SEASONAL GROWTH, MOVEMENT, AND SURVIVAL OF JUVENILE COHO

SALMON (*ONCORHYNCHUS KISUTCH*) UTILIZING RESTORED REARING

HABITAT

By

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ABSTRACT

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Monica Tonty

The Scott River supports the most robust population of threatened Coho Salmon

Oncorhynchus kisutch remaining in the Klamath River basin. Even in the Scott River,

low quality and restricted extent of juvenile rearing habitat limits the Coho Salmon

population to a small fraction of historic abundance. To support persistence and recovery

of Scott River Coho Salmon, the Scott River Watershed Council (SRWC) has constructed

a portfolio of restoration projects to improve juvenile rearing habitat, including beaver

dam analogs (BDAs). The Scott River BDAs were the first implemented anywhere in

California. This study compares juvenile Coho Salmon responses associated with

production (growth, survival, and abundance) at five different locations. I used a post-

treatment study design to compare four SRWC restoration projects, three bda-formed

sites and one other restored site, which consisted of a constructed side-channel and

engineered log jams placed in the adjacent mainstem, to a reference site. I analyzed data

from a SRWC mark-recapture field study that used passive integrated transponder (PIT)

tags to individually mark juvenile Coho Salmon, with repeated sampling during their

rearing period. The available data included five cohorts of Coho Salmon. I tracked

individual growth, survival, and movement using recaptures at subsequent sample events

and, for survival and movement, detections of tagged fish on stationary PIT antennas. I developed a multistate mark-recapture model based on in-hand captures and antenna detections to estimate site-specific weekly survival while accounting for movement between sites. I also analyzed differences in growth between sites and seasons. Isolating the effects of restoration on growth and survival was challenging because the sampling schedule was inconsistent, and individuals regularly moved in and out of restoration sites. However, I found that Coho Salmon at BDA sites generally had similar or higher growth and survival compared to other sites in all winter and spring seasons. They had lower growth and survival than mainstem habitats in summers characterized by drought. These results suggest that BDA construction can be an effective strategy for restoring juvenile Coho Salmon rearing habitat, but that a variety of options are needed to address the variable conditions juvenile coho face year to year.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The abundance and range of Coho Salmon (*Oncorhynchus kisutch)* has declined substantially relative to historic levels, largely due to habitat loss, hatcheries, and overfishing (Nehlsen et al. 1991). Of particular concern are Coho Salmon populations at the southern end of their range, such as the Southern Oregon/Northern California Coast (SONCC) evolutionary significant unit (ESU), which is listed as Threatened under the federal Endangered Species Act (National Marine Fisheries Service [NMFS] 2014). This study focuses on Coho Salmon in the Scott River, a Klamath River tributary. The Scott River represents an important stronghold for Coho Salmon within the Klamath River and SONCC ESU, but Scott River Coho Salmon are at risk due to substantial habitat loss and water withdrawal, especially during increasingly common drought conditions.

In California, Coho Salmon juveniles spend about 1.5 years rearing in fresh water before they migrate to sea, where they spend another 1.5 years. As Coho Salmon reside in fresh water for more than a year, they require access to suitable habitat across the full range of seasonal flow and temperature conditions in their natal watersheds. Low juvenile survival during the summer low-flow period and the winter high-flow period are often thought to limit Coho Salmon populations (Mason 1976; Quinn and Peterson 1996). After emergence from the gravel in the spring, most Coho Salmon fry disperse, colonizing new habitats where they will spend the summer low-flow period. With declining water levels, available habitat area is limited, and survival and growth can be strongly density-dependent (Quinn 2005). Early winter rains can trigger redistribution,

where some Coho Salmon parr move to find slow-water refuge habitat, such as flooded wetlands, beaver ponds, side channels, tributaries, and other off-channel habitats (Lestelle 2007). Movement outside of redistribution periods was thought to be uncommon, due to physical displacement from streamflow, or associated with competition forcing out smaller individuals or "surplus fry" (Hartman et al. 1982; Chapman 1962). However, there are examples of movement occurring throughout the summer in response to poor or declining habitat conditions or to find preferred habitat conditions (Kahler et al. 2001; Baldock et al. 2016; Winkowski and Zimmerman 2018).

Previous studies have revealed clear associations between seasonal abundance of juvenile Coho Salmon and habitat type, but patterns of habitat use are contingent on local conditions. For example, in large Alaskan rivers, juvenile Coho Salmon were more abundant in off-channel habitats in the summer, particularly off-channel beaver complexes, compared to slow-water main channel habitats (Murphy et al. 1989). In contrast, Coho Salmon fry densities in small streams on the Oregon Coast were highest in backwater pools and they were not present in off-channel habitats, possibly because these habitats were disconnected during their early dispersal period (Nickelson et al. 1992). A study in northern Oregon on the western slopes of the Cascade mountains found that Coho Salmon use beaver ponds at higher population densities than any other habitat in both the winter and summer (Everest et al. 1987). Side channels can also be important seasonal habitats for Coho Salmon, primarily if they are groundwater influenced and stay cool in the summer or maintain low velocities and warmer temperatures in the winter (Swales et al. 1986; Lestelle 2007). However, inferring fitness benefits of a particular

habitat from field investigations of fish habitat use alone can be inaccurate; direct comparisons of growth or survival are more informative (Rosenfeld 2003).

Projects constructed to increase the availability of salmonid rearing habitat are increasingly common. The ultimate goal of these habitat restoration projects is to increase the overall population abundance of threatened or endangered salmonids. This work represents a substantial investment: federal agencies spend at least $500 million per year on habitat restoration and protection for anadromous fish in the Columbia River basin alone (Rice 2019). Despite these expenditures, there are few studies linking watershed restoration actions with population effects on salmonids (Liermann and Roni 2008). Furthermore, a given in-stream restoration technique can have different results depending on the specific design, where it was applied, and variable yearly flow conditions. For example, Bobst et al. (2022) modeled the effects of beaver dam analogs (BDAs) on groundwater recharge and streamflow. In gaining and slightly losing reaches, BDAs increased dry-season streamflow, with off-channel pond forming BDAs causing the largest increase. However, in strongly losing reaches, all BDA treatments, other than off-channel pond forming BDAs, decreased streamflow. This suggests if BDAs are constructed in strongly losing reaches, less instream habitat will be created and the effects of these BDAs on Coho Salmon populations will be weaker.

The Scott River Watershed Council (SRWC) has constructed multiple restoration projects near Etna, CA to increase juvenile rearing habitat for Coho Salmon, including side channels, off-channel habitats, and BDAs. BDAs are a relatively new, low-cost stream restoration technique that mimic the functions of a beaver dam or encourage

beaver activity in designated locations (Pollock et al. 2015). In 2014, the SRWC constructed multiple BDAs on Sugar Creek, a tributary to the Scott River. Historically beavers maintained dams at the site, but in recent years, the Sugar Creek site often ran dry. It is unknown how many Coho Salmon the site supported prior to the construction of the BDAs, but rearing habitat for coho was minimal. However, since construction of the BDAs, recent Coho Salmon densities in Sugar Creek are often higher than those at an existing seasonal refuge site, the French Untreated Mainstem Reach. During fall 2017 the linear densities of coho were estimated as 7.9 fish/m at Sugar Creek BDA Pond 1 and 1.60 fish/m at the French Mainstem Reach (Yokel et al. 2018). Repeating population estimates for multiple years and at more sites will provide information on the variation in the abundance in these sites, however, these are localized population estimates and might only represent a shift in distribution, rather than a change in the overall population (Polivka 2022).

Because it takes substantial time and resources to measure population changes at the reach or watershed scale, growth and survival of individuals over a shorter time period can be used as surrogates for population effect (Rosenfeld 2003). Growth has survival implications because larger size at the end of summer is associated with higher overwinter survival (Quinn and Peterson 1996; Ebersole et al. 2006; Roni et al. 2012) and larger smolt size is sometimes associated with higher marine survival (Holtby et al. 1990; Irvine et al. 2013, Cochran 2015). Thus, rearing in habitats that maximize growth may have a population effect. A site with low abundance may have large individuals with above average survival, illustrating the importance of measuring these factors in addition

to abundance in order to evaluate a site's contribution to population growth (Bouwes et al. 2016; Polivka 2022). SRWC has collected varying levels of data on seasonal abundance, growth and survival since 2016. They have not formally compared the results between habitat types or across years.

No studies have published estimates of the survival and growth rates of juvenile coho in a BDA site. Only a few studies have measured juvenile steelhead growth and survival in a BDA site (Bouwes et al. 2016; Wathen et al. 2019). Since Coho Salmon sub-populations in California are listed as threatened or endangered, and BDAs are gaining in popularity as a restoration technique, this study fills an important knowledge gap to advance Coho Salmon recovery.

The objectives of this study were to: (1) Estimate fish abundance and growth rates in BDA sites in comparison to other types of restored and existing seasonal rearing habitat, over two key juvenile rearing periods: summer and winter. This is a continuation of the SRWC ongoing monitoring of these sites and will allow us to assess variation in growth and abundance across years with variable flow conditions; and (2) Characterize seasonal movement and estimate apparent survival in a multistate model to provide information on the spatial scale at which fish use the restoration sites (e.g. are they resident at a single site, do they use multiple sites, do they use multiple tributaries?). The results of these objectives will suggest the population-level effects of these projects and contribute to the larger goal of collecting information to help guide future restoration projects that target Coho Salmon recovery.

METHODS

Study Area

The Scott River, an important stream for Coho Salmon in the Klamath River basin, drains approximately 2100 km^2 in northern California. The Scott River watershed is the homeland of the Shasta Indian people. The Quartz Valley Reservation, of the federally recognized tribes of Klamath, Karuk, and Shasta Indians, is located in the watershed. The dominant land uses in the Scott River watershed are agriculture, ranching, logging, and recreation. The region is semiarid and both rainfall and spring snowmelt influence streamflow, with annual average precipitation of 56 cm in the valley and a highly variable 75-175 cm in the surrounding Marble Mountains (Yokel et al. 2018).

The Scott River watershed has a history of significant human impacts. For nearly a century, miners piled tailings along mainstem and tributary banks, constraining the Scott River to only one side of its historical floodplain (NMFS 2014). These tailing piles prevent regrowth of riparian vegetation because they are devoid of soil. Scott River was once called "Beaver Valley," but fur trappers in the 19th century removed thousands of beavers from the basin, thereby removing engineers of slow-water rearing habitat (Yokel et al. 2018). Both beaver removal and mining altered the hydrologic connectivity between the surface and groundwater. Timber harvest has occurred since the 1950s, with clear-cutting common from the 1960s to 1980s (NMFS 2014). Though the Scott River lacks any major dams, current diversions and groundwater withdrawals for agriculture, cattle

grazing, and flood control have altered flows (Van Kirk and Naman 2008) and limited access to historic habitat for Coho Salmon (NMFS 2014; O'Keefe 2021).

The Scott River Coho Salmon population is designated a core population within the SONCC salmon ESU (NMFS 2014). Despite the historic and current impacts, this designation denotes that the Scott River population is considered a stronghold for the ESU and may serve as a source of spawners for nearby populations in the Klamath Basin (NMFS 2014). However, the low quality and restricted extent of summer and winter juvenile rearing habitat are believed to limit the population, which has declined in abundance over time (Yokel et al. 2018).

In recent years, low flows have become more pronounced in the Scott River Basin, accompanied by increasing periods of surface disconnection and high water temperatures (Van Kirk and Naman 2008; NMFS 2014; Morrow et al. 2021). In the winter, water temperatures can drop to 0° C with surface freezing. Flow and temperature conditions are likely important determinants of Coho Salmon survival and growth during both seasons.

I selected five sites (plus two downstream antenna sites) for this study within two of the primary salmonid spawning and rearing tributaries to the Scott River: Sugar Creek and French Creek (Figure 1). French Creek is a third-order stream and Sugar Creek is a fourth-order stream. The sites encompass different types of restoration techniques intended to provide seasonal rearing habitat: a constructed side channel, BDA-formed ponds, an off-channel pond, and engineered log jam pools, as well as untreated tributary pools (Table 1).

The SRWC constructed the Sugar Creek BDAs in 2014, with additional features added in 2017, forming an upper (BP2) and lower (BP1) pond (Figure 2) just upstream of the confluence with the Scott River. Improvements to the BDA by beavers flooded a low-lying vegetated area referred to as "the marsh." A channel constructed in 2015 connected BP2 to an off-channel pond, a relic from mining activity along Sugar Creek, further increasing the amount of complex, slow-water habitat. Because of the high connectivity between BP2, "the marsh", and the off-channel pond, they are referred to as the Sugar BP2 complex. BP1 and the off-channel pond are groundwater influenced, while BP2 is primarily surface water influenced.

French Creek is another tributary to the Scott River, located about 9 km downstream of Sugar Creek. The SRWC constructed BDAs in a natural side channel on French Creek in summer of 2017, called French Creek Side Channel BDA, approximately 3 km upstream from the confluence with the Scott River (**Error! Reference source not found.**). The French untreated mainstem reach is a stretch of four pools adjacent to and upstream of the French Creek Side Channel BDA. A constructed side channel site, called FRGP side channel, was built about 300 meters downstream of the untreated reach in 2018. On mainstem French Creek adjacent to the FRGP side channel is a series of three engineered log jams (ELJs), forming four ELJ influenced pools, also constructed in 2018.
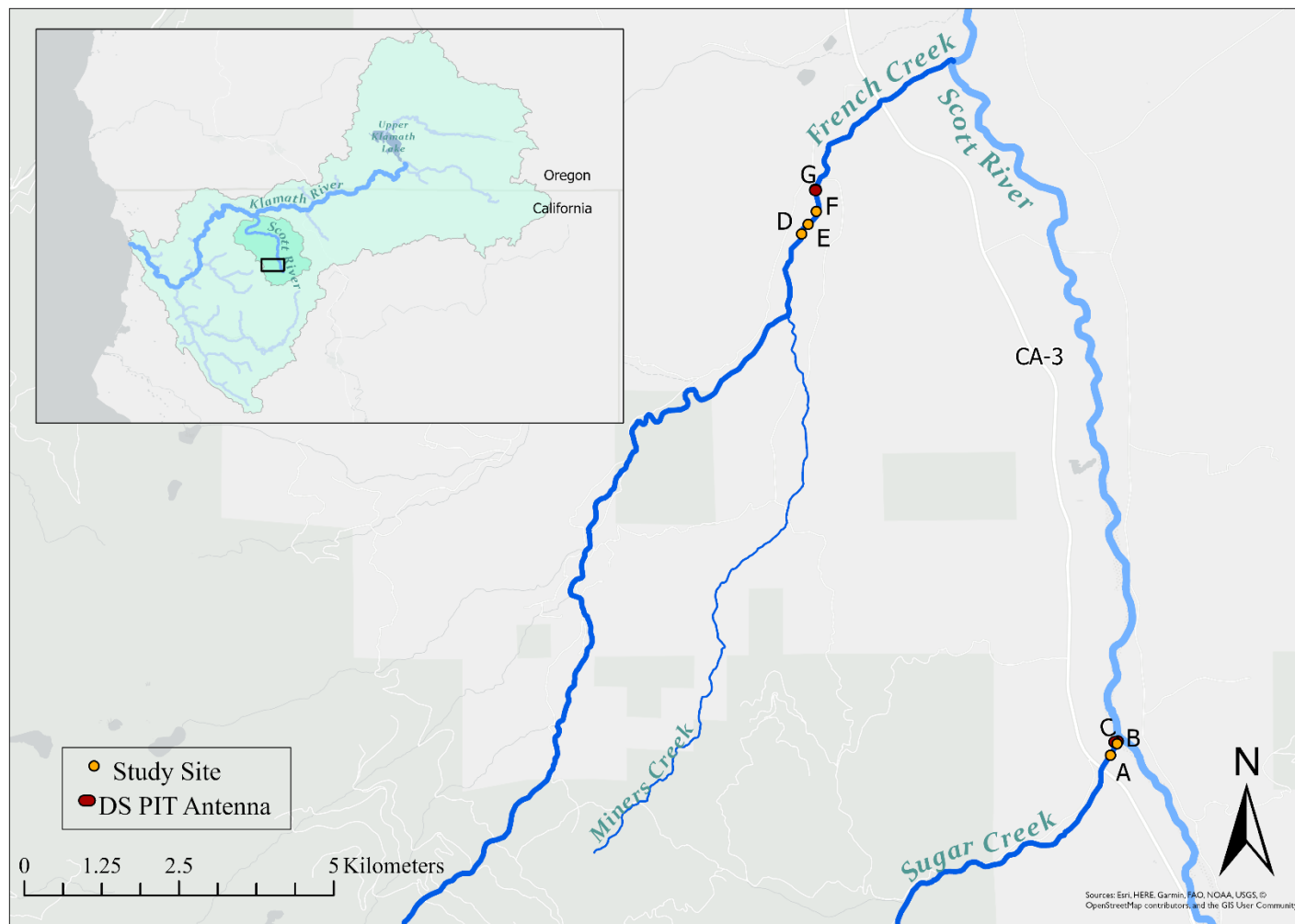
*Figure 1. Overview map of study sites in the Scott River watershed and downstream antennas: Site A= BP2 complex, Site B= BP1, Site C=DS PIT antenna, Site D= Untreated Mainstem Reach, Site E= SC BDA, Site F= FRGP SC + ELJs, Site G=DS PIT antenna (**Error! Reference source not found.**).*

Table 1. Selected study sites and descriptions in Scott River basin, California. Sites correspond with the "states" used in multistate models described below and are shown spatially on Figure 1.

