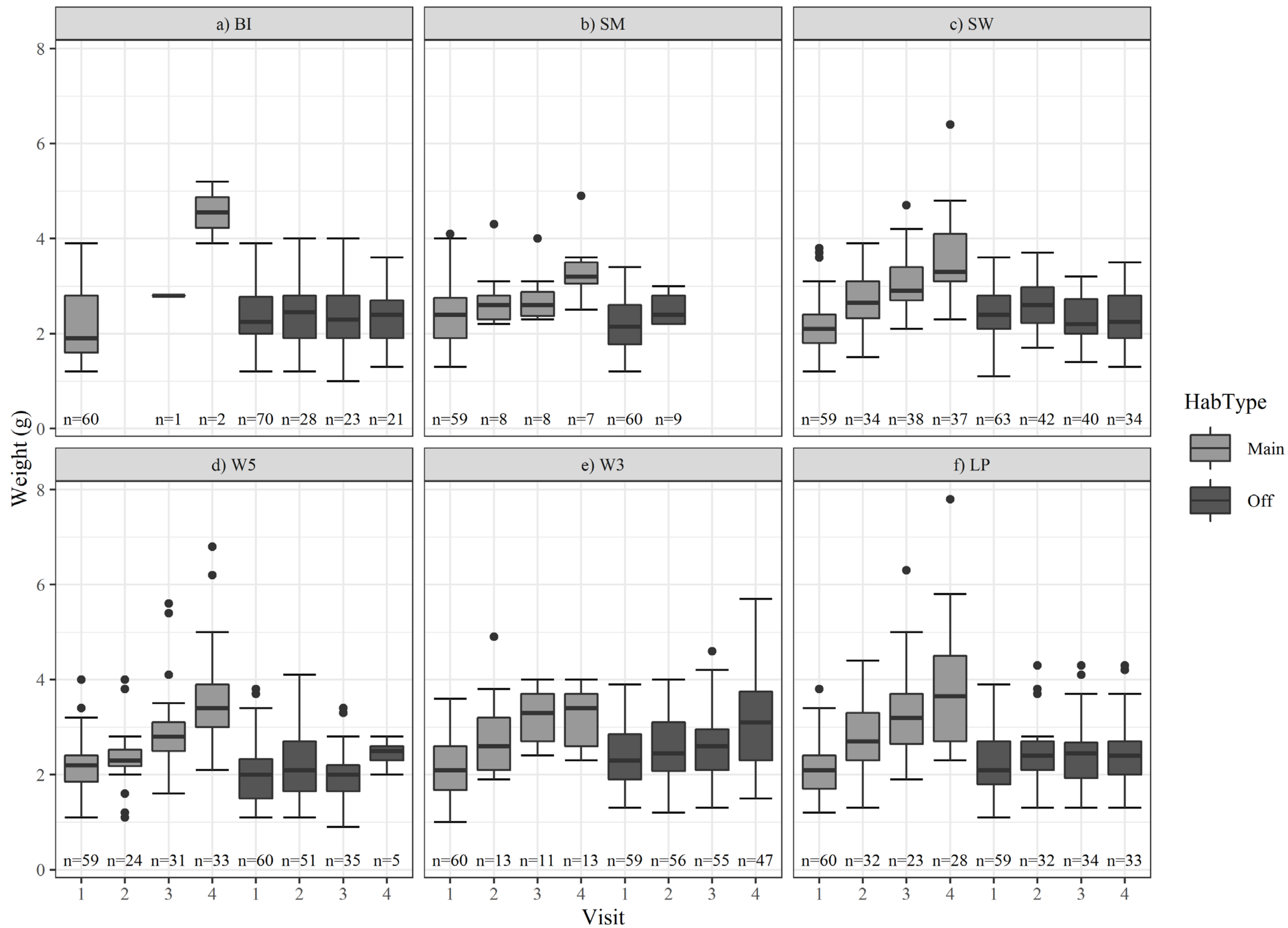

Figure 6. Box plots of individual weight (g) measurements taken during each site visit, with sample sizes (n=). The box describes the interquartile range with a middle line indicating the median value of measurements. The upper and lower whiskers extend to 1.5 times the IQR in each direction, with points beyond the whiskers representing more extreme data values. Fill distinguishes between habitat with light gray indicating mainstem enclosures and dark gray off-channel. Figure labels contain site codes, referencing sampling locations as described in Table 3.