Tributary	State	Name	Type of Site	Year Constructed
Sugar Creek	A	BP2 complex	Single BDA-formed pond + off-channel pond + flooded "marsh" habitat	2014, 2017
Sugar Creek	B	BP1	Triple BDA-formed pond	2014, 2017
Sugar Creek	C	Below BDA1 Antenna	Antenna below BDA forming BP1	NA
French Creek	D	Untreated Mainstem Reach	Reach that includes four untreated pools	NA
French Creek	E	Side channel BDA	Double-BDA formed pond in natural side channel	2017
French Creek	F	FRGP SC + ELJs	Constructed side channel + adjacent engineered log jam influenced mainstem pools	2018
French Creek	G	Downstream Antennas	Two antennas near the mouth of French Creek	NA
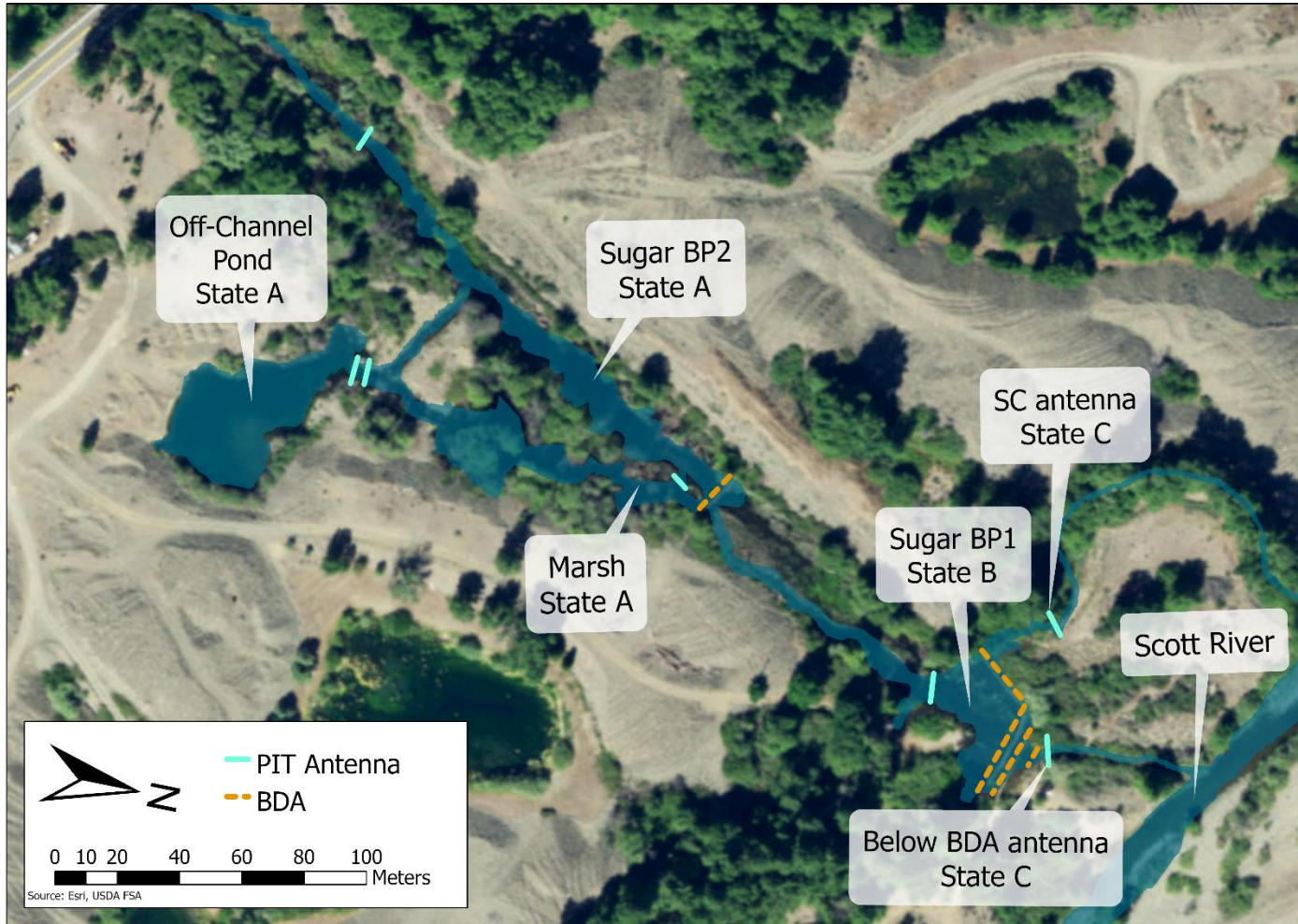
Figure 2. Map of the network of PIT antennas capturing movement between interconnected habitats around Sugar Creek restoration sites: BDA Pond 1 (BP1), BDA pond 2 (BP2), marsh, and off-channel pond (OCP) with constructed channels.
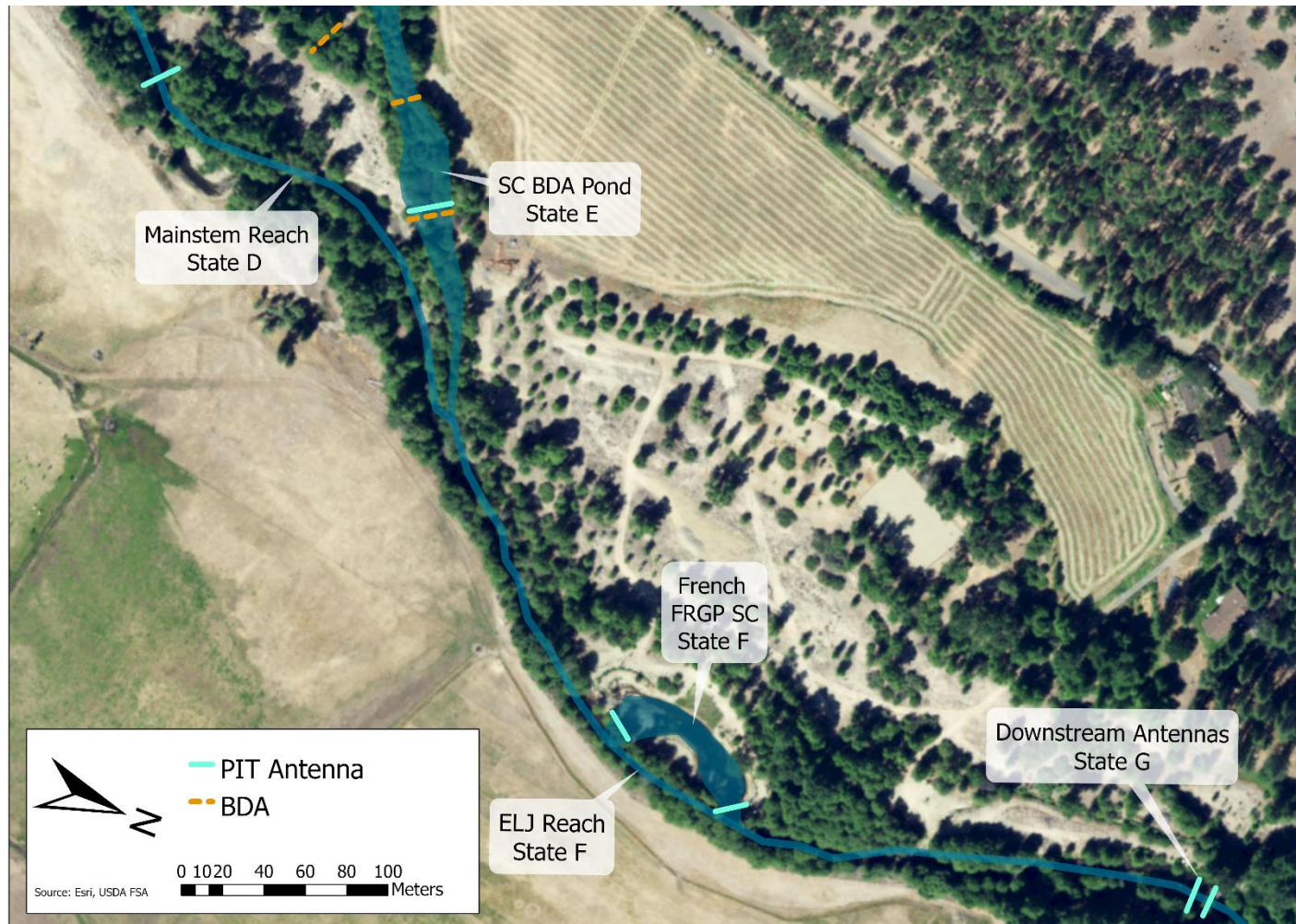
Figure 3. Map of French Creek Untreated Mainstem Reach, Side Channel BDA restoration site, and French Creek FRGP side channel + Engineered Log Jam reach restoration sites and network of PIT antennas.

Data Collection Methods

The SRWC tagged and trapped fish from 2016-2021 (e.g, Yokel et al. 2018). All

fish capture and handling procedures that I used during field work were approved March

10, 2020, under Humboldt State University Institutional Animal Care and Use Committee

(IACUC 2020F52). At each sample event we captured juvenile fish using beach seines

and traps, anesthetized them with Alka-Seltzer, collected fork length and weight, scanned

them for passive integrated transponder (PIT) tags, and PIT tagged untagged individuals

over 65 mm (fork length) before releasing them at the site of capture.

Tagging occurred at all sampling events, except the last sampling event prior to

smolt outmigration in the spring or if there were concerns of fish stress due to

environmental factors. During winter sampling, when flows are higher and fish are

primarily moving at night, we captured fish using overnight minnow traps and fyke nets.

During the summer we primarily used beach seines to capture fish. In 2019-2021, we

generally visited each site once in the late summer when fish reached taggable size (July-

August), once in early fall (October), once in the early winter (January), and once in early

spring (March). Timing of sampling varied from year to year due to environmental

constraints (drying, high temperatures, low temperatures) and COVID-19 restrictions on

travel. The planned sampling in January 2021 was postponed for most sites due to

COVID-19. To make up for the missed sampling event, we sampled in February 2021,

once COVID-19 risks had decreased. I estimated site-specific abundance and seasonal

survival and growth for the 2019-20 and 2020-21 brood years. The older SRWC dataset

from 2016-2018 did not include intensive winter sampling. I estimated abundance, growth and survival when the data were available for these years.

In my analysis, I compared cohorts of young of the year Coho Salmon (yoy), where a cohort refers to fish that hatch in spring of year x, are tagged starting in summer/fall of year x, and generally out-migrate in spring of year x+1, though some may stay another summer (referred to as "one-plus").

The SRWC operated a comprehensive network of PIT antennas primarily from 8/2019-present (Table 2). Antennas at inlets or junctions of individual habitat restoration areas provided detections of Coho Salmon moving in and out of these locations. Downstream antennas provide detections of individuals permanently emigrating out of the study area.

Table 2. Timeline showing the state, specific location within the state, and the dates running of each antenna site used in the multistate models. Scott river antennas with state "NA" were not used in the model but did provide additional information.

State	Location	Dates Running	Cohort
A	Sugar OCP Outlet	2/28/2018-present	2019-20, 2020-21
A	Sugar BP2	11/3/2017-present	2019-20, 2020-21
A	Sugar Marsh	1/7/2020-1/15/2020	2019-20
B	Sugar BP1	4/10/2017-present	2019-20, 2020-21
C	Sugar Below BDA1[a]	8/9/2019-present	2019-20, 2020-21
C	Sugar Side Channel	5/2020-7/2020	2019-20
D	French Untreated Mainstem Reach	8/3/2020-3/31/2021	2020-21
E	French SC BDA	11/25/2019-present	2019-20, 2020-21
F	French FRGP SC outlet/inlet	9/19/2019-present	2019-20, 2020-21
F	French ELJs	8/24/2020-12/2/2020, 1/22/2021-present	2020-21
G	French Mainstem DS[a]	10/22/2019-present	2019-20, 2020,21
NA	Scott River Alexander Pond	2/6/2020-present	2019-2020, 2020-21
NA	Scott River Oasis Alcove	3/22/2021-present	2020-21
NA	Scott River Rkm 28.9	12/2/2020-1/4/2021, 3/3/2021-present	2020-21

a: indicates antenna was used as the downstream outmigration state for that stream.

Abundance Estimates

When possible, sites were surveyed twice within a 2–3-day period. This approach

supports simple mark-recapture abundance estimates because we can assume the

population is "closed" between the two surveys. The goal was to estimate the population

separately for each site in the summer/early fall and winter seasons, but due to

environmental conditions, COVID-19, and sampling constraints, this did not always

occur. Population estimates were calculated using the Chapman-Robson modification

(Chapman 1951), to account for small-sample size bias, as follows:

$$\widehat{N} = \frac{(M+1)(C+1)}{R+1} - 1$$

Where:

$\widehat{N}$ =Estimate of total population size

M= Total number of Coho Salmon marked on day one

C= Total number of Coho Salmon captured on day two

R= Number of Coho Salmon recaptured on day two.

Abundance estimates were calculated for fish large enough to mark (>65 mm) and then

expanded to include fish too small to tag (<65 mm) by using the proportion of fish caught

that were less than 65 mm. I converted abundance to linear density, which Bouwes et al.

(2016) considered more representative of the increase in population due to increased

habitat area from BDA installation. Lengths of Sugar Creek sites and French Mainstem

Reach taken from Yokel et al. (2018) and length of ELJ reach taken from SRWC (2021)

(Table 3).

Chapman-Robson mark recapture models assume that all individuals (marked or not) are equally catchable and that populations are closed between the mark and recapture event. However, the estimates of the population size at the time of the initial event are robust to violation of the closure assumption if movement or mortality rates are equal for the marked and unmarked individuals.

Table 3. Length of each location used to calculate linear densities from population estimates.

Location	Cohort	Total Length (meters)	# Of pop estimates
French Mainstem Reach	All	137	4
Sugar BP1	2016-2017	108	4
Sugar BP1	2017-2018	116	3
Sugar BP1	2019-2020	116	1
Sugar BP2	2016-2017	211	2
Sugar BP2+OCP channel	2016-2017	378	1
Sugar BP2	2017-2018	220	3
French ELJ	2020-2021	104	1

Growth Analysis

In my growth analysis, I used fork length as the primary response variable because mass had more measurement error. Error in mass measurements can be due to environmental conditions (wind, precipitation), variation in gut fullness, or water on the surface of fish (Schreck and Moyle 1990).

Data Cleaning

The dataset had a small number of recording or measurement errors for fish size measurements. I cleaned the dataset using these rules:

1) If a fish was recaptured after 1-2 days with a 2-5 mm FL difference and it would affect a growth estimate because the fish had a subsequent capture, I averaged FLs. If the FL difference after 1-2 days was more than 5 mm, I just threw out both FLs.

2) If fish had 2 mm or more negative change in FL between a first and second capture more than a week apart AND they were captured a third or fourth time, I averaged the first and second capture FL and assigned this average to both dates.

Some fish were still present in the sampling area during their second summer or fall (aka "one-plus"). I used size distribution histograms to classify fish>90 mm FL in the early summer as one-plus and >100 mm FL fish in the late summer/early fall as one-plus. One-plus fish were excluded from the growth analysis.

Individual Growth Rates

Due to the variation in timing of sampling, recapture rates, and movement between sites, I was not able to conduct a more traditional growth analysis comparing growth rates (e.g. mm/day) for individuals by cohort, location and season. Using growth rate as a response variable in analyses requires measurements at similar time intervals for all the groups being compared. My limited sample size of individuals captured and recaptured on the same occasions made seasonal comparisons and site comparisons impossible in some cases. Also, growth is likely not linear over almost a year. Instead, I used a Generalized Additive Mixed Model (GAMM) approach with size as a response variable, date as a predictor, and a random effect for individual. For 2019-2020 I had sufficient recaptures to do a more traditional growth comparison for most of the sites

during three 'seasons' of approximately equal length (66-75 days): summer 2019

(8/23/2019-10/31/2019), fall 2019-2020 (10/31/2019-1/14/2020), and winter 2020

(1/14/2020-3/19/2020) (**Error! Reference source not found.**); this analysis yielded

similar conclusions for these dates as the GAM model.

<u>Generalized Additive Model</u>

      I modeled size through time using a generalized additive mixed model (GAMM).

It is likely that growth was not linear over time given that samples spanned long time

intervals (>45 days) including multiple seasons (Figure 6). GAMMs are an extension of

multiple linear regression that allows for flexible, non-linear relationships between each

variable and the response (James et al. 2013). For example, Staton (2017) used GAMMs

to predict mean length of four fish species over time based on location and environmental

variables. Using this approach avoided the assumption of linear growth over time and

preserved size data from surveys outside of the set intervals used to calculate seasonal

growth rates. All size data of recaptured fish were incorporated into the data set and used

to estimate growth. I standardized the date data so that the intercepts of random and fixed

effects represent size on October 1st when most sites had data and the size differences are

easier to interpret. Terms for cohort, location, and movement pattern were included to

identify if there was significant variation in fork length associated with these predictors

(Table 4). Repeat measurements of the same individual fish over time are not

independent data, but I included the random effect for individual to account for this lack

of independence. The random effect of individual accounts for variation not attributable

to date, site, cohort or a general movement pattern, including differences in size at first capture.

GAMMs were fit in Program R using the "gam" function within the package "mgcv" (Wood 2017). The number of basis functions (knots) and the smoothing parameter (sp) interact to control the complexity of the nonlinear relationship. There is some uncertainty in selecting the best number of knots and the level of smoothing penalty for these models. I used the "gam.check" function (which checks whether a sufficient numbers of knots were used in each smooth in the model), AICc, and visualization to select the best combination of knots and smoothing parameter, without overfitting. I started with five knots, which is equivalent to four coefficients – one for each season, and increased the knots until the gam.check() function showed p-values>0.05. Then I confirmed AICc was lowest for that model and the plots had a reasonable amount of wiggliness. Too much wiggliness, such as unrealistic declines in size or rapid changes in slope, would indicate the model was overfit. All fork lengths of young of the year Coho Salmon captured at least twice seven or more days apart were included. I excluded individuals that were only recaptured within seven days as any difference in fork length after less than seven days is most likely measurement error. Sites were included in the analysis if they had ten or more recaptured fish and three or more surveys for a cohort.

To account for differences in growth due to movement between sites, I created a binary variable (Movement) that classified individuals at a specific capture event as a "mover" or "stayer" in three different ways: (1) if they were recaptured in a different location than their last capture, (2) if they were detected at two or more PIT antenna

stations in the 30 days prior to capture, (3) if they were detected on an antenna outside of the location where they were recaptured in the 30 days prior to capture. A second variable (MultiDate30) was used to capture fish that did not necessarily move between sites but were a frequent mover within a site. MultiDate30 was a binary variable where fish detected on antennas more than three days in the last 30 days were designated as a "mover" and everyone else was designated a "stayer". This variable was intended to pick up on diel movement in and out of sites, although it may be confounded by fish that live permanently near an antenna.

I ran a global GAMM with FL as a function of time with a nonlinear smooth for each combination of site and cohort, a random effect for individual (random intercept), and linear terms for cohort, location, and movement covariates. In other words, the model constrains individuals in the same site and cohort combination to have the same growth rates (slopes) through time, but there are differences in mean FL on October 1st by cohort, by location and by movement type, and individuals can have random variation in starting FL. Percent deviance explained was used to evaluate goodness-of-fit. In results below, I present the estimated degrees of freedom (edf), F-statistic, and standard error for each covariate in the global model. Finally, the normality and equal variance assumptions were examined for the global model using the "gam.check" function in the "mgcv" package. I used the effect size estimates from this model to assess the strength and direction of effects for each predictor variable. I used a global model rather than model selection because the main question for this part of the analysis was how much size/growth difference there was between sites/cohorts/etc. The coefficients of the global model with

all sites and cohorts are estimates of those differences. Adding model selection would indicate if those predictors improve the model, but wouldn't necessarily produce estimates of all the differences.

To estimate growth rates of fish for comparison with other studies, I extracted predicted FL and standard error for each individual (each PIT ID) captured at each site. I calculated site-specific "growth rates" by calculating the slope between the FLs on two dates representing "summer", "fall", "winter", and "spring", 8/15-9/15, 10/31-12/1, 1/15-2/15, and 3/15-4/15 respectively. Growth calculations were limited to fish with a first capture prior to or up to 16 days after the first day of the season interval and with a final capture after or up to 16 days before the last day of the season interval. To estimate the uncertainty in these growth estimates, I used a bootstrapping method where I took random draws from the predicted size distribution for each individual using the predicted FL and SE, calculated growth for that individual, averaged growth for all individuals within the season/cohort/site combination, and repeated 2000 times to calculate 95% confidence intervals.

Table 4. GAM growth model covariates and descriptions.

Covariate	Description
Cohort	Factor variable: 2016-2017, 2017-2018, 2018-2019, 2019-2020, 2020-2021
Location	Factor variable: Sugar BP1, Sugar BP2 Complex, Scott-Sugar Confluence, French FRGP SC, French ELJ reach, French SC BDA, French Control Reach
Movement	Factor variable: large-scale mover or stayer – movement between sites in the last 30 days
MultiDate30	Factor variable: small-scale mover or stayer – frequent antenna detections within a site (detected on more than three days) in the last 30 days
PIT	Random effect for individual

Survival Models

I used mark-recapture models to estimate seasonal survival. Traditional Cormack Jolly Seber (CJS) mark-recapture models estimate probability of capture or detection (p) and apparent survival (φ) of marked individuals between sampling occasions at a single site. In a CJS model individuals can be assigned to spatial groups to account for differences in survival and detection across sites, but if an individual uses multiple sites during subsequent intervals, their survival would be incorrectly associated with just the habitat where they were first encountered. If an individual occupies a site where it cannot be detected, it would be treated as a mortality. A movement parameter (ψ) can be incorporated using a multistate version of the CJS model, where different states represent different locations with different survival rates and probability of capture and (ψ) is the probability of moving from one state to another (Lebreton and Cefe 2002; Ford et al. 2012). The movement parameter is conditional on survival during the interval, so survival

is assigned to the previous site and then the individual "moves" at the end of the interval (
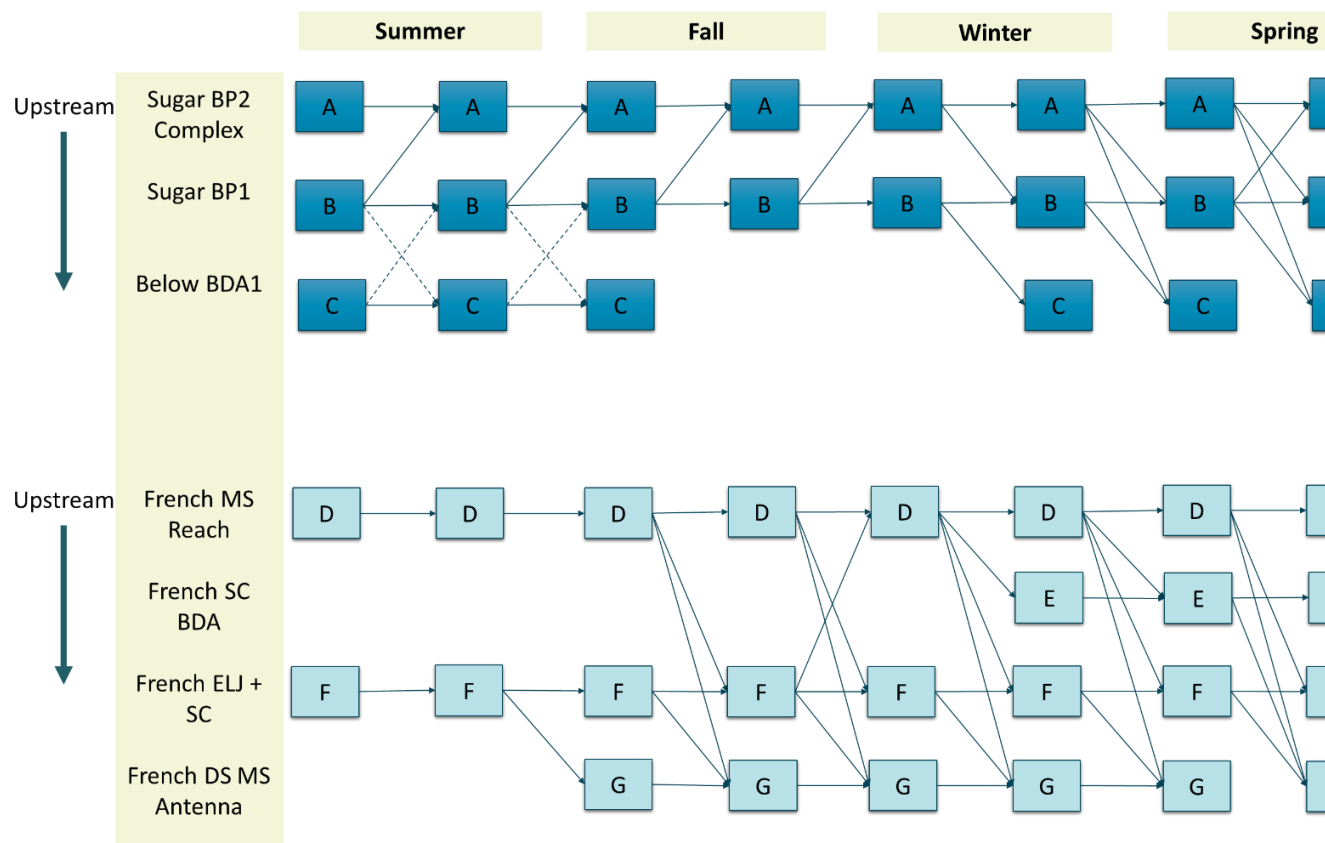
Figure 4. A conceptual diagram of the multistate model for the 2019-2020 cohort.

Rectangles represent states available within each occasion, which are the five sampling

sites: Sugar BP2 Complex, Sugar BP1, French Mainstem Reach, French FRGP SC +

ELJ. Arrows show observed transitions. Dashed arrows were used in the summer for

transitions between B and C because these "movements" were due to a passage

experiment. The model had 11 one-week occasions per season. For simplicity, only two

occasions per season are shown. Survival in the spring interval was fixed to 0 in state G

and C.

).

I used a traditional CJS model to estimate summer apparent survival with the historic 2016-2018 dataset because only summer data were collected and fewer sites were sampled. For these CJS models, the estimated apparent survival is the combined probability of surviving and staying in the sampling area for the summer. For 2019-2021, I collected recapture data year-round, so I used a multistate model to estimate survival and account for movement.

To differentiate between temporary movement (e.g. diel movements into adjacent habitats) and more permanent changes in rearing location in my multistate models, study sites were divided into separate states only if they either had a partial barrier, such as a BDA, or more than two habitat units between them. Sugar BP1 and BP2, for example, were considered separate states in the analysis because movement between the two ponds is somewhat restricted by the 1-m-tall, semipermeable BDA that separates them, especially during low flows. The off-channel pond and BP2 on the other hand, were lumped together because it is relatively easy to move through the riffle or marsh habitat that connects them. Antenna data showed a diel movement pattern between these two habitats in the winter, so fish were often utilizing both habitats in the same season. The French FRGP side channel and the Engineered Log Jam Reach (ELJ) are connected and movement between them was frequent, so they were lumped together in the multistate model. This left me with three states for Sugar Creek and four states for French Creek.

I created capture histories for each tagged fish by combining in-hand and antenna detections of fish. Continuous antenna detections were collapsed into seven-day intervals. Van Vleet (2019) found eight-day intervals had less bias in survival estimates than 15 or

24-day intervals in a simulated dataset. Each fish had a capture history with 44 occasions representing 44 seven-day intervals, where for each occasion a fish is either detected via PIT antenna or in-hand capture and is assigned a state-specific character or it is not detected at any location and is assigned a 0. For example, a fish with capture history A0B was detected in site A on the first occasion, was alive but not detected the second occasion, and was detected in site B on the third occasion. Fish that were detected in multiple states during an occasion were assigned to the last state they were encountered in. I used these capture histories to evaluate differences in apparent survival (φ), capture probability (p), and movement probability (ψ), using a multistate model design in R (R Development Core Team 2007) package RMark (Laake 2013) to construct models for program MARK (White and Burnham 1999).

Some sites only had antennas during part of the study period or had additional temporary antennas, such as French Mainstem Reach and French ELJs. Mainstem Scott River antennas were running in 2020-2021, but not 2019-2020 (Table 2). These changes lead to variation in capture probability in the multistate model. Due to these differences in antenna configuration as well as sites surveyed, and timing of surveys, I developed separate multistate models for 2019-2020 and 2020-2021.

Due to the large number of parameters, I applied 11-week seasonal constraints to reduce model complexity and make overall seasonal survival comparable between cohorts (Table 5). This seasonal constraint assumes survival, transition, and detection probabilities were constant between occasions in the same season, or a constant function of weekly covariates within the same season for models with continuous covariates.

SRWC conducted an experiment in summer of 2019, where fish were moved from Sugar BP1 to the habitat below the lower BDA to evaluate fish passage over the BDA structure (O'Keefe, 2021). To account for differences in survival and movement due to the fish passage experiment, a passage experiment grouping variable was included in the 2019-2020 models. I assumed that the Sugar Creek passage experiment would only affect fish immediately after the experiment, so I set the two groups equal in winter and spring.

For my first stage in analysis, I tallied individuals by tagging location, recapture location, and season to identify the sample size available for subsequent analyses (Appendix B). If very few fish were recorded making a particular transition, I excluded that transition from the multistate analysis by fixing the movement parameter to zero (Figure 4). For example, little movement was observed between Sugar Creek and French Creek (6 individuals in 2019-2020, 3 individuals in 2020-2021), so this transition was fixed to 0 and these transitions edited out of the capture histories.

Within each tributary, the last detection of a fish at the downstream antenna represented the transition to an unobservable state (outmigration, state C for Sugar Creek or state G for French Creek). On Sugar Creek the downstream antenna that provides the final detection of outmigrants has been running since 2019 and is located approximately 10 m downstream of the BDAs that form Sugar BP1. On French Creek the downstream antenna has been located 300 m downstream of the FRGP side channel since 2019. Once most fish detected on the downstream antenna did not return upstream to be detected anywhere else, I fixed survival to 0 in the downstream state to represent that they cannot

be detected again and are out of the system because they have outmigrated as smolts. In 2019-2020 Sugar Creek survival in state C was set to 0 in all seasons, except for fish passage experiment fish in summer and fall. In 2020-2021 survival was set to 0 only in spring in 2020-21 due to high numbers of fish moving into the habitat below BDA 1 (state C) in the winter from the Scott River. In French Creek, survival in state G was set to 0 only in spring both years. Some French Creek fish were detected moving back upstream in the spring after being detected on the DS antennas (2019-2020: 12 fish, 2020-2021: 15 fish). The capture histories of those fish were edited to remove the encounter at the DS antennas. If a fish outmigrated before survival was set to zero, it was removed from survival estimates after its last capture on a downstream antenna using the "-1" notation in the capture histories (White and Burnham 1999). Though there were some fish who moved into state G prior to outmigration and stayed there for multiple occasions, the survival probability at this antenna site was not of interest in this analysis and the number of fish was low, so I arbitrarily set survival to 1 in these occasions to help with model convergence.

I manually calculated and fixed detection probability for the outmigration state because it cannot be calculated in the model. For French Creek, the downstream outmigration state (G) had a paired upstream and downstream array. I assumed fish detected on only one array passed both but was not detected and calculated detection probability of the entire system using methods described in Connolly (2010), as follows:

$$P_d = \frac{N_{ud}}{(N_{ud} + N_u)}$$

$$N_t = \frac{N_d}{P_d}$$

$$P = \frac{(N_u + N_{ud} + N_d)}{N_t}$$

Where:

N_u = number detected on upstream antenna only

N_d= number detected on downstream antenna only

N_{ud}= number detected on both antennas

N_t= estimated total number of fish that passed both antennas

P_d= downstream antenna efficiency

P = overall detection efficiency for the entire system

In 2019-2020, detection probability at the French Creek downstream antennas (state G) was 0.99. In 2020-2021, detection probability was 0.98. These may be biased high because the paired antennas arrays are not independent. If one is not functioning or flows are high, fish could be missed on both antennas. In Sugar Creek, there is only one downstream antenna array below BDA1 (state C), so I calculated detection probability as p=x/y where y= number of fish detected outside of the Sugar Creek basin and x = the number of fish detected outside of the Sugar Creek basin and in state C. This assumes that p was constant over the entire period. I knew this assumption was violated in 2019-2020 because 37 fish were detected in Sugar Creek and then the Scott River between 3/08-4/26/20, without being detected in State C. Most of them first appeared in the Scott River between 4/12-4/19/20. They likely moved down an ephemeral side channel that

connects Sugar BP1 to the Scott River prior to antenna installation in May of 2020. This skewed average detection probability over the entire period for State C low, so I reran the model with the lowest AIC using a range of detection probabilities (0.56-0.75) starting with the calculated value of p. The fish that likely outmigrated using the side channel were right-censored using the dot notation in the capture history, starting with the first detection in Scott River. This signifies that they were not detected, but could have been detected up until the first detection in the Scott River. The "-1" notation on the other hand, would have removed these individuals from the dataset after their last detection in state A or B. In 2020-2021, the below BDA1 antenna had an estimated detection probability of 0.80.

Transitions with greater than 0 and less than five fish per season were grouped together into a "background transition rate" for each season to help the model converge and accurately assign survival state. I fixed survival to 0 in states and covariate groups where I did not tag or detect any fish in a particular season. This helped decrease unidentifiable parameters.

I used the sin link function for survival and detection probability (p) to better estimate parameters near the boundaries (0 and 1), except in models that cannot use an identity matrix, which is required for sin link (Cooch & White 2019). Models that cannot use an identity matrix include those with additive covariates and continuous covariates. When sin link was used, it is notated as "Parameter(-1+variable1:variable2, link="sin")".

I used multinomial logit link for Psi to constrain all transitions from one stratum to add to

1.

In models where I could no longer use the sin link, I continued to use the

"Parameter(-1+variable1:variable2)" formulation. The traditional formulation in MARK:

parameter(variable1*variable2), shows results relative to an intercept, whereas the

formulation I used clearly shows the separate intercepts for each combination of

variable1-variable2 and any slopes (continuous covariates) being used. This was helpful

in my more complicated models with temperature and/or flow.

I assessed the goodness of fit of the most complex model that converged with

minimal parameter convergence issues (SE=0) using the median $\hat{c}$ test in program

MARK. I used the estimated median $\hat{c}$ value to correct for overdispersion.

I compared candidate models with different combinations of covariates decided a priori based on project goals and how they likely affect survival and movement (Table 6Table 5. Multistate model 11-week seasonal constraints and dates included in each weekly occasion.

Season	Occasion	2019- Start Date	2020 End Date	2020- Start Date	2021 End Date
Summer	1	7/29/2019	8/4/2019	7/22/2020	7/28/2020
Summer	2	8/5/2019	8/11/2019	7/29/2020	8/4/2020
Summer	3	8/12/2019	8/18/2019	8/5/2020	8/11/2020
Summer	4	8/19/2019	8/25/2019	8/12/2020	8/18/2020
Summer	5	8/26/2019	9/1/2019	8/19/2020	8/25/2020
Summer	6	9/2/2019	9/8/2019	8/26/2020	9/1/2020
Summer	7	9/9/2019	9/15/2019	9/2/2020	9/8/2020
Summer	8	9/16/2019	9/22/2019	9/9/2020	9/15/2020
Summer	9	9/23/2019	9/29/2019	9/16/2020	9/22/2020
Summer	10	9/30/2019	10/6/2019	9/23/2020	9/29/2020
Summer	11	10/7/2019	10/13/2019	9/30/2020	10/6/2020
Fall	12	10/14/2019	10/20/2019	10/7/2020	10/13/2020
Fall	13	10/21/2019	10/27/2019	10/14/2020	10/20/2020
Fall	14	10/28/2019	11/3/2019	10/21/2020	10/27/2020

Season	Occasion	2019- Start Date	2020 End Date	2020- Start Date	2021 End Date
Fall	15	11/4/2019	11/10/2019	10/28/2020	11/3/2020
Fall	16	11/11/2019	11/17/2019	11/4/2020	11/10/2020
Fall	17	11/18/2019	11/24/2019	11/11/2020	11/17/2020
Fall	18	11/25/2019	12/1/2019	11/18/2020	11/24/2020
Fall	19	12/2/2019	12/8/2019	11/25/2020	12/1/2020
Fall	20	12/9/2019	12/15/2019	12/2/2020	12/8/2020
Fall	21	12/16/2019	12/22/2019	12/9/2020	12/15/2020
Fall	22	12/23/2019	12/29/2019	12/16/2020	12/22/2020
Winter	23	12/30/2019	1/5/2020	12/23/2020	12/29/2020
Winter	24	1/6/2020	1/12/2020	12/30/2020	1/5/2021
Winter	25	1/13/2020	1/19/2020	1/6/2021	1/12/2021
Winter	26	1/20/2020	1/26/2020	1/13/2021	1/19/2021
Winter	27	1/27/2020	2/2/2020	1/20/2021	1/26/2021
Winter	28	2/3/2020	2/9/2020	1/27/2021	2/2/2021
Winter	29	2/10/2020	2/16/2020	2/3/2021	2/9/2021
Winter	30	2/17/2020	2/23/2020	2/10/2021	2/16/2021
Winter	31	2/24/2020	3/1/2020	2/17/2021	2/23/2021
Winter	32	3/2/2020	3/8/2020	2/24/2021	3/2/2021
Winter	33	3/9/2020	3/15/2020	3/3/2021	3/9/2021
Spring	34	3/16/2020	3/22/2020	3/10/2021	3/16/2021
Spring	35	3/23/2020	3/29/2020	3/17/2021	3/23/2021
Spring	36	3/30/2020	4/5/2020	3/24/2021	3/30/2021
Spring	37	4/6/2020	4/12/2020	3/31/2021	4/6/2021
Spring	38	4/13/2020	4/19/2020	4/7/2021	4/13/2021
Spring	39	4/20/2020	4/26/2020	4/14/2021	4/20/2021
Spring	40	4/27/2020	5/3/2020	4/21/2021	4/27/2021
Spring	41	5/4/2020	5/10/2020	4/28/2021	5/4/2021
Spring	42	5/11/2020	5/17/2020	5/5/2021	5/11/2021
Spring	43	5/18/2020	5/24/2020	5/12/2021	5/18/2021
Spring	44	5/25/2020	5/31/2020	5/19/2021	5/25/2021

Table 6). I used season as a grouping factor for survival, movement, and detection probabilities because I was interested in whether some sites have higher survival only in particular seasons and if fall/winter redistribution increased movement out of some sites

more than others. I included weekly average streamflow and temperature as covariates for movement because they have been shown to affect movement rates of juvenile Coho Salmon (Hartman et al. 1982; Tschaplinski and Hartman 1983; Giannico and Healey 1998; Giannico & Hinch 2003). I tested models with and without temperature as a covariate for survival because it can affect freshwater survival of Coho Salmon (Obedzinski et al. 2018), though the effect of temperature on survival is dependent on the interaction of temperature, energy expenditure, and food availability (Lusardi et al. 2020). I expected the relationships between survival and movement and these environmental covariates to be season dependent, so I applied an interaction with season. To make the effect sizes of streamflow and temperature comparable, I standardized both to z-scores. Stream-specific streamflow was standardized to z-scores using the stream's mean and standard deviation. Flow data came from CA Department of Water Resources station number F25650 French Creek at Highway 3 near Callahan (41.411746, -122.8588) and F25890 Sugar Creek near Callahan (41.328594, -122.843389). I also used continuous HOBO temp loggers to calculate a maximum weekly temperature (MWT) for each site. I standardized MWT to z-scores using the global mean and SD. I also assumed weeks with recapture surveys would have higher detection probability than weeks with just antenna detections, so capture method was included as a covariate for detection probability.

I calculated overall season survival by taking the product of all probability estimates within a season. I also calculated the probability of moving from state r to state s at any time within a season (aka overall seasonal movement probability) as:

$$\Psi^{rs}_{Season} = 1 - \Pi^{11}_1 (1 - \Psi^{rs}_t)$$

Where Ψ^{rs}_t is the probability of moving from state *r* to state *s* during a given time interval

within a particular season. Then I used 2000 bootstrap iterations to calculate 95%

confidence intervals for each overall seasonal movement probability. To avoid estimates

greater than 1, bootstrapping was performed on the logit-transformed real estimates and

then back-transformed.

Like single-state models, multistate models assume:

1) tags are not lost, and all tags and states are correctly identified.

2) the tagging of individuals does not affect their probabilities of capture, survival

or movement.

3) every individual in the same state at the same time has the same capture,

survival, and movement probabilities. In my system, this assumption may have been

violated due to differences in capture probabilities of fish where multiple habitats were

lumped together into one "state", such as the Sugar OCP and Sugar BP2. Fish may have

also temporarily emigrated upstream of the study area, where I did not sample and there

are no antennas available to detect fish. This is not necessarily a violation of assumption

3, but it would bias estimates of capture and movement low and could bias survival high.

 4) the fate of each individual is independent of the fates of others (Calvert et al.

2009).

The additional assumptions of a multistate model include (Cooch & White 2019):

5) the probability of making a given transition between occasion (*i*) and (*i*+1) is

dependent only on the state at time (*i*).

6) the survival from (i) to ($i+1$) is assigned to the site at time (i). In other words, all mortality occurs before movement and movement occurs immediately before the next interval.

7) All individuals make the transitions at the same time (relative to the start or end of the time interval). This assumption is not true in my system or any natural system.
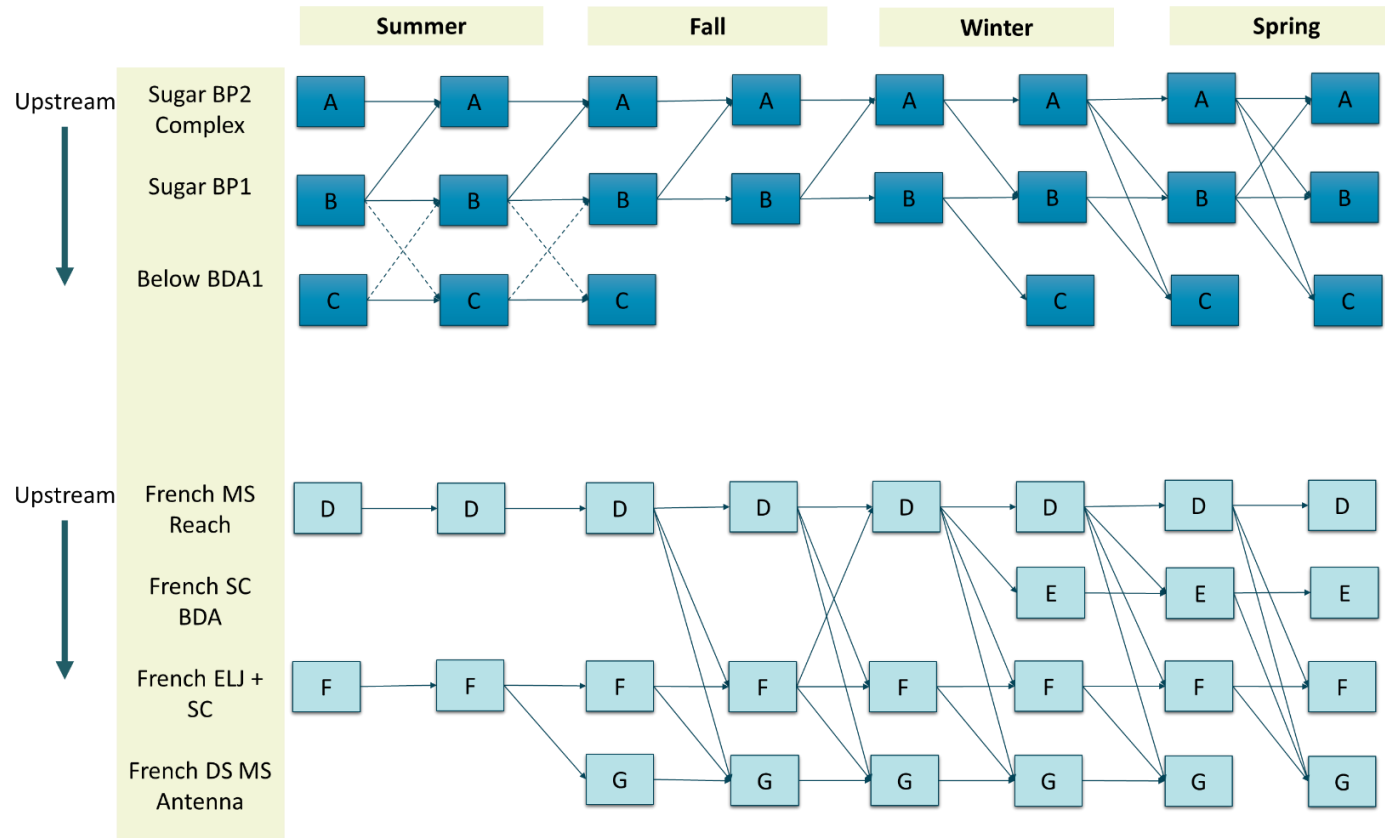
Figure 4. A conceptual diagram of the multistate model for the 2019-2020 cohort. Rectangles represent states available within each occasion, which are the five sampling sites: Sugar BP2 Complex, Sugar BP1, French Mainstem Reach, French FRGP SC + ELJ. Arrows show observed transitions. Dashed arrows were used in the summer for transitions between B and C because these "movements" were due to a passage experiment. The model had 11 one-week occasions per season. For simplicity, only two occasions per season are shown. Survival in the spring interval was fixed to 0 in state G and C.