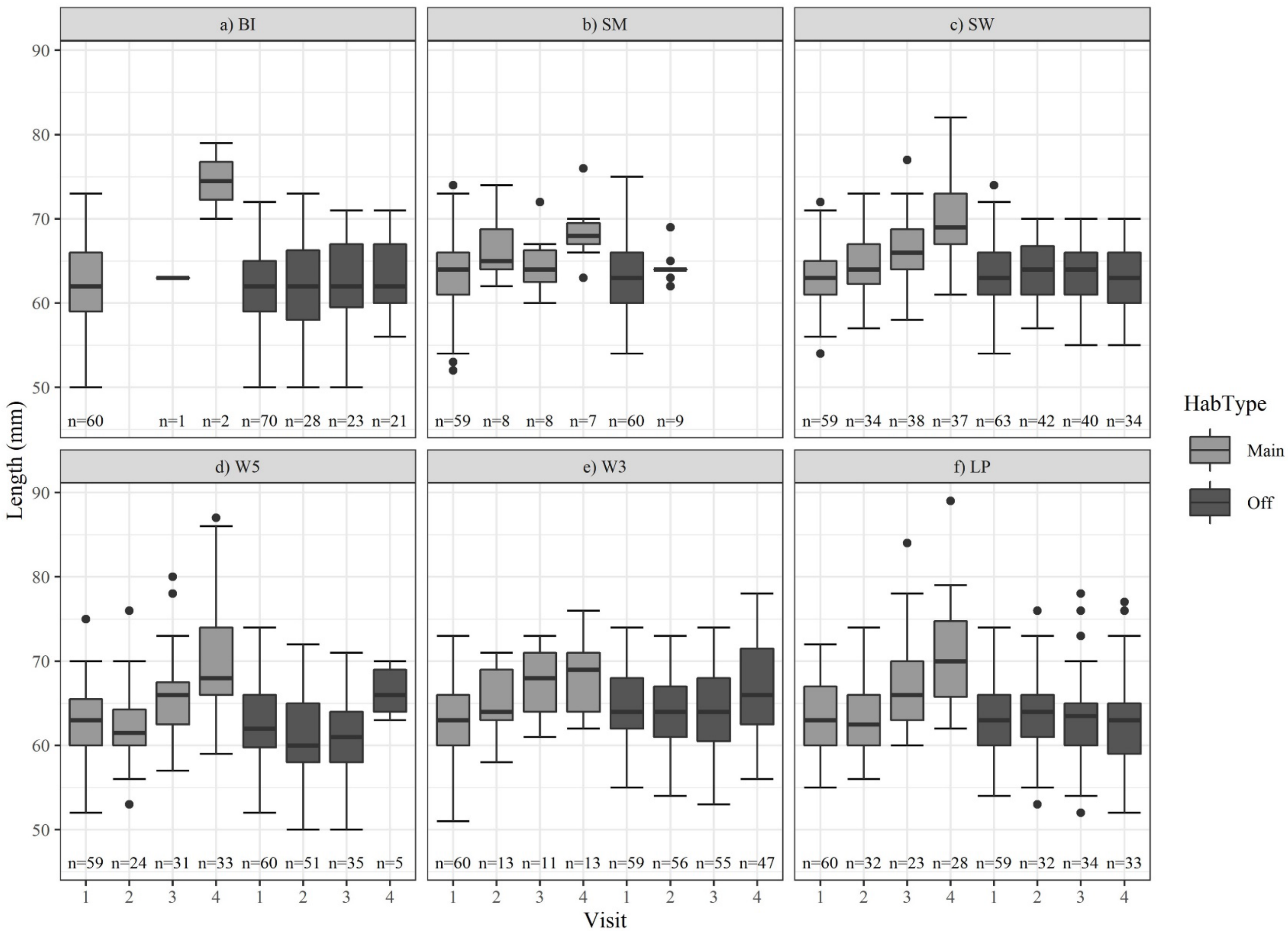

Figure 7. Box plots of individual length (mm) measurements taken during each site visit, with sample sizes (n=). The box describes the interquartile range with a middle line indicating the median value of measurements. The upper and lower whiskers extend to 1.5 times the IQR in each direction, with points beyond the whiskers representing more extreme data values. Fill distinguishes between habitat with light gray indicating mainstem enclosures and dark gray off-channel. Figure labels contain site codes, referencing sampling locations as described in Table 3.

From May to mid-June, Bear Island off-channel fish decreased in number from 70 to 21 and their sizes remained relatively constant, on average around 62 mm and 2.3 g. There were only two fish recaptured at the last visit to BI mainstem site on June 15. The SM off-channel site fostered no detectable survivors after May 19. This is the only site we are confident that fish were missing due to mortality, not escape from enclosures, because conditions were unsuitable for fish of any species. There were only seven study fish captured by the last site visit on June 15 out of 59 initial fish at the SM mainstem site but increases in fish size were observed on average by 3.0 mm in length by the last site visit. Fish size at the SW mainstem site increased on average by about 1.0 mm length and 0.30 g weight over each site visit. Conversely, SW off-channel fish size remained fairly constant over the six-week enclosed portion of the study, with about the same average length (63 mm) and weight (2.3 g) from site visit 1 to visit 4. The greatest fish growth among off-channel sites occurred in the downstream W3 site, where length and weight increased on average by 2.0 mm and 0.75 g, respectively, from visit 1 to visit 4. Among mainstem sites, the greatest fish growth (with adequate sample size) occurred in the upstream location site SW and the downstream location sites W5 and LP (Figures 6 and 7). Average fish lengths and weights in SW mainstem site increased by 5.0 mm and 1.2 g, in W5 mainstem by 5.0 mm and 1.2 g, and in LP mainstem by 7.5 mm and 1.8 g, respectively.