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Table 5. Multistate model 11-week seasonal constraints and dates included in each weekly occasion.

Season	Occasion	2019-2020 Start Date	2020 End Date	2020-2021 Start Date	2021 End Date
Summer	1	7/29/2019	8/4/2019	7/22/2020	7/28/2020
Summer	2	8/5/2019	8/11/2019	7/29/2020	8/4/2020
Summer	3	8/12/2019	8/18/2019	8/5/2020	8/11/2020
Summer	4	8/19/2019	8/25/2019	8/12/2020	8/18/2020
Summer	5	8/26/2019	9/1/2019	8/19/2020	8/25/2020
Summer	6	9/2/2019	9/8/2019	8/26/2020	9/1/2020
Summer	7	9/9/2019	9/15/2019	9/2/2020	9/8/2020
Summer	8	9/16/2019	9/22/2019	9/9/2020	9/15/2020
Summer	9	9/23/2019	9/29/2019	9/16/2020	9/22/2020
Summer	10	9/30/2019	10/6/2019	9/23/2020	9/29/2020
Summer	11	10/7/2019	10/13/2019	9/30/2020	10/6/2020
Fall	12	10/14/2019	10/20/2019	10/7/2020	10/13/2020
Fall	13	10/21/2019	10/27/2019	10/14/2020	10/20/2020
Fall	14	10/28/2019	11/3/2019	10/21/2020	10/27/2020
Fall	15	11/4/2019	11/10/2019	10/28/2020	11/3/2020
Fall	16	11/11/2019	11/17/2019	11/4/2020	11/10/2020
Fall	17	11/18/2019	11/24/2019	11/11/2020	11/17/2020
Fall	18	11/25/2019	12/1/2019	11/18/2020	11/24/2020
Fall	19	12/2/2019	12/8/2019	11/25/2020	12/1/2020
Fall	20	12/9/2019	12/15/2019	12/2/2020	12/8/2020
Fall	21	12/16/2019	12/22/2019	12/9/2020	12/15/2020
Fall	22	12/23/2019	12/29/2019	12/16/2020	12/22/2020
Winter	23	12/30/2019	1/5/2020	12/23/2020	12/29/2020
Winter	24	1/6/2020	1/12/2020	12/30/2020	1/5/2021
Winter	25	1/13/2020	1/19/2020	1/6/2021	1/12/2021
Winter	26	1/20/2020	1/26/2020	1/13/2021	1/19/2021
Winter	27	1/27/2020	2/2/2020	1/20/2021	1/26/2021
Winter	28	2/3/2020	2/9/2020	1/27/2021	2/2/2021
Winter	29	2/10/2020	2/16/2020	2/3/2021	2/9/2021
Winter	30	2/17/2020	2/23/2020	2/10/2021	2/16/2021
Winter	31	2/24/2020	3/1/2020	2/17/2021	2/23/2021
Winter	32	3/2/2020	3/8/2020	2/24/2021	3/2/2021
Winter	33	3/9/2020	3/15/2020	3/3/2021	3/9/2021
Spring	34	3/16/2020	3/22/2020	3/10/2021	3/16/2021
Spring	35	3/23/2020	3/29/2020	3/17/2021	3/23/2021
Spring	36	3/30/2020	4/5/2020	3/24/2021	3/30/2021
Spring	37	4/6/2020	4/12/2020	3/31/2021	4/6/2021
Spring	38	4/13/2020	4/19/2020	4/7/2021	4/13/2021

Season	Occasion	2019-2020		2020-2021	
		Start Date	End Date	Start Date	End Date
Spring	39	4/20/2020	4/26/2020	4/14/2021	4/20/2021
Spring	40	4/27/2020	5/3/2020	4/21/2021	4/27/2021
Spring	41	5/4/2020	5/10/2020	4/28/2021	5/4/2021
Spring	42	5/11/2020	5/17/2020	5/5/2021	5/11/2021
Spring	43	5/18/2020	5/24/2020	5/12/2021	5/18/2021
Spring	44	5/25/2020	5/31/2020	5/19/2021	5/25/2021

Table 6. Covariates used in 2019-2020 multistate model, descriptions, and which parameters they were used for where S=survival, p=detection probability, and Ψ=movement/transition probability.

Covariate	Covariate Description	Parameter
Flow	Average weekly streamflow (cfs) of Sugar Creek or French Creek, converted to a z-score.	Ψ
Season	Temporal constraint: summer, fall, winter, spring	S, Ψ, p
Temperature	Stratum-specific maximum weekly temperature	S, Ψ
Passage Experiment	Moved in a summer BDA passage experiment (y/n)	S, Ψ
Method	Detection method (in hand + antenna or antenna only)	p

RESULTS

Site Narrative

Drought conditions impacted the first half of the 2018-2019 cohort, the second half of the 2019-2020 cohort, and the entirety of the 2020-2021 cohort (Table 7). Site conditions varied between drought and non-drought years, but generally fish followed a consistent seasonal pattern of usage at each site. Some sites were used during either winter or summer, while other sites were used year-round (Table 7). Habitats used primarily in summer included French Controls and French ELJs, with catch decreasing from summer-winter. In contrast, the French SC BDA was not utilized by fish during summer, when it was disconnected from the stream. Fish entered French SC BDA when rains triggered redistribution in the fall/winter. Fish remained in the site until spring, however in some extreme drought years (2021), the habitat became disconnected prior to spring outmigration. Due to concern that fish might become trapped behind the BDA, a subset of fish from SC BDA were captured and released immediately below the BDA in 2021. However, continued monitoring showed that remaining fish out migrated on a spring freshet. The French FRGP SC was accessible year-round, with catch increasing from summer-winter. Fish were not observed utilizing the habitat in the summer of 2020, likely due to drought conditions decreasing water quality. Fish moved into French FRGP SC in the fall/winter that year. The Sugar BDA ponds were utilized year-round most years, however, during the extreme drought conditions of 2020-2021, Sugar BP1

completely dried by September 2020. No juveniles were observed in Sugar BP2 that summer, even though it remained wetted. This corroborated reports that no fish were observed spawning above Sugar BDA 2 in December 2019-February 2020, likely due to low winter flows. However, juveniles did move into Sugar BP1 and BP2 in December 2020 after rain events, likely from the summer refuge pools in the Scott River near the confluence with Sugar Creek. These fish must have passed upstream over the BDA.

Table 7. Timeline with fish habitat utilization patterns. Drought condition in Siskiyou County, CA are on the top bar where different colors indicate different drought categories: D0-Abnormally Dry, D1-Moderate Drought, D2- Severe Drought, D3- Extreme Drought, D4-Exceptional Drought (www.drought.gov/states/california/county/siskiyou). Seasons were assigned the most severe drought category recorded for at least half of land area for at least half of the season. Grey shading indicates site was not constructed yet. Dark fish indicates confirmed fish presence via surveys, clear fish indicates presumed fish presence, but no surveys done (E. Yokel, personal communication, March 23, 2023). Smaller sized fish indicates fish were present but not abundant, larger fish size indicates fish were presence and abundant. Blank cells indicate no fish present.

	2016–2017				2017–2018				2018–2019				2019–2020				2020–2021			
	S	F	W	Sp	S	F	W	Sp	S	F	W	Sp	S	F	W	Sp	S	F	W	Sp
Drought (USDM)	D0						D0	D0	D1	D2	D1			D0	D2	D3	D3	D3	D3	D3
Sugar BP1																				
Sugar BP2 Complex																				
French MS Reach																				
French FRGP SC																				
French ELJ reach																				
French SC BDA																				

Abundance Estimates

From 2016 to 2021 we tagged between 1048-3489 Coho Salmon each sampling season and the overall rate of fish recaptured at least once varied between 7%-62% (Table 8).

Based on Chapman estimators, summer/fall abundance ranged from 377 (95% CI: 312-342) - 1992 (95% CI: 1651-2333) in Sugar BP1, 543 (95% CI: 473-614) - 1557 (95% CI: 1200-1913) in Sugar BP2, 216 (95% CI: 193-239) – 763 (95% CI: 693-834) in French Untreated Mainstem Reach, and 750 (95% CI: 699-801) in the French ELJ reach (only one year) (Table 9). As mentioned previously, Sugar BP1 was not surveyed in fall 2020 because the site went completely dry. Generally, low water conditions forced most fish into mainstem habitats in summer/fall 2020, so only two mainstem sites, French Untreated Mainstem Reach and French ELJs, were sampled for population abundance estimates.

Fish densities were highest in Sugar BP1 (Figure 5). Despite high abundance estimates, Sugar BP2 complex had similar fish densities as the French Untreated Mainstem Reach. This is in part due to the large amount of habitat in this site and the difficulty sampling in connected habitats like the Sugar off-channel pond and marsh. Only one attempt was made to sample outside of the main BDA-formed pond at BP2 during population estimates. The Sugar off-channel pond outlet channel was sampled in August 2016 and the length of that channel was included in the linear density estimate for that effort.

During winter abundance estimates, baited minnow traps were used instead of seine nets, and there appeared to be a 'trap-shyness' effect. There was also a subset of fish that frequently moved back and forth between adjacent sites in the winter, such as the French FRGP SC and French ELJ reach, and Sugar BP2 and Sugar Off-channel Pond. Individuals that showed this behavior usually moved at dusk and dawn every few days. These differences violated the Chapman assumption of equal catchability, so I do not report winter population estimates here. However, there were at least 399 individuals in Sugar BP1 and 136 in Sugar BP2 Complex in winter 2017-2018, 761 in Sugar BP1 and 563 in French FRGP SC + ELJ Reach in winter 2019-2020, and 498 in French FRGP SC + ELJ Reach and 112 in French SC BDA in winter 2020-2021 (Table 10).

Table 8. *The overall number of fish PIT tagged and recaptured in a subsequent survey by year and tributary.*

Cohort	Tributary	N Tagged	N Recap	Recap Rate	n Surveys
2016-2017	French Creek	315	194	0.62	6
	Sugar Creek	731	292	0.4	17
2017-2018	French Creek	341	181	0.53	11
	Sugar Creek	1014	315	0.31	11
2018-2019	French Creek	764	106	0.14	9
	Sugar Creek	490	61	0.12	7
2019-2020	French Creek	1513	475	0.31	12
	Sugar Creek	1976	677	0.34	18
2020-2021	French Creek	1709	615	0.36	17
	Sugar Creek	202	14	0.07	4

Table 9. Summer-fall juvenile Coho Salmon population estimates. Total estimates ($\widehat{N}$ all) are based on Chapman estimates of the abundance greater than 65 mm ($\widehat{N}$ >65) expanded using the proportion of fish greater than 65 mm (**Mean Prop >65**).

Cohort	Location	Start Date	End Date	$\widehat{N}$ >65	SD	Mean Prop >65	$\widehat{N}$ all	Lower CI	Upper CI
2016-2017	French Mainstem Reach	8/8	8/9	302	26	0.78	389	339	439
2016-2017	French Mainstem Reach	9/1	9/2	264	16	0.84	314	282	346
2016-2017	French Mainstem Reach	9/26	9/28	200	12	0.92	216	193	239
2016-2017	Sugar BP1	7/20	7/21	233	56	0.57	408	299	518
2016-2017	Sugar BP1	8/10	8/11	1098	357	0.71	1539	839	2240
2016-2017	Sugar BP1	8/29	8/31	542	126	0.89	610	364	857
2016-2017	Sugar BP1	9/29	9/30	374	33	0.99	378	313	443
2016-2017	Sugar BP2, OCP Channel	8/22	8/23	119	74	0.75	158	13	304
2016-2017	Sugar BP2	8/30	8/31	504	90	0.65	775	598	952
2016-2017	Sugar BP2	9/30	10/1	1375	182	0.88	1557	1200	1913
2017-2018	French Mainstem Reach	7/27	7/28	191	17	0.72	265	232	299
2017-2018	French Mainstem Reach	8/14	8/15	327	35	0.82	397	328	467
2017-2018	French Mainstem Reach	9/25	9/26	214	12	0.98	218	194	241
2017-2018	Sugar BP1	7/24	7/25	1271	274	0.68	1857	1320	2393
2017-2018	Sugar BP1	8/16	8/17	682	97	0.91	746	556	936
2017-2018	Sugar BP1	9/27	9/28	870	133	1	873	613	1133
2017-2018	Sugar BP2	7/24	7/25	88	36	0.16	544	473	614
2017-2018	Sugar BP2	8/16	8/17	95	44	0.19	490	404	576
2017-2018	Sugar BP2	9/27	9/28	241	26	0.8	302	251	353
2018-2019	French Mainstem Reach	9/25	9/26	516	36	0.68	763	693	834
2019-2020	French Mainstem Reach	10/28	10/29	541	23	0.92	587	542	633
2019-2020	Sugar BP1	10/31	11/1	1990	174	1	1993	1652	2333
2020-2021	French ELJ	10/8	10/9	455	26	0.61	750	699	801
2020-2021	French Mainstem Reach	10/7	10/9	427	9	0.77	558	539	576
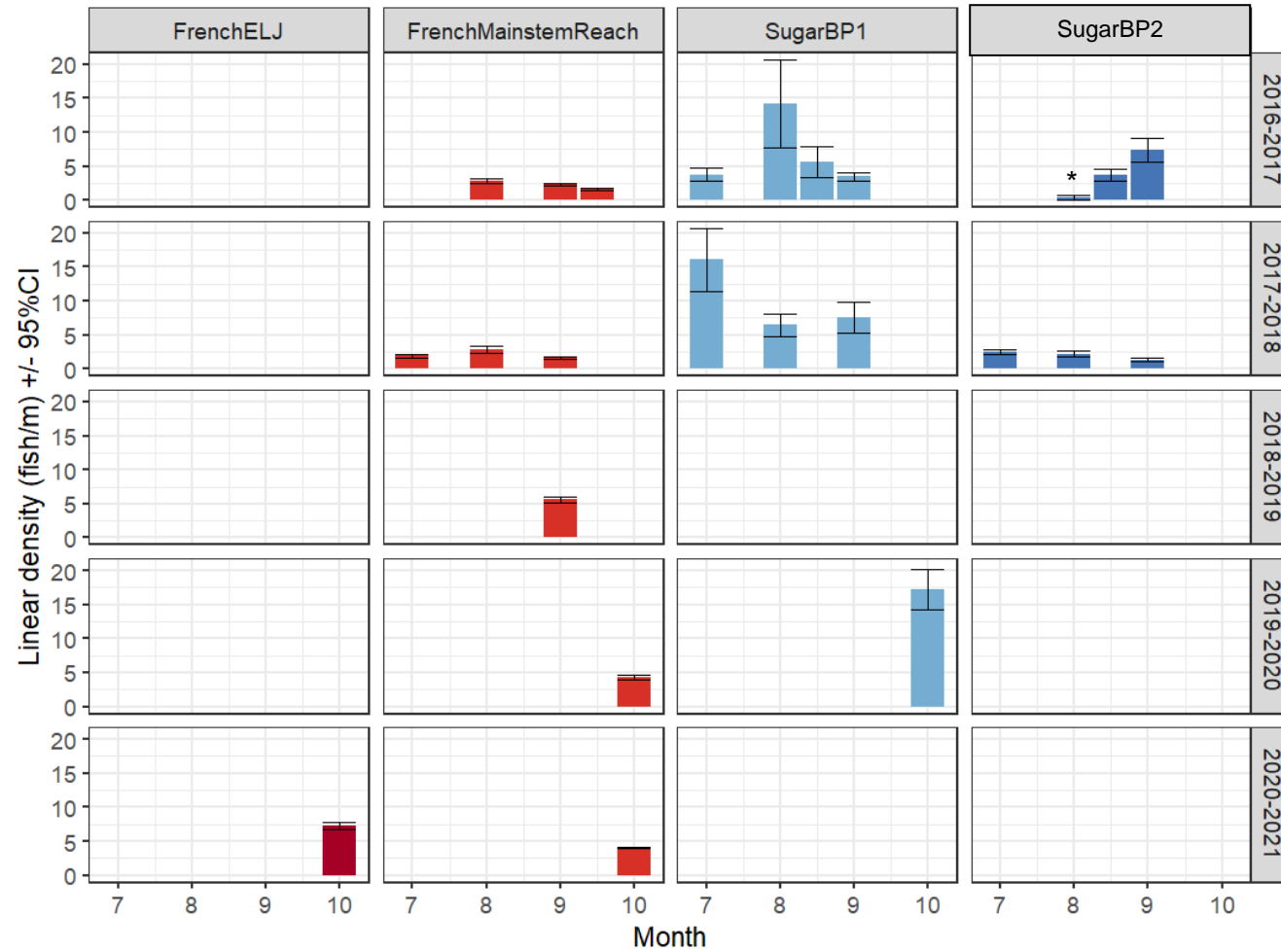
*Figure 5. Summer-fall juvenile coho average linear density estimates (fish/m). A correction was made to include individuals too small to tag (<65 mm). Not all sites were surveyed every year. *Population estimate included the Sugar off-channel pond channel.*

Table 10. Juvenile Coho Salmon captured or detected during winter mark-recapture surveys.

Cohort	Location	Date	In hand	Antenna	Min Known Alive
2017-2018	Sugar BP1	4/2/-4/4/18	78	321	399
	Sugar BP2 Complex	4/2/-4/4/18	47	89	136
2019-2020	Sugar BP1	1/8-1/9/20	467	294	761
	French FRGP SC + ELJ Reach	1/14-1/15/20	515	48	563
2020-2021	French FRGP SC + ELJ Reach	2/23-2/24/21	431	67	498
	French SC BDA Pond	2/24-2/25/21	106	6	112

Growth

Generalized Additive Mixed Model

The 2019-2020 GAM model of size through time was constructed with seven knots and a smoothing parameter = 0.08. It explained 96.8% of the deviance. The variables with the largest effect on the relationship between fork length (FL) and time in the global model were the smoothed interaction of location and cohort and a random intercept effect for individuals. The variable with the strongest categorical effect on the intercept was cohort. The varying intercept for cohort suggests overall mean FL on October 1st was higher for 2019-2020 than 2020-2021, in addition to having different overall shapes to the smooths for each location-cohort combination. The intercept for Sugar BP2 Complex, French Control, French ELJ, and French SC BDA were significantly lower than Sugar BP1. However, the French SC BDA intercept was extrapolated beyond any biological relevance because there is no data near the intercept (Oct 1st). Neither of the movement variables had a significant effect on the intercept.

Because the 2019-2021 model did not show an effect from either of the movement variables, I re-ran a model that excluded movement variables using the entire dataset from 2016-2021 (Figure 7). This model was also constructed with seven knots and a smoothing parameter=0.08. It described 96.6% of the deviance, adjusted r-squared of 0.943, n=5475. In agreement with the 2019-2021 model, the model showed support for a categorical effect of cohort on the intercepts (Table 21; Table 11). Mean FL on October 1st was significantly lower in 2018-2020 than 2016-2018, and 2020-2021 was lower than

all other cohorts (Table 11). This could reflect variation in sampling timing and fish presence each year, such as environmental conditions changing the timing of fish presence in a site, rather than due to fish being smaller for a biological reason. For example, drought conditions were most severe in 2020-2021, so three out of six sites did not have data around October 1st. Unlike the 2019-2020-only model, the only location with significant effect on the intercept was a negative effect of French SC BDA, but as stated earlier, there are no data near the intercept (Oct 1st) for French SC BDA.

Growth rates were extracted from the slopes of each smooth for each season (Figure 8). Only combinations of sites and seasons with five or more individuals were included. Due to the drying event in summer 2020, there were no summer or fall growth rates calculated in Sugar BP1. However, fish from the Scott River confluence with Sugar Creek moved into Sugar BP1 in the winter of 2021 and saw relatively high growth rates compared to other sites that season, including fish that stayed in the Scott-Sugar Confluence. There was some movement into Sugar BP2 detected on antennas in the winter and spring, but no fish were captured inhand for growth measurements. Generally, Sugar BP2 complex had higher growth rates than other sites in all seasons when fish were present and sampling occurred. French SC BDA pond also had relatively high growth rates in the spring, despite drought conditions in spring 2020 and spring 2021. The French ELJ had very similar growth rates to the French Mainstem Reach. All other restoration sites had higher growth rates when compared to French Mainstem Reach in the same year and season, except in 2019-2020, when growth rates were similar.

Table 11. Summary results from the Generalized Additive Model (GAM) describing juvenile coho fork length through time for 2016-2021. Table values indicate the significance of each level of the linear explanatory variables, cohort and location. Affects the intercept of the smooth. The intercept was set to October 1ˢᵗ, so this is the partial effect on model predicted FL on October 1ˢᵗ.

Predictor	Estimate	SE	t	P
(Intercept: Cohort2016-2017)	85.54	0.78	109.46	<0.001
Cohort2017-2018	-1.58	0.99	-1.60	0.11
Cohort2018-2019	-6.60	1.18	-5.57	<0.001
Cohort2019-2020	-7.58	0.88	-8.57	<0.001
Cohort2020-2021	-11.18	1.02	-10.94	<0.001
LocationFrench Mainstem Reach	-0.57	0.67	-0.86	0.39
LocationSugar BP1	0.90	0.58	1.54	0.12
LocationFrench FRGP SC	-0.28	0.75	-0.38	0.71
LocationFrench ELJ	-0.94	0.70	-1.34	0.18
LocationMid French SC BDA	-6.85	3.22	-2.13	0.03
LocationScott Sugar Confluence	0.13	1.85	0.07	0.94
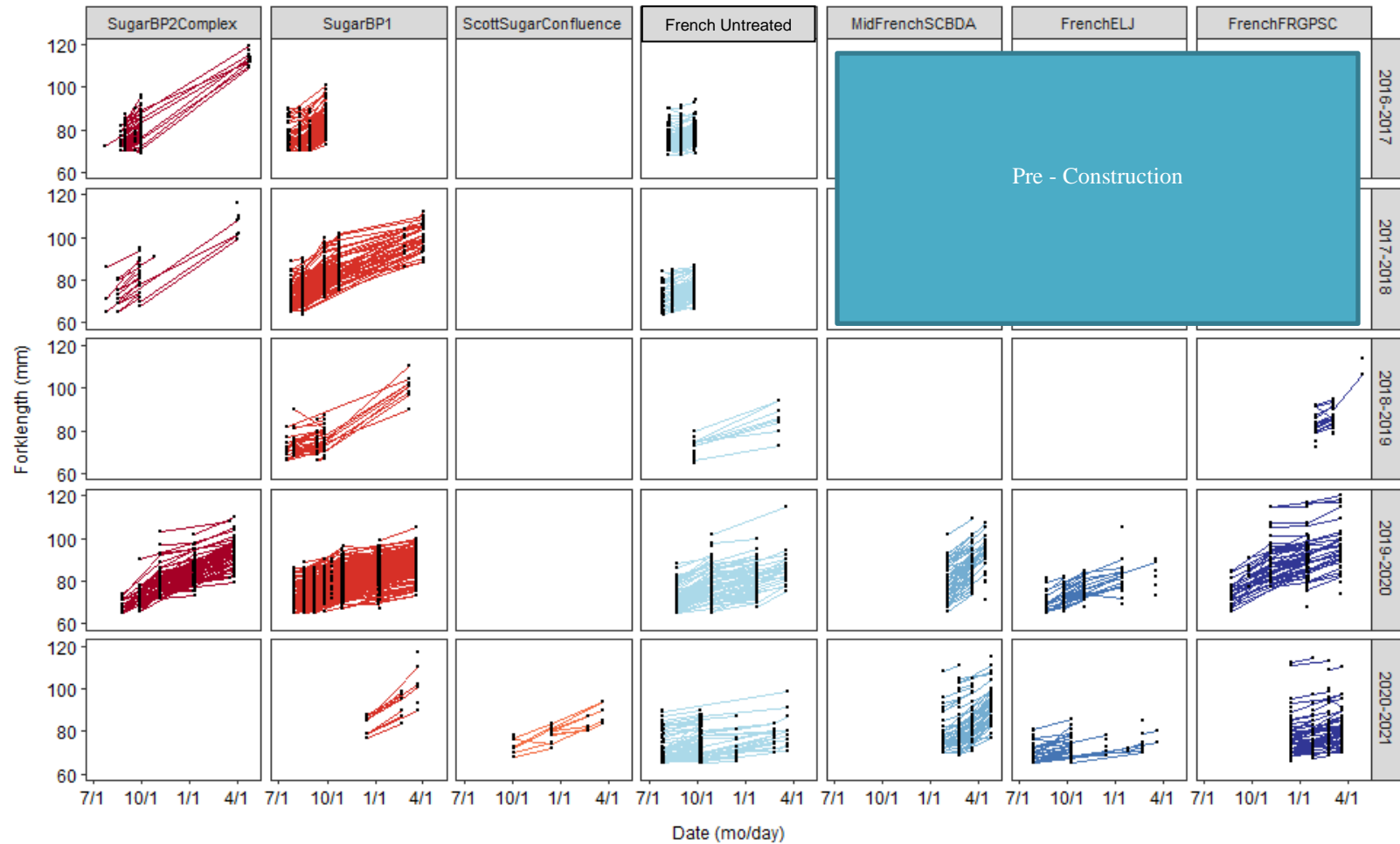
Figure 6. Fork length of fish captured at least twice by date, site, and cohort. Lines are drawn between two captures of individual fish captured in the same location at least twice, representing growth. Columns designate site and rows designate cohort. Dots that do not connect are fish that moved to a different site and were only captured once at that site.
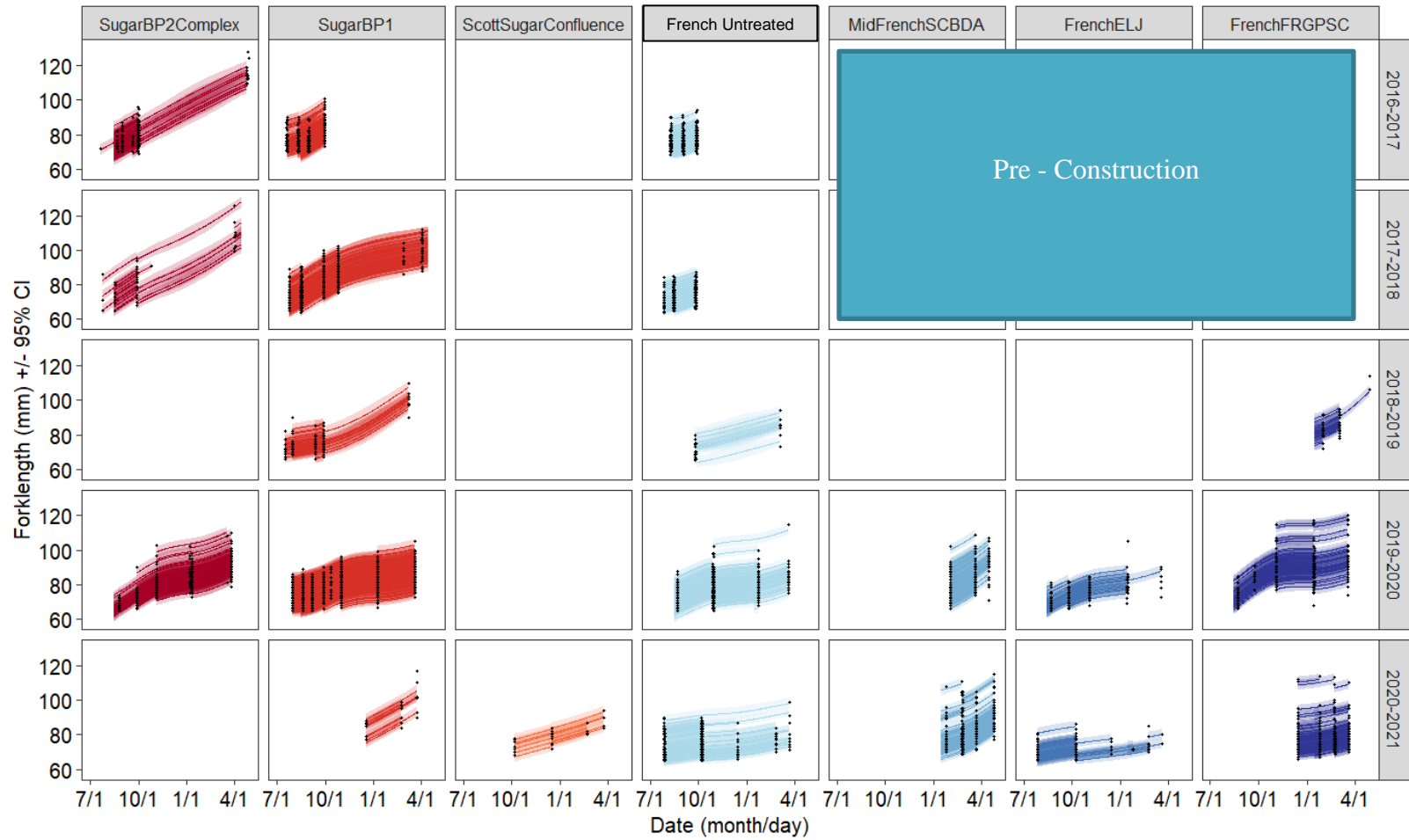
Figure 7. Predicted fork length vs time for each fish and 95% confidence limits from the best generalized additive model. Raw data points are also plotted for reference. Each column is a different location, and each row is a different cohort. Dots that do not connect are fish that moved to a different site and were only captured once at that site.
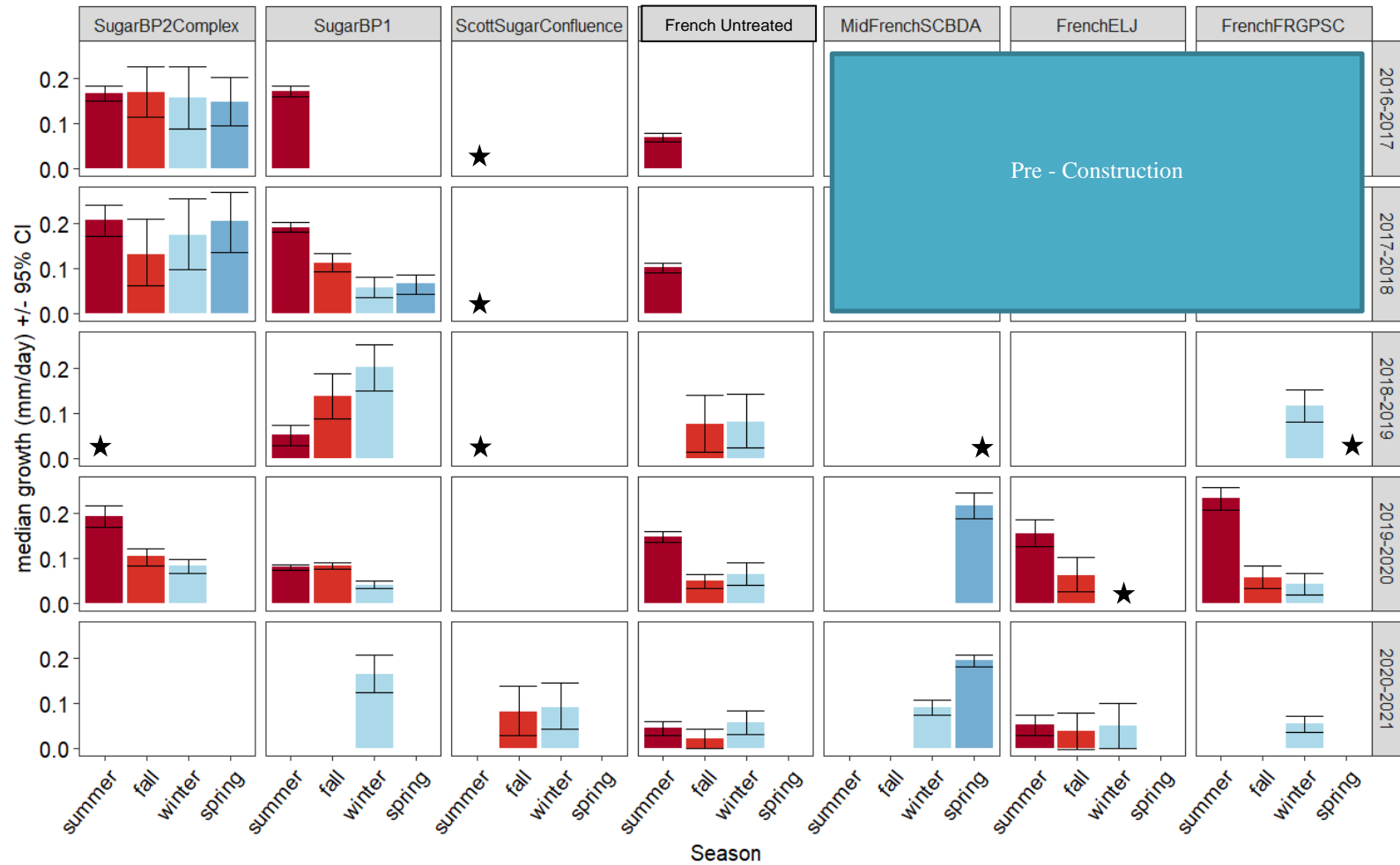
Figure 8. Bootstrapped GAM predicted growth (mm/day) and 95% confidence interval by site, cohort, and season. Season intervals were 8/15-9/15, 10/31-12/11, 1/15-2/15, 3/15-4/15. Stars indicate sampling occurred, but sample size was too small to calculate growth. Blanks indicate no sampling.

<u>Individual Growth Rates</u>

I calculated growth rates using standard methods to compare to my GAM results (Appendix A). This approach substantially reduced the sample size and required lumping of fish from different capture occasions to produce comparable time intervals. Generally, these methods for calculating average individual growth had similar results to the GAM "growth" rates extracted from the model predictions.

Survival Models and Movement

2016-2018

Overall apparent survival from late July to late September was estimated using a CJS model for each cohort from 2016-2018 in French Control, Sugar BP1, and Sugar BP2. Only Sugar BP1 was sampled three or more times in 2018-2019, but these results were excluded because model estimated confidence intervals were 0-1, likely due to the short interval between occasions 1-2 and 3- 4 (2 weeks) and low recapture rates. Weekly survival estimates were transformed to an 11-week summer season using bootstrapping and the delta method, so they were constrained between 0 and 1 and more comparable to the multistate model. In both cohorts with valid results, the best CJS model was Phi(~Location) p(~-1 + Location:time, link = "sin"); the -1 in the model statement indicates that the model uses a cell-means formulation with separate intercepts for each location instead of a reference location with deviations for other locations. Sugar BP1 had the highest survival both years and survival was very similar among years (Figure 13). Summer apparent survival estimates from these CJS models were very low compared to survival estimates from more extensive seasonal sampling conducted in 2019-2021 and analyzed with the multi state model.

2019-2020

The number of fish encountered per week at a given site varied between 0 and 800, with different seasonal patterns at each site (Figure 9; Figure 10). The overall number of fish detected each season also varied widely between sites. Not including sites

with no fish in summer and fall, total encounters by season varied between 1 and 891

(Appendix B). Streamflow varied in Sugar Creek from 1.48-40.00 CFS. Streamflow

varied in French Creek from 0.36-49.57 CFS. Maximum weekly temperature (MWT)

varied from 2.87-20.55 °C in Sugar Creek and 3.05 -19.81 °C in French Creek.

Both streams had a substantial number of fish that were last detected leaving the

site (i.e. last detection on the downstream antenna) in spring during smolt outmigration

(Sugar-419, French-718). However, 36.7% of the 1513 tagged fish in French Creek were

early outmigrants that apparently left the site in fall or winter. In contrast, in Sugar Creek,

only 0.6% of the 1978 tagged fish were early emigrants (Table 13). CDFW operated a

smolt trap in spring 2020 on the lower Scott River (river km 7) and they detected nine out

of a total of 3491 fish tagged (Massie & Morrow 2020).

Movement between tributaries was infrequent, but several Sugar Creek fish were

detected rearing in the Scott River (Table 12). Five individuals moved from Sugar Creek

to French Creek, one fish moved from French Creek to Sugar Creek. There were 42

Sugar Creek fish detected on PIT antennas rearing in a pond further downstream in the

Scott River basin in the spring. No fish from French Creek were detected in this pond, so

it is unclear where the previously mentioned early emigrants from French Creek reared or

if they survived the winter.

The general model I used to assess goodness of fit was: S(-

1+stratum:time:PassExp, link="sin") p(stratum*Season+Method)

Ψ(Season:stratum:tostratum:PassExp). This model had a median c-hat value of 1.34,

indicating slight overdispersion. I used this c-hat value to adjust the QAIC values of all

my models in RMARK and adjust the standard errors of the parameter estimates from the best model. From my candidate model set, I took the model with the most support and reran it using a range of state c detection probabilities (0.551-0.75) due to the issues with the manual calculation of the downstream Sugar Creek antenna, which is described in the methods section. Only models with detection probabilities between 0.59-0.70 had estimable survival parameters. I chose a value closer to the manual calculation, 0.60 to show in the results. As detection probability increased from 0.60 to 0.70, spring survival estimates decreased in Sugar BP1 from 0.47 to 0.29, but the rest of the survival estimates were unchanged.

I assumed fish used in the passage experiment would have different transition probabilities because they were artificially moved into state C, so the passage experiment group covariate was incorporated into all but the simplest model. The best model was S(~-1 + Season:stratum:PassExp + Season:zMWT) p(~stratum * Season + Method)(~Psi(~-1 +Season:stratum:tostratum:PassExp+ zMWT:Season) (Table 14).

Survival probability was a function of the interaction between season, stratum, and whether a fish was used in a passage experiment and the interaction between temperature and season. MWT had a negative effect on survival for summer (beta = -1.80, SE= 0.34), fall (beta = -1.70, SE= 0.47) and spring (beta = -2.39, SE = 0.29) (Figure 16). In winter, MWT had a slightly positive effect, but confidence intervals overlapped with 0 (beta = 0.84, SE= 0.49). After accounting for participation in the passage experiment, summer survival was higher in the French FRGP SC than the Sugar BDA sites (Figure 14). Summer survival in the French Mainstem Reach was estimated with

confidence limits from 0 to 1. This estimate was likely inestimable because French

Mainstem Reach did not have an antenna to contribute data to weekly survival estimates,

and only had one in-hand sampling occasion in the summer. Fall and winter survival

were lowest in the French mainstem reach and similar among the other sites. Spring

survival was inestimable in Sugar BP2 Complex and had relatively wide 95% confidence

intervals but appeared lowest in French SC BDA pond and highest in the French

Mainstem Reach.

Transition probability was a function of:

1) the interaction between the season, the two states, and whether a fish was used

   in a passage experiment,

2) The interaction between weekly temperature and season (Figure 28; Figure

   29).

MWT had a positive relationship with movement in the winter (beta= 3.30, SE= 0.23)

and spring (beta=2.21, SE=0.10) and an insignificant effect in the summer and fall

(Figure 24). After accounting for the passage experiment, the only significant movement

in Sugar Creek in the summer was from BP1 (state B) to BP2 (state A), which had an

overall probability of 14% of moving at some point across the summer (Figure 20). Low

rates of movement continued between these two states in the fall, slightly increasing in

the winter. In the spring, movement was primarily to the downstream BDA antenna (state

c), but there was some movement from B to A and A to B. In French creek, there was

very little movement in the summer, but some fall movement between the French

untreated mainstem reach to the French FRGP SC + ELJ reach (Figure 21). In the winter

there was a low overall probability of moving out of the French untreated mainstem reach

into the SC BDA (4%) and the FRGP SC + ELJ reach (31%). There was also a relatively

high probability of leaving states D, E, and F to migrate downstream (23-61%). In the

spring, movement was primarily to the downstream mainstem antennas, but some

probability of moving into the SC BDA and the FRGP SC + ELJ reach.

<u>2020-2021</u>

In 2020-2021, the number of fish encountered per week at a given site varied

between 1 and 510, with different seasonal patterns at each site (Figure 11; Figure 12).