Outliers of one or two relatively much larger fish were observed from deployment (~early May) to site visit 4 (~mid-June) in upstream mainstem sites SM and SW as well as in downstream mainstem sites W5 and LP. A few mortalities were observed among fish in W5 off-channel enclosures, and fish that were found alive were mostly in very poor and sometimes apparently moribund condition, indicating that mortality accounted for at least some loss of fish at this site. At most locations, we observed a greater range in growth from start to finish in mainstem sites compared to off-channel sites. One exception where fish growth and size was comparable among main and off-channel sites was at Sheridan W3, where there were some larger individuals in the off-channel site than in the mainstem site by June 16.

Fish Growth and Temperature

Relationships between growth per day and temperature were clustered with almost no overlap between mainstem and off-channel sites (Figure 8). There was no apparent trend among mainstem sites with a similar range of growth rates observed across the range of average temperatures from 9.5-15.4°C. Notably, the highest growth rate (0.057g/day) among mainstem sites was observed at a suboptimal average temperature of 11.8°C. Growth was positive at all mainstem sites. Growth rates among off-channel sites were generally lower than in mainstem sites and were often negative, indicating very poor growing conditions. In contrast to mainstem sites, growth rates became more variable in off-channel sites as temperatures increased. The highest growth rate in off-channel sites was observed at an average temperature above the optimal range at 19.0°C, which was still only slightly more than half the highest growth rate observed in mainstem sites. Some sites were omitted due to fish loss or missing temperature data within the spring observation period. Two of the most extreme weight loss observations (> -0.020 g/day) occurred in off-channel sites with average temperatures around 21ºC. One of the most extreme weight loss (-0.024 g/day) occurred in an off-channel site where temperatures were within the optimal range at 15.2ºC. The greatest off-channel weight gain occurred at an average temperature of 19.0ºC, and the greatest mainstem weight gain occurred at 11.8ºC.