Not including sites with no fish in summer and fall, total seasonal count varied between 3

and 838 (Appendix B). Streamflow varied in Sugar Creek from 0.87-30.89 CFS.

However, Sugar BP1 which is located downstream of the stream gauge, went completely

dry during weeks 5-10. French Creek SC BDA Pond also went dry at the temp logger

location from weeks 2-5, but this was prior to fish movement into the pond. Streamflow

varied in French Creek from 0.80-46.30 CFS. Maximum weekly temperature (MWT)

varied by 2.64 - 23.02 °C in Sugar Creek habitats that stayed wetted and 2.84-20.33 °C in

French Creek habitats that stayed wetted.

The 433 fish that were last detected leaving French Creek (i.e., last detection on

the downstream antenna) in spring during smolt outmigration was slightly lower than

2019-2020. Only 31 fish were detected outmigrating from Sugar Creek in the Spring, due

to the low population after the drying event. Early outmigration was lower in 2020-2021

than in 2019-2020. 24.6% of the 1709 tagged fish in French Creek were early

outmigrants that left in the fall or winter (Table 13). However, more fish left in the fall in

2020-2021 (11.9%) than in 2019-2020 (1.6%). The few fish detected as possible 'early emigrants' in Sugar Creek were more likely fish moving into Sugar Creek from the Scott River that were not detected again. Of 64 French Creek fish detected at the Scott River (river km 28.9) antenna site, 18 were early emigrants out of French Creek. CDFW operated a smolt trap in spring 2021 on the lower Scott River (river km 7) and they detected three out of a total of 1490 fish tagged (Morrow et al., 2021).

Movement between tributaries was infrequent (Table 12). One individual moved from Sugar Creek to French Creek, one fish moved from French Creek to Sugar Creek, and one moved from Scott River to French Creek. However, 29 Scott River fish moved into lower Sugar Creek once it rewetted in the fall. Of these, four were detected on PIT antennas rearing in off-channel habitats further downstream on the Scott River in the spring. An additional four fish originally tagged in Sugar Creek eventually reared in off-channel Scott River habitats. No fish from French Creek were detected rearing in off-channel Scott River habitats, so it is unknown where previously mentioned early emigrants reared.

Due to the drying event in Sugar Creek, I ran separate multistate models for French and Sugar creeks in 2020-2021. The Sugar Creek model only included winter and spring, after fish moved back into the sites.

The general model I used to assess goodness of fit in French Creek was: S(-1+time:stratum, link="sin") p(-1+stratum:time, link="sin") Ψ(Season:stratum:tostratum). This model had a median c-hat value of 1.37, indicating slight overdispersion. I used this c-hat value to adjust the QAIC values of all my models in RMARK and adjust the

standard errors of the parameter estimates from the best model. The general model I used to assess goodness of fit in Sugar Creek was: S(-1+Season:stratum, link="sin") p stratum*Season+Method) Ψ(Season:stratum:tostratum) and had a median c-hat of 1.23.

In French Creek, the best model was: S(-1+Season:stratum+Season:zMWT) p(-1+ stratum:Season +Method) Ψ(Season:stratum:tostratum +zflow: Season +zMWT:Season). Survival was a function of the interaction of season and stratum and the interaction of season and maximum weekly max temperature (MWT) (Figure 19). MWT had negative relationship with survival in the fall (beta=-2.02, SE= 0.44), winter (beta=-7.60, SE= 1.71), and spring (beta=-1.16, SE=0.37) (Figure 18). In the summer, MWT had a negative effect, but standard error was relatively large and confidence limits overlapped with 0 (beta=-1.21, SE=2.56). No fish were present in French SC BDA in the summer or fall. The FRGP SC + ELJ reach had slightly lower overall summer and fall survival than the French mainstem reach (Figure 15**Error! Reference source not found.**). In the winter, FRGP SC + ELJ Reach had relatively lower survival, while the SC BDA and the mainstem reach had similar survival. Very few fish were observed in the French mainstem reach in the spring, so I could not estimate survival.

Transition probability was a function of:

1) the interaction between the season and the two states,

2) the interaction between MWT and season,

3) the interaction between weekly streamflow and season.

MWT had a positive effect on movement in the fall (beta=2.13, SE=0.30) and spring (beta=0.94, SE=0.35) (Figure 26). The effect of MWT on movement was insignificant in

the winter. In the summer there was a strong positive effect (beta=8.89, SE=5.86), but the SE was large and confidence limits overlapped with 0. Streamflow had a positive relationship with movement in all seasons, but this was more pronounced in summer (beta=171.82, SE=18.70) and fall (beta=2.08, SE= 0.17) than in winter (beta=0.25, SE=0.09) and spring (beta=0.63, SE=0.16) (Figure 27). There was very little movement in the summer, except from the French ELJ Reach to the French Mainstem reach at the beginning of summer (Figure 23). Normally the ELJ reach and French FRGP SC were lumped as one site, but due to extreme drought conditions and poor water quality, few fish were present in the side channel. Movement between the French ELJ Reach + FRGP SC to the French Mainstem reach continued in the fall and winter. There was also some fall movement out of both sites to the downstream antennas, indicating fall early outmigrants. In the winter there was increased movement out of the mainstem French Creek reach (State D) to the downstream antennas (State G). In the spring, movement from all sites was primarily to the downstream antennas, with some probability of moving between the other three sites.

In Sugar Creek, low sample size due to the drying event affected the performance of the models. To help with parameter convergence, I used a reduced detection probability (p) model: p~Season+Method. Most survival parameters did not converge in the top model based on QAICc (Table 16). I reran the top model with initial values from a simpler model, which helped survival estimates converge and I used that model for inference. Survival was a function of the interaction of season and stratum and the interaction of season and MWT. MWT had a positive effect on survival in the winter

(beta=10.12, SE=15.63) and a negative effect in the spring (beta=-4165.04, se=104.89)

(Figure 17). Transition probability was a function of the interaction between the season

and the two states and the interaction between MWT and season. MWT had a positive

effect on movement in the winter (beta= 19.01, se=9.16) and in the spring (beta= 8.81,

SE=1.64) (Figure 22).
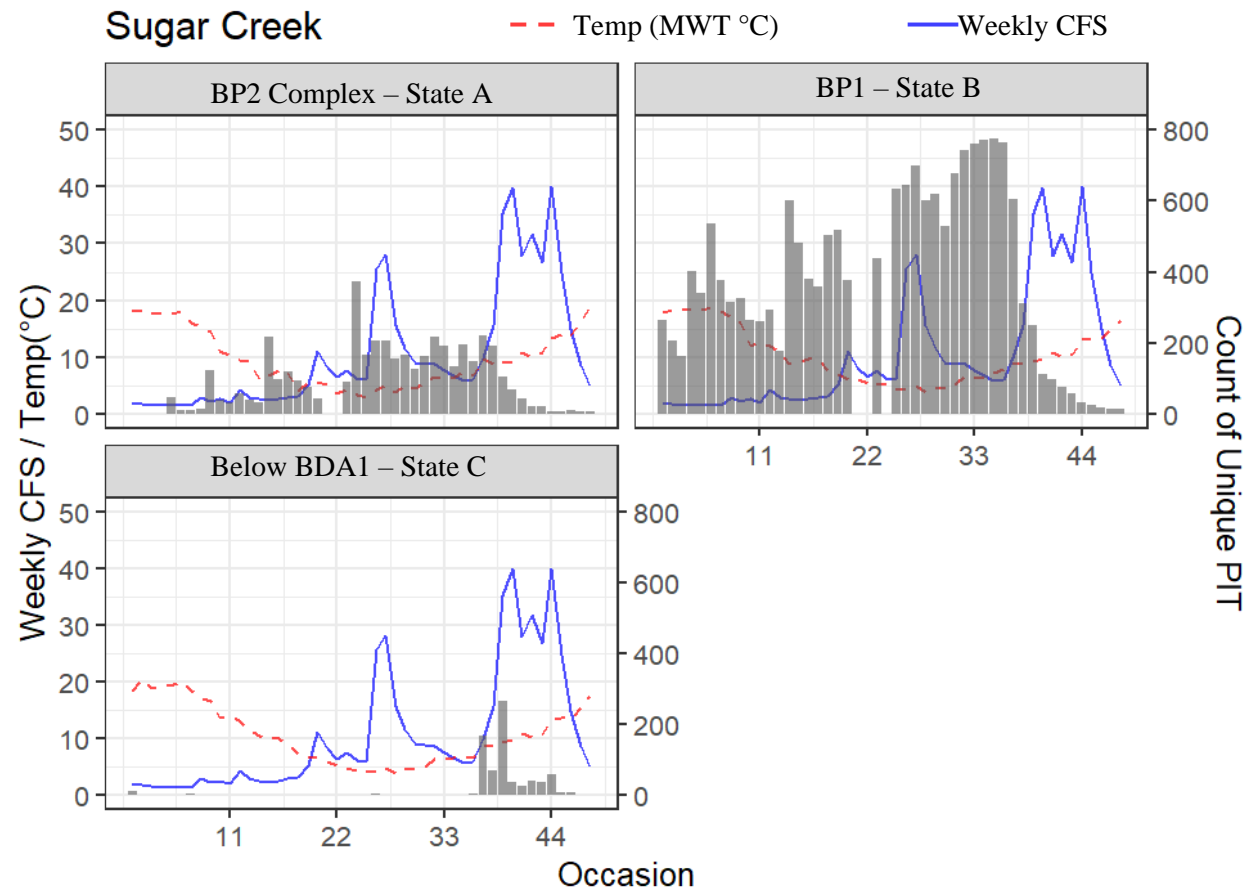
Figure 9. 2019-2020 unique weekly detections (vertical bars) and Sugar Creek average weekly streamflow and maximum weekly temperature (°C) in each location. Detections include both antenna and in-hand captures. Occasions (weeks) were constrained into four seasons in the multistate model: 1-11 (summer), 12-22 (fall), 23-33 (winter), 34-44 (spring).
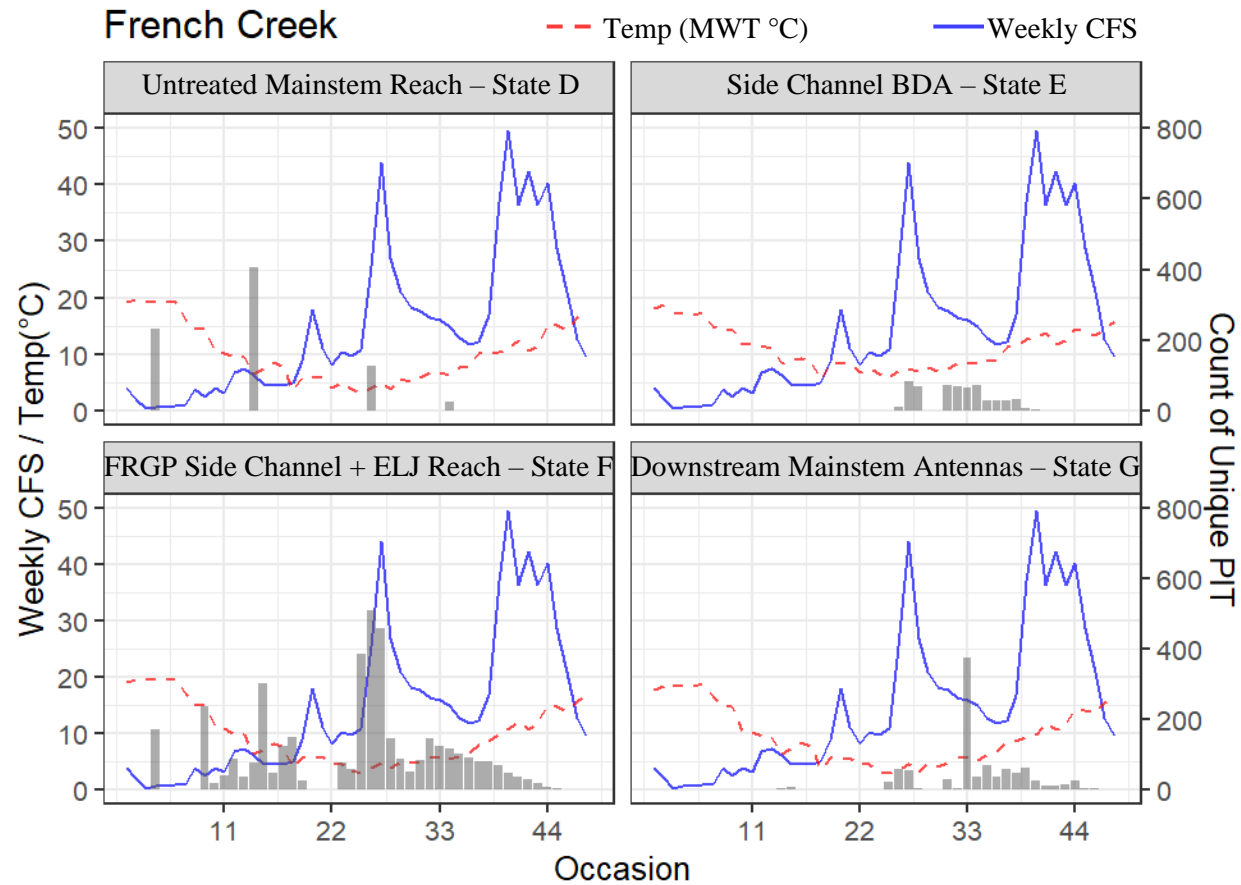
Figure 10. *2019-2020 unique weekly detections (vertical bars) and French Creek average weekly streamflow and maximum weekly temp (°C) for each location. Detections include both antenna and in-hand captures. Occasions (weeks) were constrained into four seasons in the multistate model: 1-11 (summer), 12-22 (fall), 23-33 (winter), 34-44 (spring).*
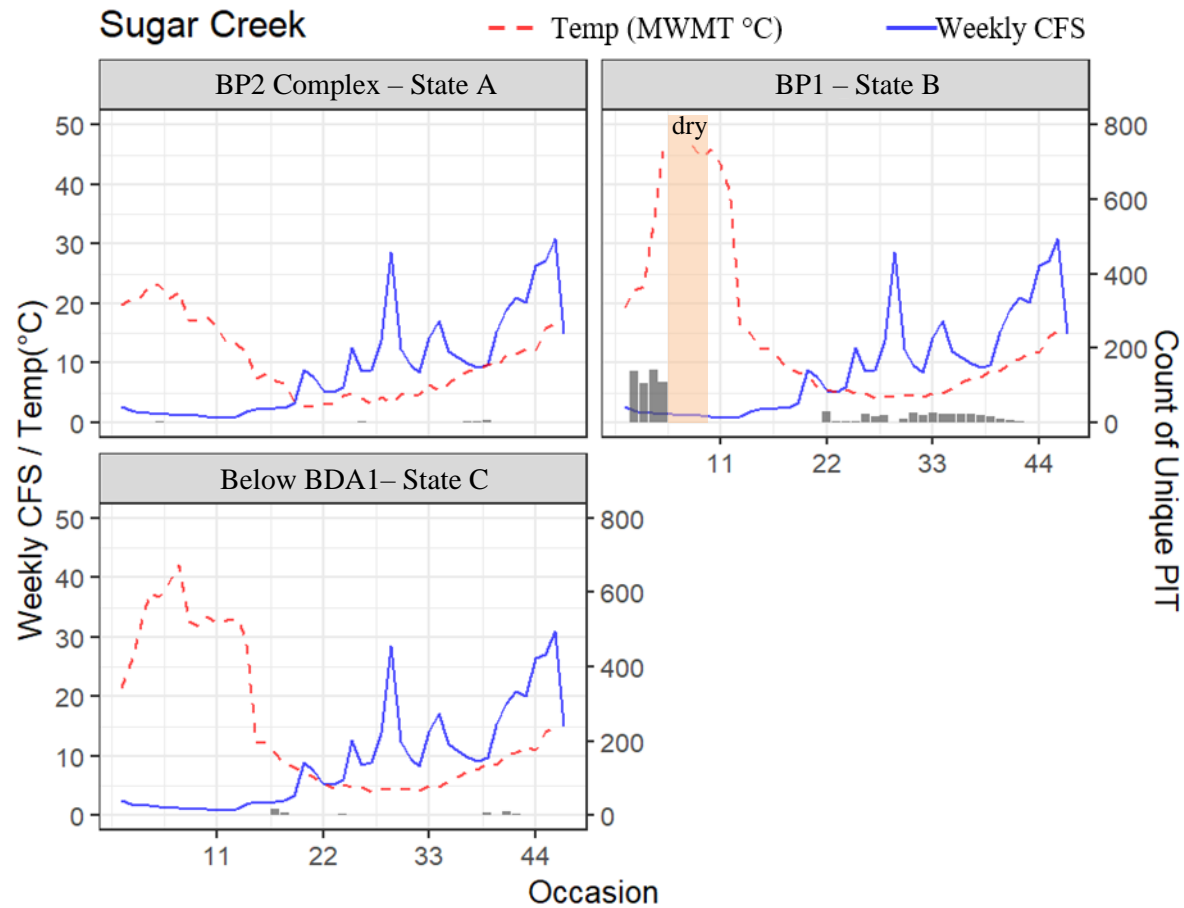
Figure 11. 2020-2021 unique weekly detections (vertical bars) and Sugar Creek average weekly streamflow and maximum weekly temp (°C) in each location. Detections include both antenna and in-hand captures. Occasions (weeks) were constrained into four seasons in the multistate model: 1-11 (summer), 12-22 (fall), 23-33 (winter), 34-44 (spring).
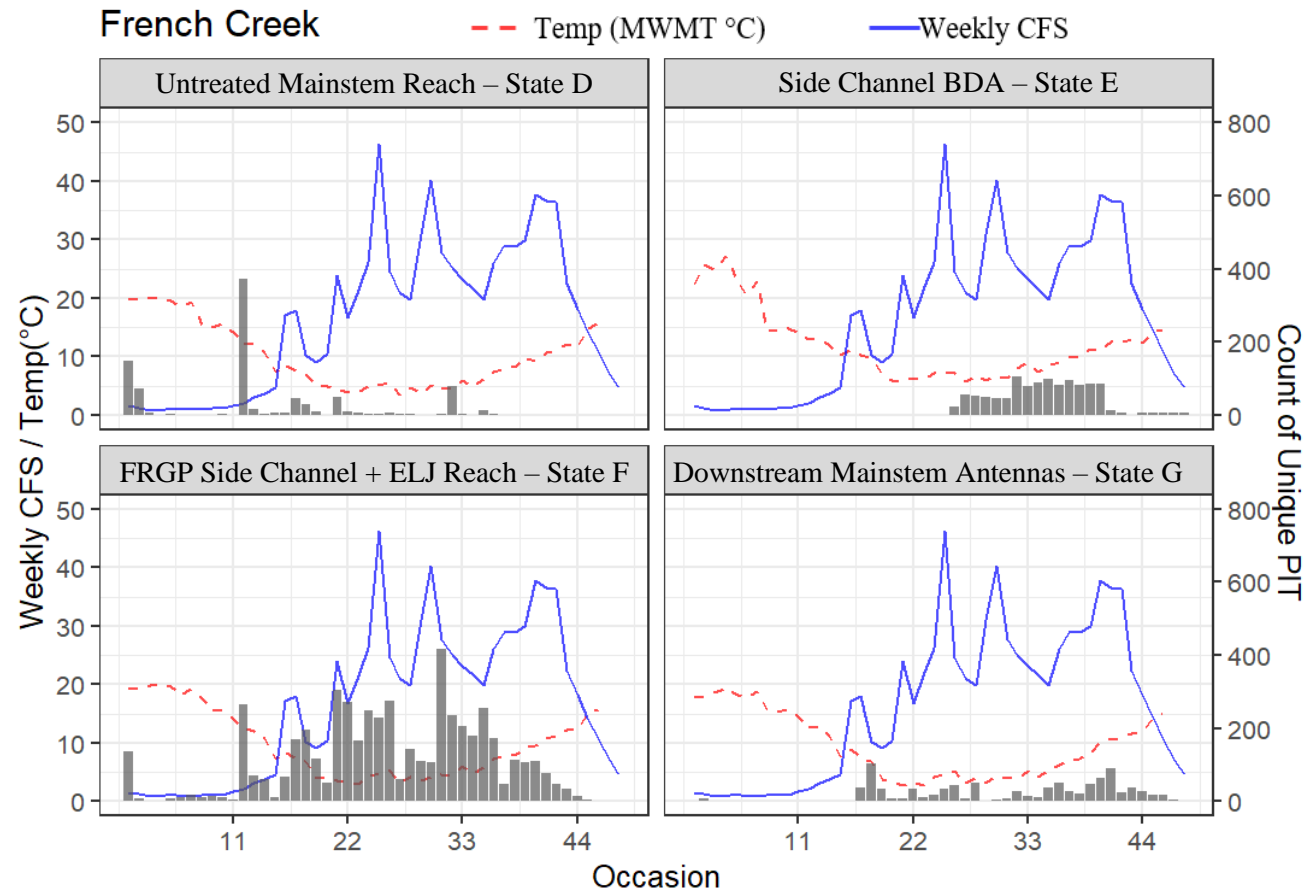
Figure 12. 2020-2021 unique weekly detections (vertical bars) and French Creek average weekly streamflow and maximum weekly temp (°C) in each location. Detections include both antenna and in-hand captures. Occasions (weeks) were constrained into four seasons in the multistate model: 1-11 (summer), 12-22 (fall), 23-33 (winter), 34-44 (spring).