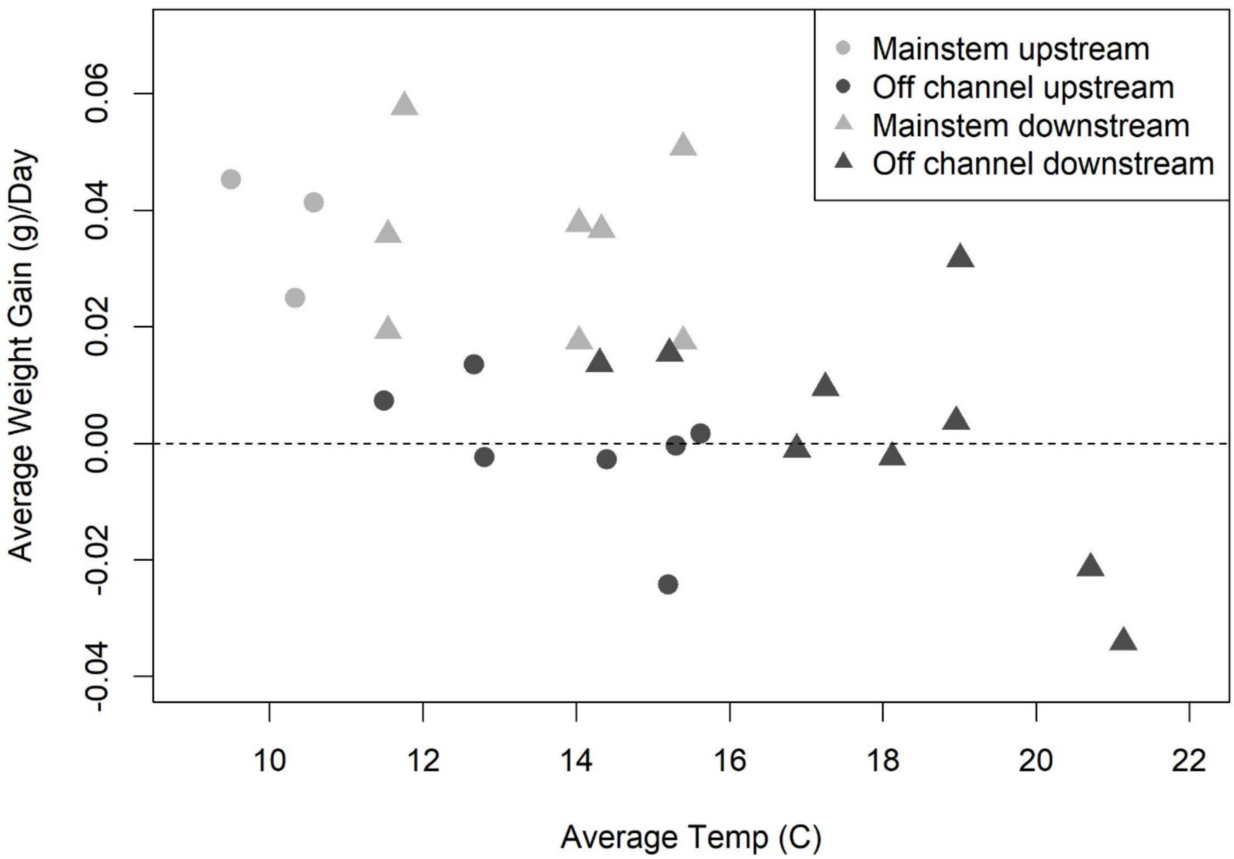

Figure 8. Scatterplot of average weight gain per day (g/day) at mainstem and off-channel sites in the Lewiston (upstream) and Junction City (downstream) areas. Each observation represents growth between site visits from early May to mid-June.

Off Channel Connectivity between Water Years

The water year designation in 2020 was Critically Dry, in contrast to the two pilot years of 2017 (Extremely Wet) and 2019 (Wet), which led to less frequent and shorter duration of connectivity between the mainstem and off-channel features. In three different water years at our off-channel sites, connection to the mainstem occurred at either 2,500 or 3,500 cfs and varied in timing, frequency, and duration during ROD flow releases or accretionary flows (Figure 9). Wetter water years 2017 and 2019 had greater frequency and duration of off channel connection flows than in the Critically Dry water year 2020 at both upstream and downstream locations. Winter accretionary flows in the Junction City area contributed to earlier timing as well as greater frequencies and duration of off channel connection flows than in the Lewiston area.

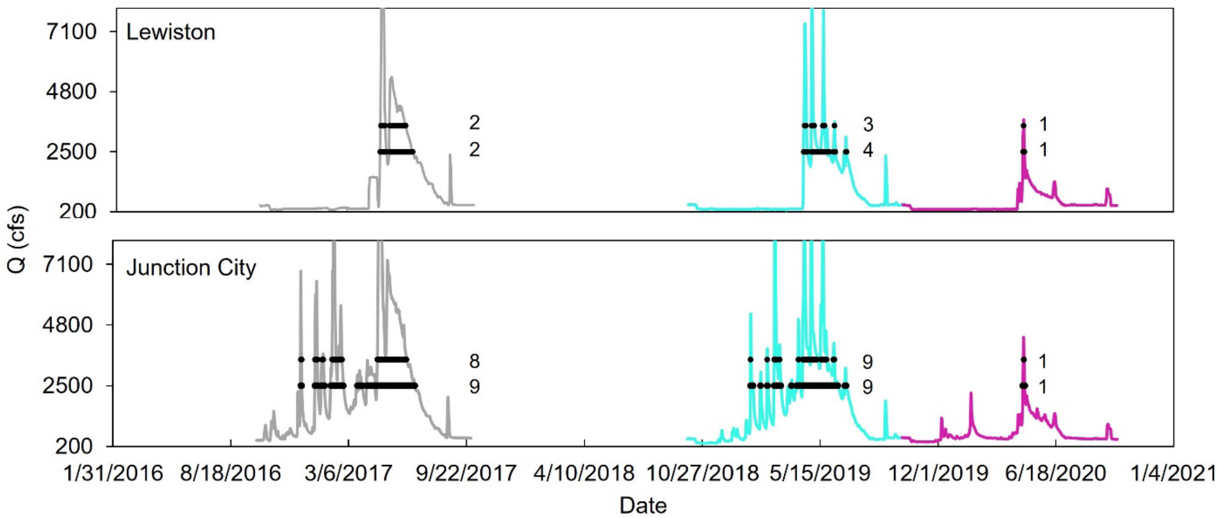

Figure 9. Hydrographs of water years 2017 (gray), 2019 (blue), and 2020 (magenta) plotted with black symbols representing the timing, frequency, and duration of flows that connected off-channel features to the mainstem (≥2,500 or ≥3,500 cfs) in locations upstream near Lewiston and downstream near Junction City. The number of flow events ≥2,500 or ≥3,500 cfs is noted for each water year in each plot.

DISCUSSION

This study encountered multiple challenges, which compromised data quality and limited conclusions that could be drawn from the study. Uninhabitable conditions at the Sawmill Macro site and insufficiently sealed enclosures allowing escapement of fish compromised our study design. The loss of fish and data at several sites did not allow for a quantitative analysis to test our hypotheses, resulting in a presentation of results as largely descriptive and qualitative.