Table 12. *Spatial scale of site usage. The Number tagged by site is included for reference, but stayer and mover columns are organized by the site of first detection. Stayers were only detected at the site they were first detected or only detected at the site they were first detected and emigrating in the spring, 'movers within tributary' were detected rearing in another site in the same tributary they were first detected, 'movers between tributaries' were detected moving between French and Sugar, and 'movers in the Scott River' were fish detected moving into the Scott River prior to June 1st. Fish may be counted as more than one type of mover. Fish detected after June 1st were considered emigrating smolts and were included in the 'Stayer' category.*

Cohort	State Tagged	Location Tagged	Number Tagged	Stayer	Mover (within tributary)	Mover (between tributaries)	Mover (Scott River)
2019-2020	A	Sugar BP2 Complex	561	449	96	2	14
	B	Sugar BP1	1325	1261	34	3	28
	C	Sugar Below BDA1	12	4	8	0	0
	D	French Untreated Mainstem Reach	626	475	153	0	0
	E	French SC BDA Pond	71	70	2	0	0
	F	French FRGP SC + ELJ Reach	804	796	8	1	0
2020-2021	A	Sugar BP2 Complex	0	0	0	0	0
	B	Sugar BP1	37	188	10	1	4
	C	Sugar Below BDA1	0	0	0	0	0
	NA	Scott Sugar Confluence	136	90	16[a]	30[b]	NA
	D	French Untreated Mainstem Reach	649	339	230	1	18
	E	French SC BDA Pond	101	93	7	0	1
	F	French FRGP SC + ELJ Reach	842	792	56	0	20

a: moved from Scott Sugar Confluence into downstream Scott sites prior to June 1st.
b: moved from Scott Sugar Confluence to Sugar Creek (29) or French Creek (1)

Table 13. Timing of final detection by stream. Includes the number of fish with a final detection each season and the cumulative number of tagged fish. No additional fish were tagged in the spring.

Cohort	Tributary	Season	State	Location	# of Final Detections	Cumulative # tagged
2019-2020	French	summer	G	mainstem DS antenna	3	622
		fall	G	mainstem DS antenna	24	1134
		winter	G	mainstem DS antenna	532	1513
		spring	G	mainstem DS antenna	408	
		summer1+	G	mainstem DS antenna	12	
	Sugar	summer	C	below BDA 1 antenna	10	928
		fall	C	below BDA 1 antenna	1	1379
		winter	C	below BDA 1 antenna	11	1976
		spring	C	below BDA 1 antenna	707	
		summer1+	C	below BDA 1 antenna	20	
2020-2021	French	summer	G	mainstem DS antenna	7	1013
		fall	G	mainstem DS antenna	204	1257
		winter	G	mainstem DS antenna	199	1709
		spring	G	mainstem DS antenna	395	
		summer1+	G	mainstem DS antenna	35	
	Sugar	summer	C	below BDA 1 antenna	0	165
		fall	C	below BDA 1 antenna	3	192
		winter	C	below BDA 1 antenna	5	202
		spring	C	below BDA 1 antenna	30	

Table 14. Candidate model set for survival, movement, and detection probabilities for 2019-2020 multistate model. All models used p(~stratum * Season + Method). C-hat adjusted to 1.34.

Model	npar	QAICc	Delta QAICc	weight	QDeviance
S(~-1 + Season:stratum:PassExpB + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum:PassExpB + ZMWT:Season)	78	57303.17	0.00	1.00	37411.81
S(~-1 + Season:stratum:PassExpB) Psi(~-1 + Season:stratum:tostratum:PassExpB + Zflow:Season + ZMWT:Season)	78	57338.72	35.55	0.00	37447.37
S(~-1 + Season:stratum:PassExpB) Psi(~-1 + Season:stratum:tostratum:PassExpB + ZMWT:Season)	74	57376.55	73.38	0.00	37493.24
S(~-1 + Season:stratum:PassExpB + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum:PassExpB + Zflow:Season + ZMWT:Season)	82	57377.72	74.55	0.00	37478.32
S(~-1 + Season:stratum:PassExpB + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum:PassExpB + Zflow:Season)	78	57473.15	169.99	0.00	37581.80
S(~-1 + Season:stratum:PassExpB) Psi(~-1 + Season:stratum:tostratum:PassExpB + Zflow:Season)	74	57574.53	271.36	0.00	37691.22
S(~-1 + Season:stratum:PassExpB + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum:PassExpB)	74	57838.44	535.27	0.00	37955.13
S(~-1 + Season:stratum:PassExpB) Psi(~-1 + Season:stratum:tostratum:PassExpB)	70	57965.78	662.61	0.00	38090.51
S(~-1 + Season:stratum) Psi(~-1 + Season:stratum:tostratum:PassExpB)	66	58002.97	699.80	0.00	38135.74

Model	npar	QAICc	Delta QAICc	weight	QDeviance
S(~Season) Psi(~-1 + Season:stratum:tostratum)	47	58228.01	924.84	0.00	38398.93
S(~-1 + Season:stratum:PassExpB) Psi(~-1 + Season:Zflow + Season:ZMWT)	51	59423.86	2120.69	0.00	39586.76

*Table 15. Candidate model set for survival, movement, and detection probabilities for French Creek 2020-2021 multistate model. All models used p(~stratum * Season + Method). C-hat adjusted to 1.37.*

Model	npar	QAICc	DeltaQAICc	weight	QDeviance
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum + Zflow:Season + ZMWT:Season)	52	36875.17	0.00	1.00	28668.19
S(~-1 + Season:stratum) Psi(~-1 +Season:stratum:tostratum + Zflow:Season + ZMWT:Season)	48	36904.79	29.62	0.00	28705.93
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum + Zflow:Season)	48	36939.79	64.61	0.00	28740.92
S(~-1 + Season:stratum) Psi(~-1 + Season:stratum:tostratum + Zflow:Season)	44	36967.73	92.56	0.00	28776.97
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum + ZMWT:Season)	48	37050.16	174.99	0.00	28851.30
S(~-1 + Season:stratum) Psi(~-1 + Season:stratum:tostratum + ZMWT:Season)	44	37081.00	205.83	0.00	28890.24
S(~-1 + Season:stratum) Psi(~-1 + Season:stratum:tostratum)	40	37130.50	255.32	0.00	28947.83
S(~Season) Psi(~-1 + Season:stratum:tostratum)	34	37198.76	323.59	0.00	29028.23
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum)	44	37253.41	378.24	0.00	29062.65
S(~-1 + Season:stratum) Psi(~-1 + Season:Zflow + Season:ZMWT)	30	37816.76	941.59	0.00	29654.30

Table 16. Candidate model set for survival, movement, and detection probabilities for Sugar Creek 2020-2021 multistate model. All models used p(~Season + Method). C-hat adjusted to 1.23.

Model	npar	QAICc	DeltaQAICc	weight	QDeviance
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum + ZMWT:Season)	22	2070.49	0.00	0.86	1814.04
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum + Zflow:Season + ZMWT:Season)	25	2074.32	3.83	0.13	1811.00
S(~-1 + Season:stratum) Psi(~-1 + Season:stratum:tostratum + ZMWT:Season)	19	2079.94	9.45	0.01	1830.24
S(~-1 + Season:stratum) Psi(~-1 + Season:Zflow + Season:ZMWT)	16	2083.10	12.60	0.00	1840.02
S(~-1 + Season:stratum) Psi(~-1 +Season:stratum:tostratum + Zflow:Season + ZMWT:Season)	22	2083.91	13.42	0.00	1827.46
S(~-1 + Season:stratum) Psi(~-1 + ZMWT:Season)	13	2085.50	15.00	0.00	1848.94
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum + Zflow:Season)	22	2104.27	33.77	0.00	1847.81
S(~-1 + Season:stratum + Season:ZMWT) Psi(~-1 + Season:stratum:tostratum)	19	2105.74	35.25	0.00	1856.04
S(~-1 + Season:stratum) Psi(~-1 + Season:stratum:tostratum + Zflow:Season)	19	2114.05	43.55	0.00	1864.34
S(~-1 + Season:stratum) Psi(~-1 + Season:stratum:tostratum)	16	2115.06	44.57	0.00	1871.99
S(~-1 + Season) Psi(~-1 + Season:stratum:tostratum)	13	2134.93	64.43	0.00	1898.37