Anecdotally, we observed higher fish growth rates in warmer mainstem temperatures in locations farther downstream of Lewiston Dam, where temperatures were optimal for longer durations in late spring. In addition, we found higher growth rates among juvenile Chinook Salmon in cooler mainstem habitats compared to warmer off-channel habitats. This is contrary to our hypothesis, but additional data is needed to test for differences in growth and draw conclusions. Temperatures in some off-channel features became stressful for salmonids in late May, while some offered warmer temperatures that have been found to foster juvenile growth in other studies. The phenology of off-channel connectivity to the mainstem as it changes between water years may be an important factor in providing food resources and thermal diversity required for juvenile growth and survival that should be further investigated in the Trinity River.

Juvenile salmonids' biological response to thermal environments contributes to their spatiotemporal distribution. This response is manifested through changes in metabolic rates, feeding behavior, growth, phenology (e.g. timing of migration), survival, and environmental changes in food web dynamics (Caissie 2006, Webb et al. 2008, Fullerton et al. 2017, Armstrong et al. 2021). As a river's thermal regime changes annually, seasonally, daily, and spatially from natural cycles and anthropogenic impacts, diversity of habitat through lateral morphological complexity (Carmichael et al. 2020) can offer increased thermal variability or refugia required for the growth and survival of rearing juvenile salmonids, as investigated in this study.

The theory that optimal temperatures foster higher growth rates for juvenile salmonids was supported with our observations in upstream versus downstream mainstem habitats, but not in comparing off-channel to mainstem habitats. Despite many of our off-channel study sites maintaining optimal temperatures while mainstem sites experienced more suboptimal temperatures, we observed greater fish growth in mainstem sites compared to their paired off-channel sites. Off-channel sites at Bear Island and Sawmill SC experienced optimal temperatures the majority of the spring observation period, but fish size remained constant. At Sawmill SC, a similar number of fish were observed between visits at mainstem and off-channel sites. Temperatures in the Sawmill Macro mainstem (used for comparison to Sawmill SC off-channel feature due to missing mainstem data at that site) remained below optimums throughout the spring, yet fish growth was observed.

One off-channel site in this study, Sheridan W3, had comparable fish growth to its paired mainstem site, and its temperature conditions were warmer than optimal, yet stratified with temperatures 17 - 22 ºC at its bottom during its warmest week. There were also 3.6 times more fish in the off-channel feature at Sheridan W3 than in the paired mainstem site by the last site visit in mid-June. Fish in Sheridan W3 found favorable conditions for growth and survival, whether that was attributed to high thermal diversity, high prey density, low predator risk, flow, or some combination of those factors.

Prey availability can be different between off-channel and mainstem habitat and affect fish growth, with potentially greater benthic or terrestrial resources in off-channel features and greater drift resources in mainstem areas. However, general prey availability may have been a more important driver of growth despite thermally diverse habitats in this study. While focused presumably on drift foraging salmonids, Railsback (2021) suggests that prey availability may play a more important role in growth than temperature, recognizing that observed growth in natural environments is a complex integration of food availability, temperature, size and stage dependent metabolic rates, competition, predator avoidance, and other factors. Metabolic costs of being confined to warmer conditions can be mitigated by ample prey availability, as observed among summertime rearing juvenile Coho Salmon in the Shasta River whose growth rates peaked at temperatures >16.5° C and were six times greater than juveniles at temperatures around 13° C (Lusardi et al. 2020). The timing, frequency, and duration of connection between mainstem and off-channel features may affect drift delivery or benthic prey production in Trinity River off-channel features, where food resources may have been low. We suspect, but do not have data to confirm, that the observed poor growth in off-channel features was due largely to starvation. Off-channel features were stagnant whereas mainstem enclosures experienced constant flow. The mesh size of enclosures likely limited drift forage opportunity for study fish, but some drift food must have replenished food resources in mainstem enclosures throughout the six-week study. In contrast, fish in off-channel enclosures had to rely on terrestrial or benthic food supplies that were likely replenished at a much lower rate than drift food supplies in mainstem enclosures.

The dynamic between foraging and metabolic thermoregulation opportunity with flows that maintain connectivity, thermal diversity, and prey availability between off-channel and mainstem habitats may all play a critical role in guiding Trinity River rehabilitation and flow management for juvenile salmonid growth and survival. Limm and Marchetti (2009) compared juvenile growth in off-channel habitats with nearby main-channel habitats in the Sacramento River and found higher growth rates in the off-channel habitats. All but one off-channel feature in that study maintained surface connection to the mainstem and all had average daily temperatures in March and April that remained at optimal levels between about 13–17°C, which were higher than suboptimal mainstem temperatures between 10– 3.5°C. Huntsman and Falke (2018) found greater biomass in off-channel juvenile Chinook Salmon diets when those features were connected to the mainstem, but greater biomass in mainstem diets when the off-channel features were isolated from the mainstem and had warmer thermal regimes from the mainstem. Fish sampled in Limm and Marchetti (2009) and in Huntsman and Falke (2018) were all free swimming (i.e., no enclosures were used), providing opportunity for fish to fully capitalize on the resources available within their respective off-channel habitats.

Timing, frequency, and duration of off-channel connection through spring rearing may be an important factor in habitat utilization for juvenile salmonids (Heim et al. 2019). Resource exploitation for foraging fish in off-channel habitats versus mainstem habitats can be different, and movement between the colder, sometimes more productive mainstem and warmer, sometimes metabolically favorable off-channel environment to enhance growth may be important. Such thermoregulatory behavior by salmon was documented in previous studies in Alaskan streams with thermally suboptimal mainstem habitats (Armstrong and Schindler 2013, Armstrong et al. 2013, Baldock et al. 2016). There is evidence of juvenile salmonid habitat selection in response to low flow connectivity, where selection was not impacted by susceptibility to limited connectivity in parafluvial (within the active channel) off-channel features (Malison et al. 2014, Huntsman and Falke 2018) but off-channel features were not selected in orthofluvial zones (within riparian floodplain channels) when susceptible to low flow disconnection (Malison et al 2014). Off channel location relative to the active mainstem channel as identified in Huntsman and Falke (2018) may be a factor in selection of off-channel habitat that is not an option in our off-channel sites due to increasingly isolated off-channel conditions with drier water years and current flow management.

Changes in the value of off-channel habitat for rearing juvenile salmonids, whether from water year type, anthropogenic impacts, or some combination, should be further investigated. More frequent and longer durations of connectivity over winter and spring between off-channel and mainstem areas of the Trinity River may affect optimal temperature duration or food resource delivery in some off-channel features while maintaining the option for fish to move between habitats as needed. The difference observed in timing, frequency, and duration of off channel connectivity between water years 2017, 2019, and 2020 should be more closely evaluated for its effect on fish growth. As a case study, the Sheridan W5 off-channel site provided excellent habitat and hundreds of juvenile salmonids were observed during the pilot study in 2019. It was a Wet water year type, and cold subsurface flow from Sheridan Creek into W5 was evident. This subsurface flow was clearly absent in 2020 based on personal observation of the authors and corroborated by temperature data. While 2020 was a Critically Dry water year, a new and very large Cannabis farm was developed in proximity upstream of W5 next to Sheridan Creek by the start of our study in 2020. It is likely that surface or groundwater extraction to support this new agricultural development substantially reduced subsurface delivery of water from Sheridan Creek into W5 because all properties along Sky Ranch Road rely on wells for water supply. In addition to warm water temperatures, numerous invasive predatory species were observed in W5 in 2020, including several adult green sunfish and bullfrog.

Jeffres et al. (2008) observed great benefits among hatchery juvenile Chinook Salmon utilizing intermittently inundated floodplain areas while wild fish life histories would utilize those habitats before outmigrating in late spring. Synchronizing flow management with life history phenology may provide habitat and food resources that better support spring juvenile growth. Reconnection of off-channel features to the mainstem does not occur until the ROD flow releases in mid-April. Connectivity between mainstem and off-channel habitats in the winter may provide opportunity for over-wintering fish to exploit mainstem habitats sooner or begin their outmigration with more variable opportunities. Increased access to more variable habitats is expected to increase life history diversity, which in turn is expected to improve resilience and survival (Schindler et al. 2010).

RECOMMENDATIONS

Most importantly, this study should be repeated in a wetter water year to provide contrast to the findings presented, particularly with respect to the unexpected lower growth in thermally optimal conditions in off-channel features. If enclosures are used again, improvements to their construction should be made to avoid loss of fish, including the stitching together of overlapping seams using string or cord. A pilot study evaluating enclosure durability and fish retention at higher flows should be conducted before implementing enclosure installations on a larger scale. Potential changes to the study design could include the use of enclosures for mainstem fish but not for off-channel fish, so that off-channel fish have greater access to food resources and can better capitalize on optimal thermal conditions. However, this may simply introduce a different bias by attempting to compare free-swimming fish (in off-channel habitats) to caged fish (in the mainstem). Otolith analysis may be a better technique to measure growth because recapturing free-swimming fish in off-channel features multiple times would be challenging. Tracking fish movement between off-channel and mainstem habitats using PIT tags and PIT tag arrays at connection points between off-channel and mainstem areas, if the water year allows such conditions, may provide insight into thermoregulatory behavior or life history phenology response.

There remains a challenge in comparing growth trajectories of fish occupying off-channel features vs. mainstem habitats. It seems evident that confining fish to enclosures in off-channel features does not represent actual growth potential in these features because they are unable to forage as needed in a lentic environment. Allowing them to swim freely alleviates this issue and the location history can be known if the off-channel feature remains disconnected from the mainstem during the study period (i.e., they would be known to have remained in the feature). However, comparing growth to mainstem fish in enclosures (thus with a known location history) introduces bias by confining them to the enclosures, whereas comparing growth to free-swimming fish in the mainstem precludes us from knowing location histories (thus the habitat conditions affecting growth). This is a critical issue that should be addressed before attempting to replicate this study. Notably, growth rate alone can be viewed as the integration of prey availability, foraging behaviors and opportunities, thermal conditions, and numerous other habitat and physiological factors, so comparison of growth of free-swimming fish in off-channel vs. mainstem fish may be insightful by itself when off-channel features remain disconnected during a study period (i.e., all fish would be known to have reared in either habitat).

The over-summer growth and survival component of this study was unsuccessful, but the methods could also be improved. In retrospect, using enclosed fish for this component of the study has the potential to introduce bias from a carryover effect of growth conditions during the enclosed portion of the study. Using different fish for this part of the study would alleviate this potential bias.

ACKNOWLEDGEMENTS

We would like to commend field staff for their dedication to the project under the difficult circumstances surrounding the COVID pandemic and two anonymous reviewers that helped us improve the manuscript.

LITERATURE CITED

Armstrong, J. B., and D. E. Schindler. 2013. Going with the flow: spatial distributions of juvenile Coho Salmon track an annually shifting mosaic of water temperature. Ecosystems 16:1429-1441. https://doi.org/10.1007/s10021-013-9693-9

Armstrong, J. B., D. E. Schindler, C. P. Ruff, G. T. Brooks, K. E. Bentley, and C. E. Torgersen. 2013. Diel horizontal migration in streams: juvenile fish exploit spatial heterogeneity in thermal and trophic resources. Ecology 94:2066-2075. https://doi.org/10.1890/12-1200.1

Armstrong, J. B., A. H. Fullerton, C. E. Jordan, J. L. Ebersole, J. R. Bellmore, I. Arismendi, B. E. Penaluna, and G. H. Reeves. 2021. The importance of warm habitat to the growth regime of cold-water fishes. Nature Climate Change 11:354-361. https://doi.org/10.1038/s41558-021-00994-y

Baldock, J. R., J. B. Armstrong, D. E. Schindler and J. L. Carter. 2016. Juvenile coho salmon track a seasonally shifting thermal mosaic across a river floodplain. Freshwater Biology 61:1454-1465. https://doi.org/10.1111/fwb.12784

Bradley, D. N. 2016. Trinity River 40 mile hydraulic model: development and analysis. Report SRH-2016-27 for the Trinity River Restoration Program (TRRP). U.S. Bureau of Reclamation, Technical Service Center, Denver, Colorado. http://www.trrp.net/library/document?id=2297

Caissie, D. 2006. The thermal regime of rivers: a review. Freshwater Biology 51:1389-1406. https://doi.org/10.1111/j.1365-2427.2006.01597.x

Carmichael, R. A., D. Tonina, E. R. Keeley, R. M. Benjankar, and K. E. See. 2020. Some like it slow: a bioenergetic evaluation of habitat quality for juvenile Chinook Salmon in the Lemhi River, Idaho. Canadian Journal of Fisheries and Aquatic Sciences 77:1221-1232. https://doi.org/10.1139/cjfas-2019-0136

Davids, N., P. Petros, W. D. Pinnix, and A. D. Heacock. 2013. Juvenile salmonid monitoring on the mainstem Trinity River, California, 2012. Yurok Tribal Fisheries Program, Hoopa Valley Tribal Fisheries Department, and U.S. Fish and Wildlife Service. Arcata Fisheries Data Series Report Number DS 2013-34, Arcata, California.

Esri, DeLorme, HERE, MapmyIndia. 2021. “Light Gray Canvas Map.” Accessed June 2021.

Fullerton, A. H., B. J. Burke, J. J. Lawler, C. E. Torgersen, J. L. Ebersole, and S. G. Leibowitz. 2017. Simulated juvenile salmon growth and phenology respond to altered thermal regimes and stream network shape. Ecosphere 8(12): https://doi.org/10.1002/ecs2.2052.

Harris, N. J., P. Petros, and W. D. Pinnix. 2016. Juvenile salmonid monitoring on the mainstem Trinity River, California, 2015. Yurok Tribal Fisheries Program, Hoopa Valley Tribal Fisheries Department, and U.S. Fish and Wildlife Service. Arcata Fisheries Data Series Report Number DS 2016-46, Arcata, California.

Heim, K. C., T. E. McMahon, L. Calle, M. S. Wipfli, J. A. Falke. 2019. A general model of temporary aquatic habitat use: water phenology as a life history filter. Fish and Fisheries 20:802-816. https://doi.org/10.1111/faf.12386

Huntsman, B. M. and J. A. Falke. 2018. Main stem and off-channel habitat use by juvenile Chinook Salmon in a sub-Arctic riverscape. Freshwater Biology 64:433-446. https://doi.org/10.1111/fwb.13232

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook Salmon in a California river. Environmental Biology of Fishes 83:449-458.

Limm, M. P. and M. P. Marchetti. 2009. Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) growth in off-channel and main-channel habitats on the Sacramento River, CA using otolith increment widths. Environmental Biology of Fishes 85:141-151.

Lusardi, R. A., B. G. Hammock, C. A. Jeffres, R. A. Dahlgren, and J. D. Kiernan 2020. Oversummer growth and survival of juvenile Coho Salmon (*Oncorhynchus kisutch*) across a natural gradient of stream water temperature and prey availability: an in situ enclosure experiment. Canadian Journal of Fisheries and Aquatic Sciences 77:413-424.

Malison, R. L., M. S. Lorang, D. C. Whited, and J. A. Stanford. 2014. Beavers (*Castor canadensis*) influence habitat for juvenile salmon in a large Alaskan river floodplain. Freshwater Biology 59:1229-1246. https://doi.org/10.1111/fwb.12343.

Petros, P., A. D. Heacock, and W. D. Pinnix. 2014. Juvenile salmonid monitoring on the mainstem Trinity River, California, 2013. Hoopa Valley Tribal Fisheries Department, Yurok Tribal Fisheries Program, and U.S. Fish and Wildlife Service. Arcata Fisheries Data Series Report Number DS 2014-38, Arcata, California.

Petros, P., W. D. Pinnix and N. J. Harris. 2017. Juvenile salmonid monitoring on the mainstem Trinity River, California, 2016. Hoopa Valley Tribal Fisheries Department, Yurok Tribal Fisheries Program, and U.S. Fish and Wildlife Service. Arcata Fisheries Data Series Report Number DS 2017-51, Arcata, California.

Pryor, C. 2018. 2017 Deep Gulch Sheridan Creek as-built survey report. Data Package for the Trinity River Restoration Program (TRRP) under U.S. Bureau of Reclamation contract R14PC00122. GMA Hydrology, Arcata, California. http://www.trrp.net/library/data?id=110.

Railsback, S. F. 2021. What we don't know about the effects of temperature on salmonid growth. Transactions of the American Fisheries Society 151:3-12.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. *Nature* 465:609-612.

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

U.S. Department of the Interior (DOI). 2000. Record of Decision, Trinity River Mainstem Fishery Restoration Final Environmental Impact Statement/Environmental Impact Report (EIS/EIR), December. Washington, D.C.

Webb B. W., D. M. Hannah, R. D. Moore, L. E. Brown, F. Nobilis. 2008. Recent advances in stream and river temperature research. Hydrological Processes 22:902-918.

Zeug, S. C., J. Wiesenfeld, K. Sellheim, A. Brodsky, and J. E. Merz. 2019. Assessment of juvenile Chinook Salmon rearing habitat potential prior to species reintroduction. North American Journal of Fisheries Management 39:762-777.

APPENDIX

Table A1. Summary statistics for MC and OC sites in Lewiston and Junction City areas during visits two through four, including number of juvenile Chinook Salmon (n), number of days between site visits, average water temperature between site visits, and mean fish growth (G) over site visits from May – mid June 2020 at six locations in the Trinity River with paired off channel and main channel sites.

Area	Site	Visit	n	Days	Average Temp (C°)	Average Growth (g/day)
Lewiston	BI-MC	4	1	14	NA	0.079
Lewiston	BI-OC	2	27	14	12.8	-0.002
Lewiston	BI-OC	3	23	14	14.4	-0.003
Lewiston	BI-OC	4	19	14	15.3	0.000
Lewiston	SM-MC	2	8	14	NA	0.010
Lewiston	SM-MC	3	5	14	NA	0.003
Lewiston	SM-MC	4	5	14	NA	0.034
Lewiston	SM-OC	2	22	14	12.7	0.013
Lewiston	SW-MC	2	33	14	9.5	0.045
Lewiston	SW-MC	3	30	13	10.3	0.025
Lewiston	SW-MC	4	36	14	10.6	0.041
Lewiston	SW-OC	2	43	14	11.5	0.007
Lewiston	SW-OC	3	39	13	15.2	-0.024
Lewiston	SW-OC	4	34	14	15.6	0.002
Junction City	W5-MC	2	23	14	11.5	0.019
Junction City	W5-MC	3	22	14	14.0	0.038
Junction City	W5-MC	4	31	14	15.4	0.051
Junction City	W5-OC	2	51	14	17.2	0.010
Junction City	W5-OC	3	34	14	21.1	-0.034
Junction City	W5-OC	4	6	14	20.7	-0.021
Junction City	W3-MC	2	13	14	11.5	0.036
Junction City	W3-MC	3	9	14	14.0	0.017
Junction City	W3-MC	4	10	14	15.4	0.017
Junction City	W3-OC	2	55	13	15.2	0.015
Junction City	W3-OC	3	52	13	19.0	0.004
Junction City	W3-OC	4	44	14	19.0	0.032
Junction City	LP-MC	2	32	13	11.8	0.058
Junction City	LP-MC	3	22	13	14.3	0.037
Junction City	LP-MC	4	23	8	NA	0.054
Junction City	LP-OC	2	31	13	14.3	0.014
Junction City	LP-OC	3	30	13	16.9	-0.001
Junction City	LP-OC	4	31	8	18.1	-0.002