Model	npar	QAICc	DeltaQAICc	weight	QDeviance
S(~-1 + Season:stratum) Psi(~-1 + Season:Zflow)	13	2449.50	379.01	0.00	2212.95
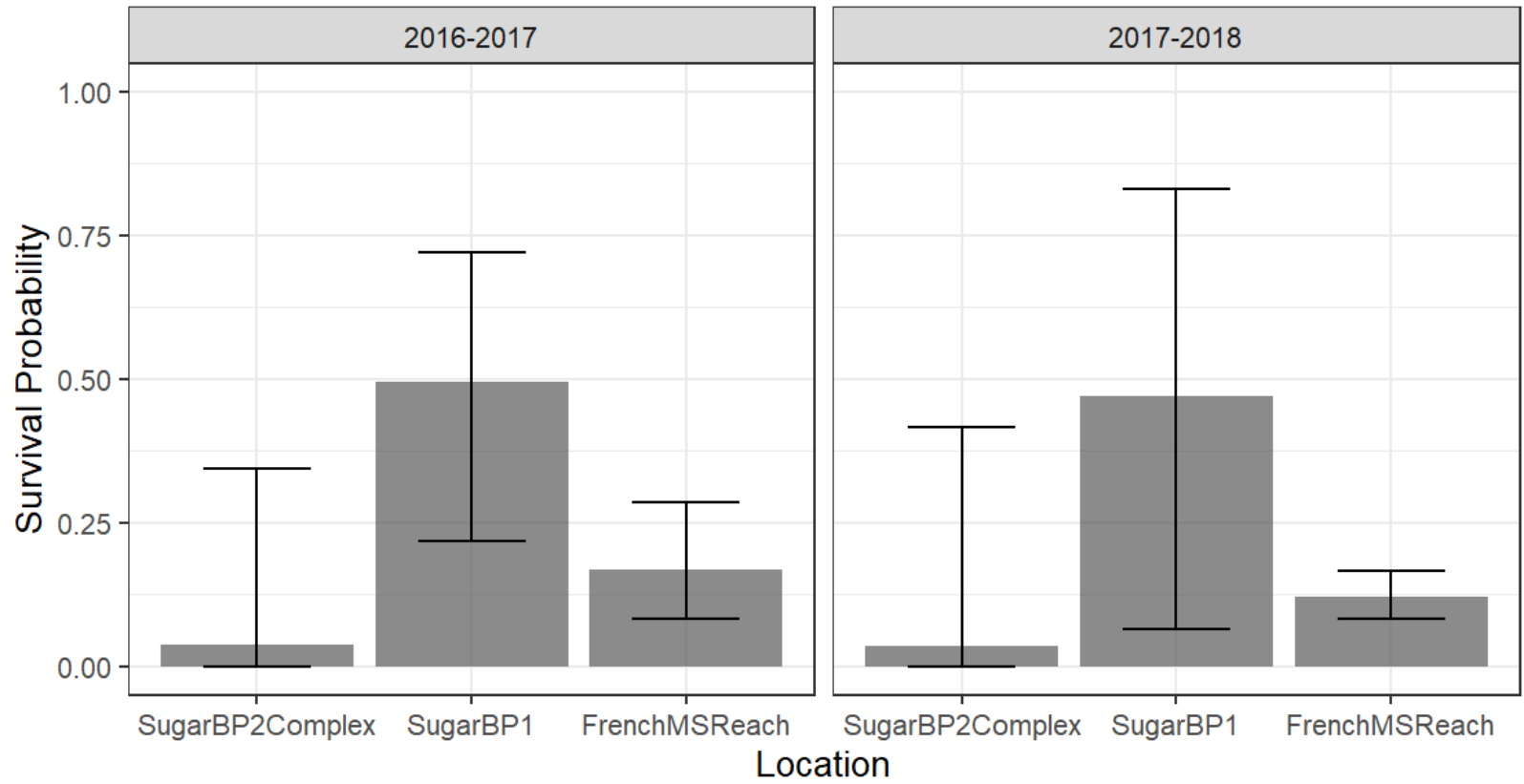
Figure 13. Overall apparent summer survival and bootstrapped 95% CI standardized to 11-weeks by site for the 2016-2017 and the 2017-2018 cohorts. Estimates derived from CJS models and SE calculated using the delta method and bootstrapping.
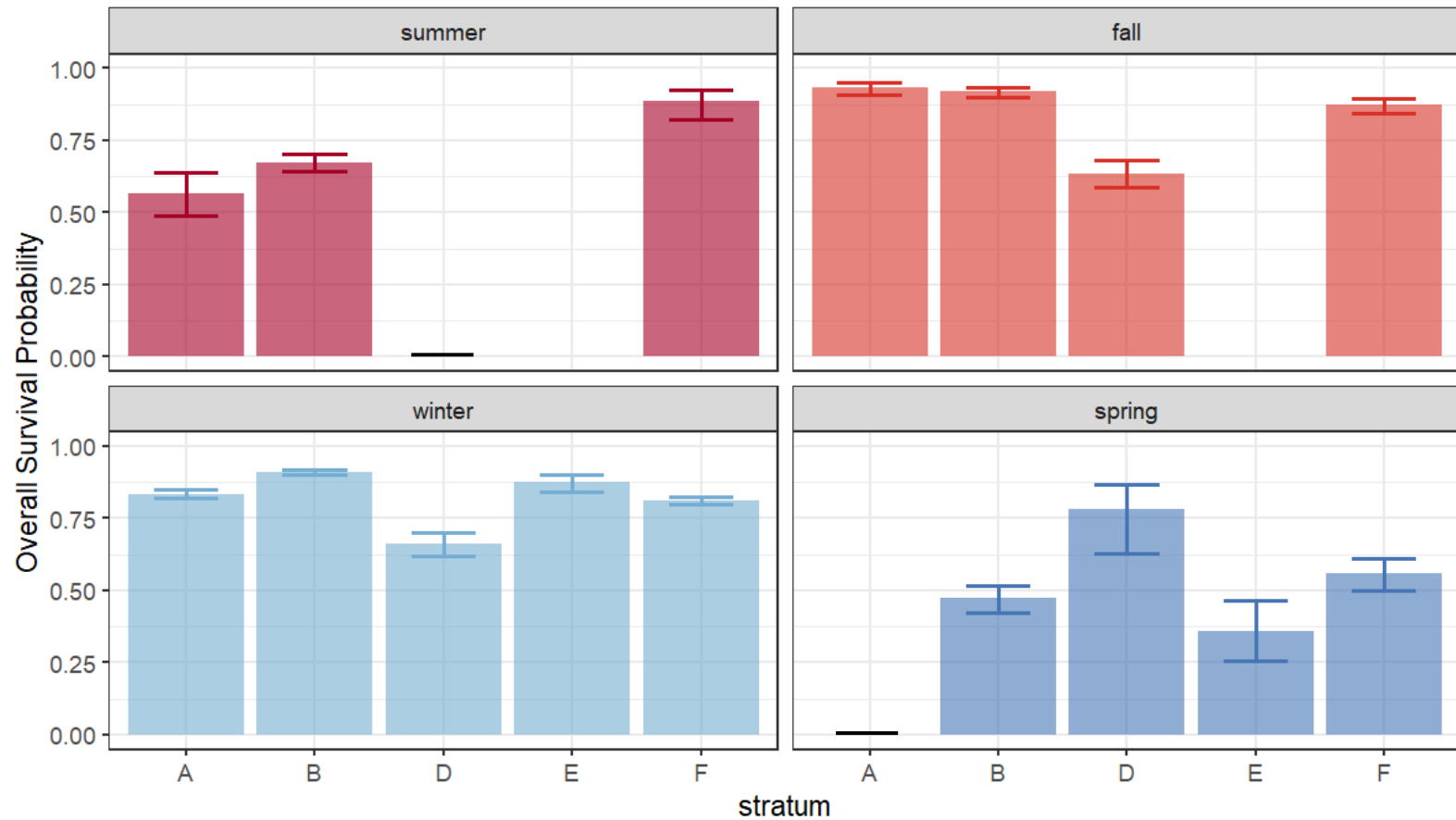
Figure 14. 2019-2020 median overall seasonal survival probability and 95% quantiles for 2000 bootstrap iterations: (A) Sugar BP2 Complex, (B) Sugar BP1, (D) French Untreated Mainstem Reach, (E) Side channel BDA, (F) FRGP Side Channel + ELJs. Figure shows model that used estimated detection probability (p) = 0.60 for state C. Blank columns indicate no fish in site during season. Single line at 0 indicates there were fish at the site, but the survival estimate did not converge.
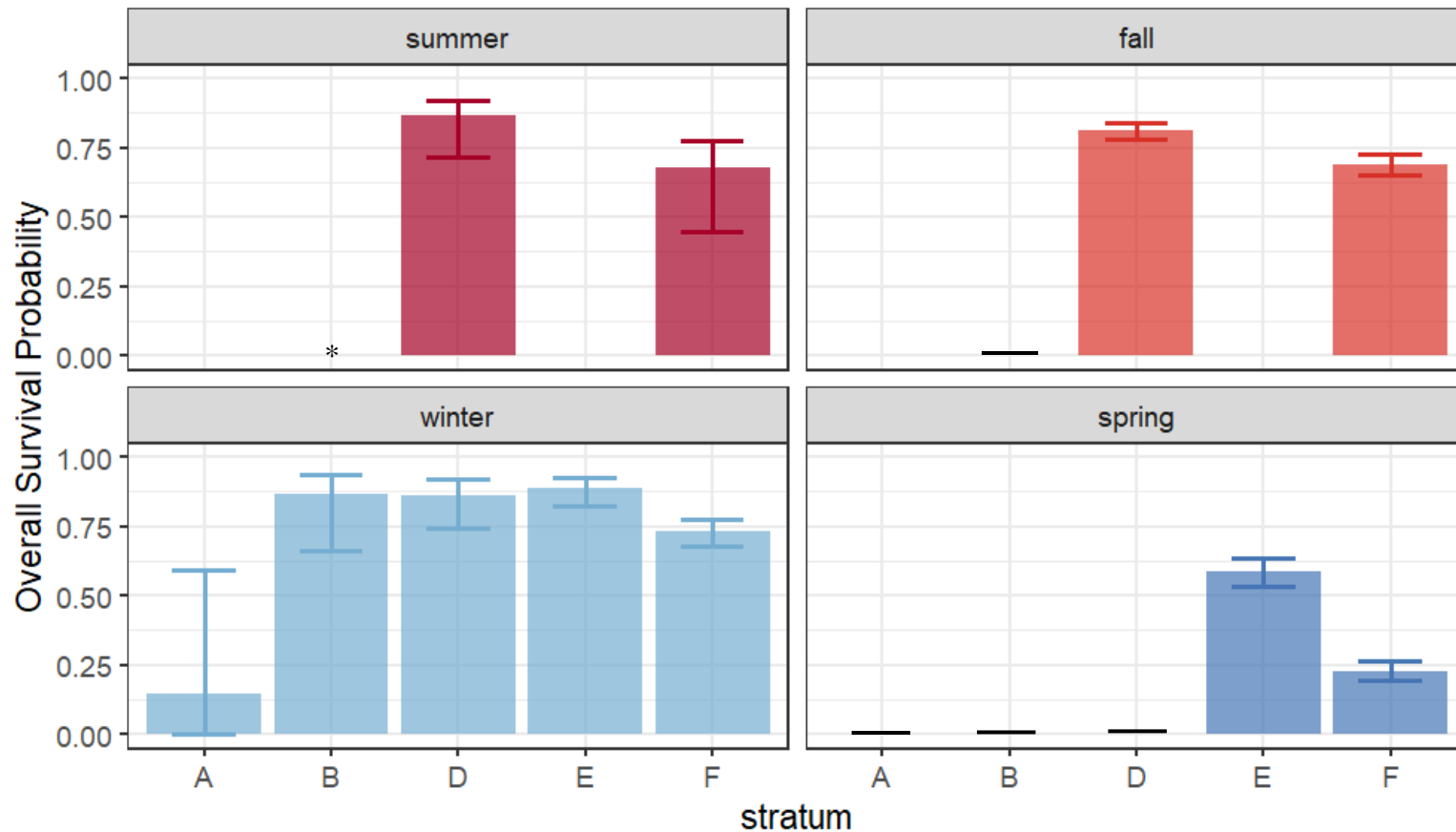
Figure 15. 2020-2021 median overall seasonal survival probability and 95% quantiles for 2000 bootstrap iterations: (A) Sugar BDA Pond 2 Complex, (B) Sugar BDA Pond 1, (D) French Untreated Mainstem Reach, (E) Side channel BDA Pond, (F) FRGP Side Channel + ELJs. Confidence intervals calculated using bootstrapping and delta method. Blank columns indicate no fish in site during season. Single line at 0 indicates there were fish at the site, but the survival estimate did not converge. Only ELJs were surveyed in state F in summer and fall due to poor water quality in FRGP SC. *Assumed no fish survived summer drying event in (B) Sugar BP1.
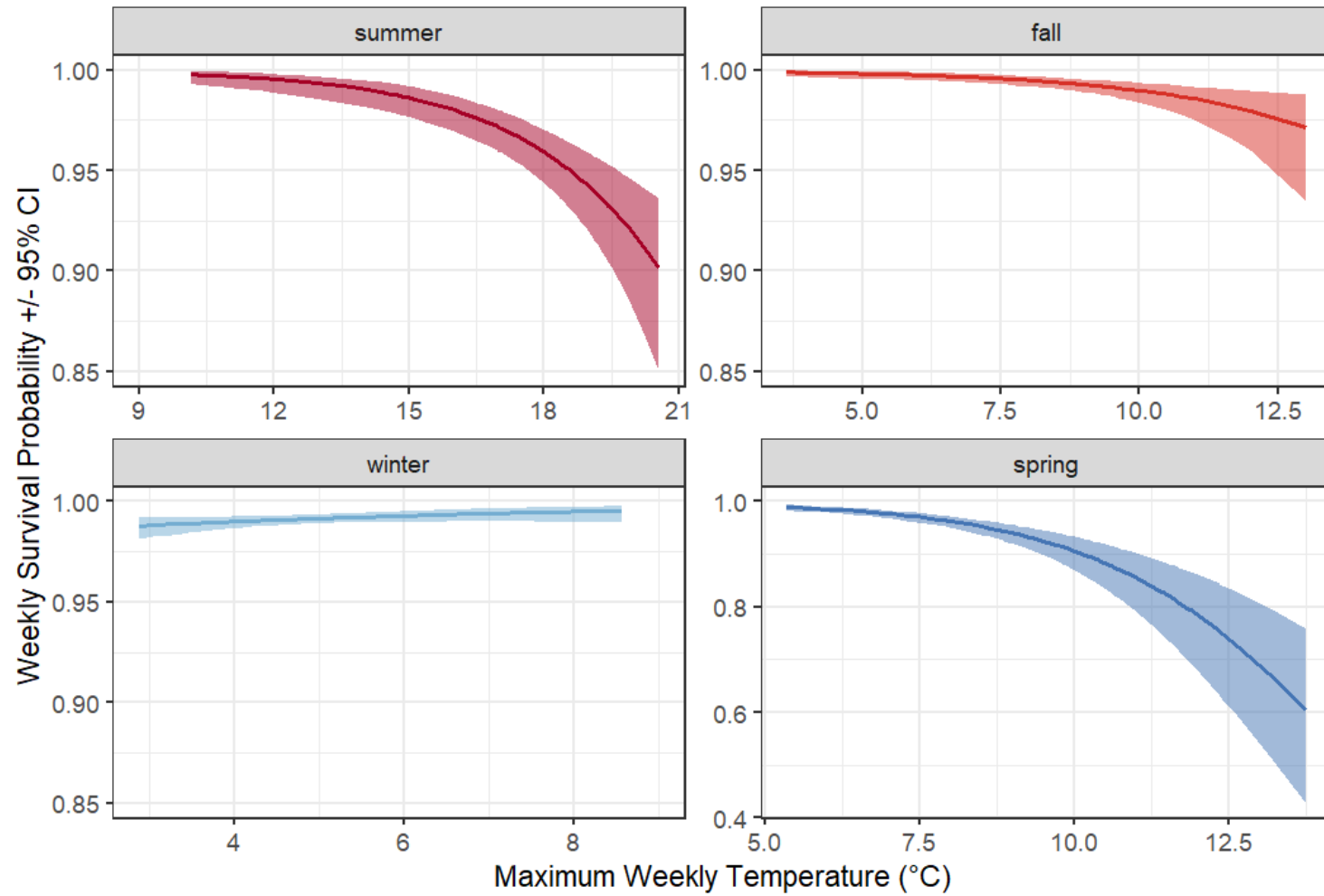
Figure 16. 2019-2020 predicted relationship between weekly survival and maximum weekly temperature by season.
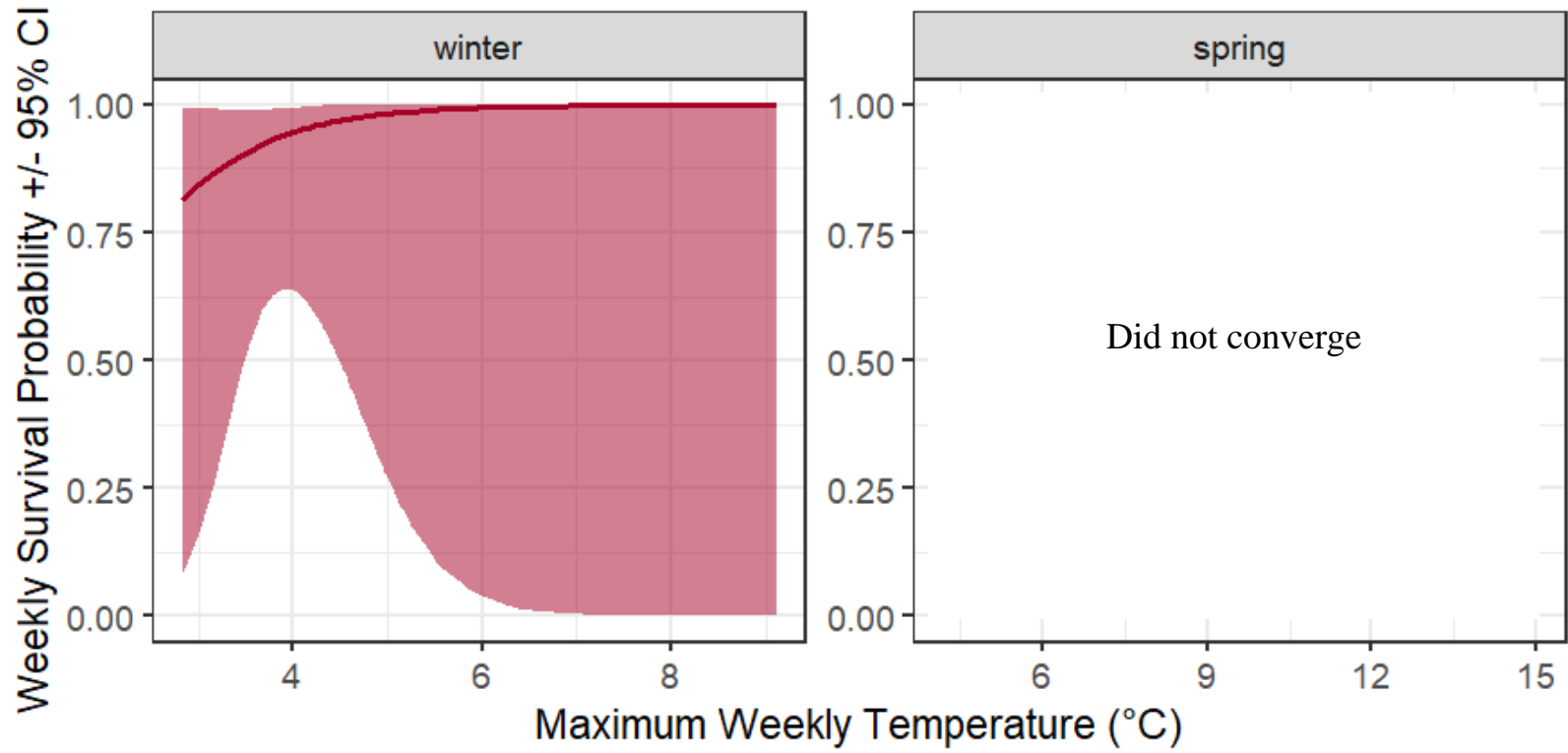
Figure 17. 2020-2021 Sugar Creek model predicted relationship between weekly survival and maximum weekly temperature by season.
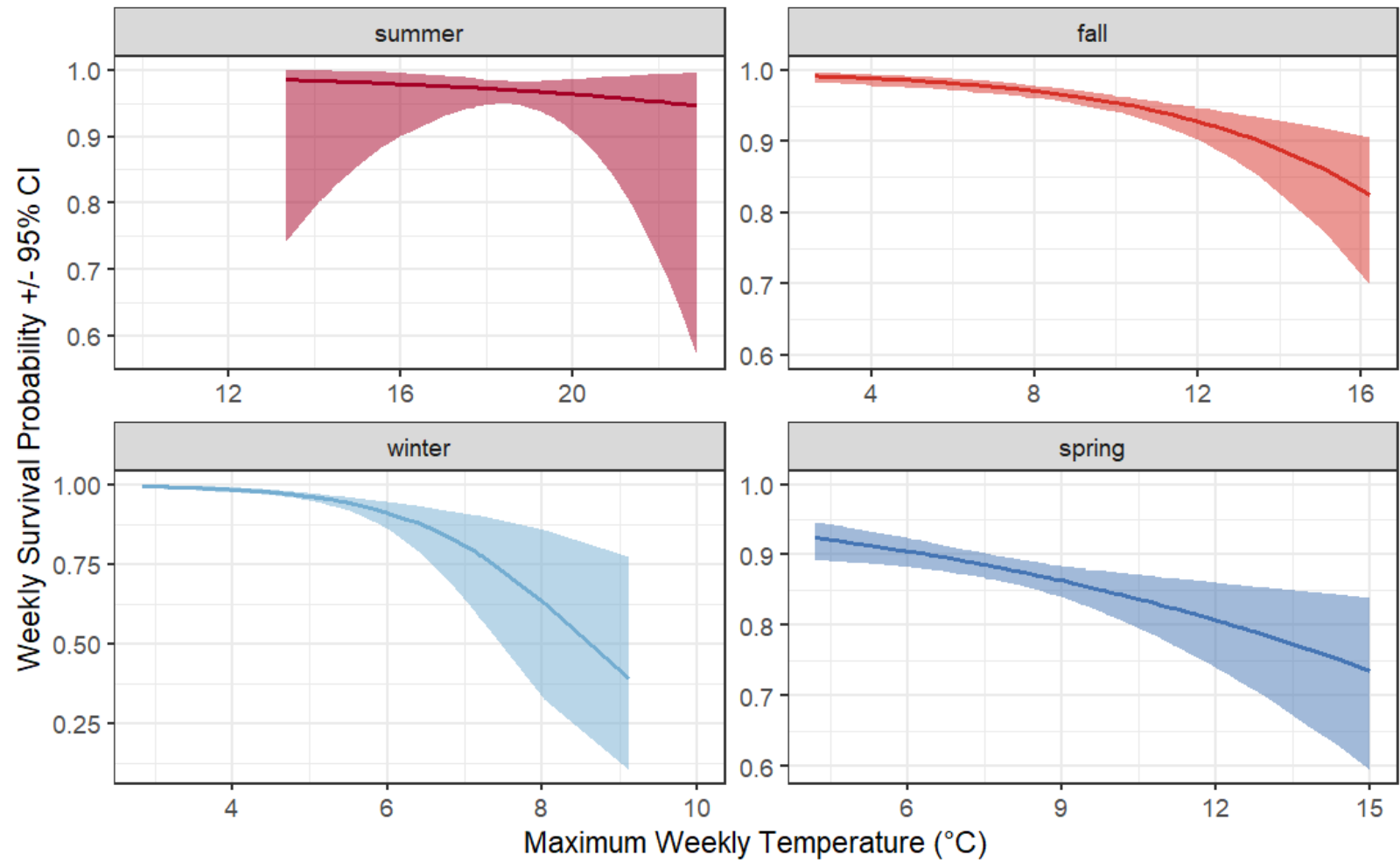
Figure 18. 2020-2021 French Creek model predicted relationship between weekly survival and maximum weekly temperature by season.
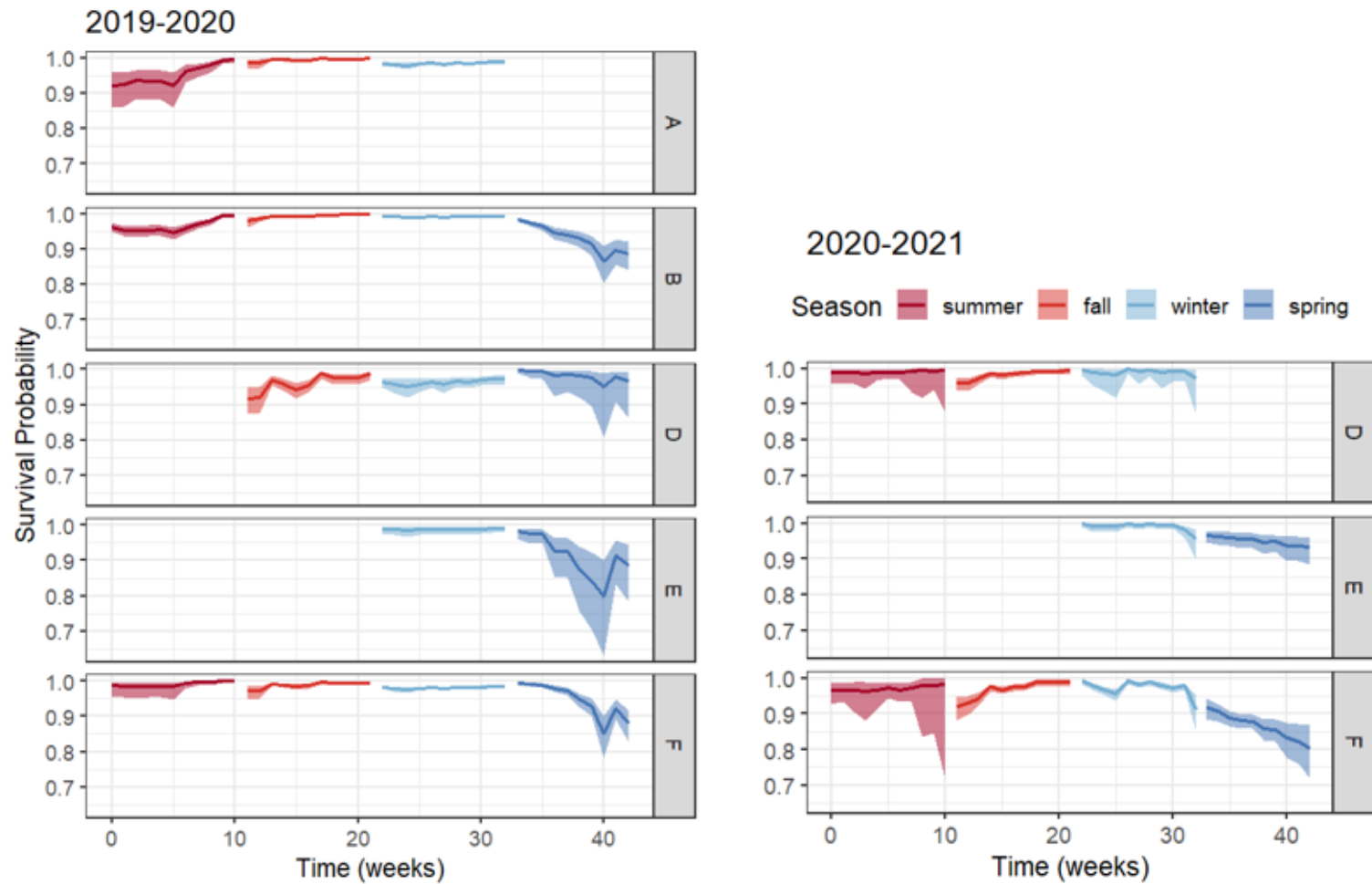
Figure 19. Weekly Survival (S) of juvenile Coho Salmon by state and season in 2019-2020 (left) and 2020-2021 (right). Summer, fall, winter, and spring spanned weeks: 1-11, 12-22, 23-33, and 34-44, respectively.
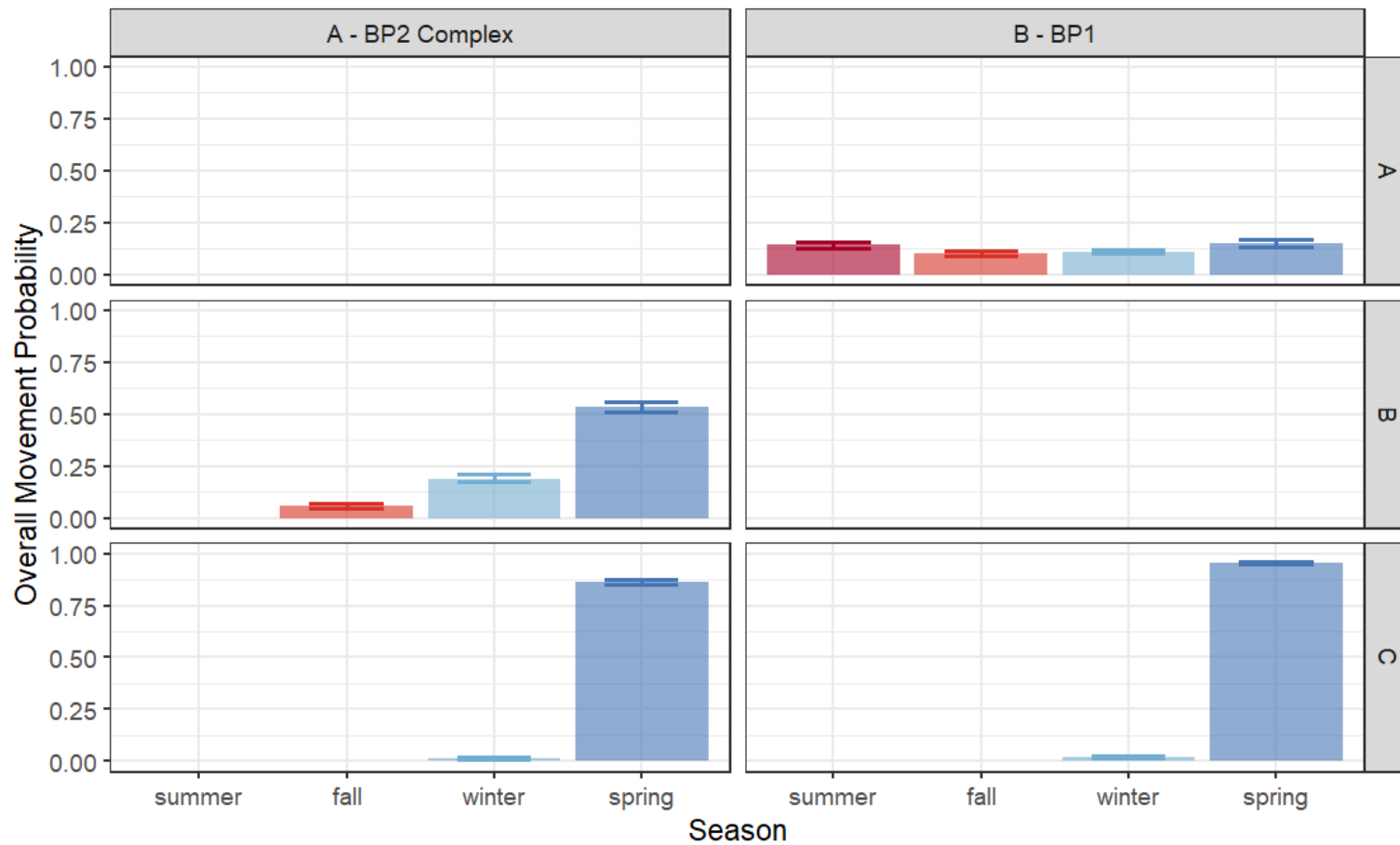
Figure 20. Sugar Creek 2019-2020 median overall movement probability (Ψ) and 95% quantiles for 2000 bootstrap iterations from one state (column) to another state (row): (A) Sugar BP2, (B) Sugar BP1, (C) Sugar below BDA1 aka outmigration. Figure shows model that used estimated detection probability (p) = 0.60 for state C. Blanks columns indicate the transition was fixed to 0.
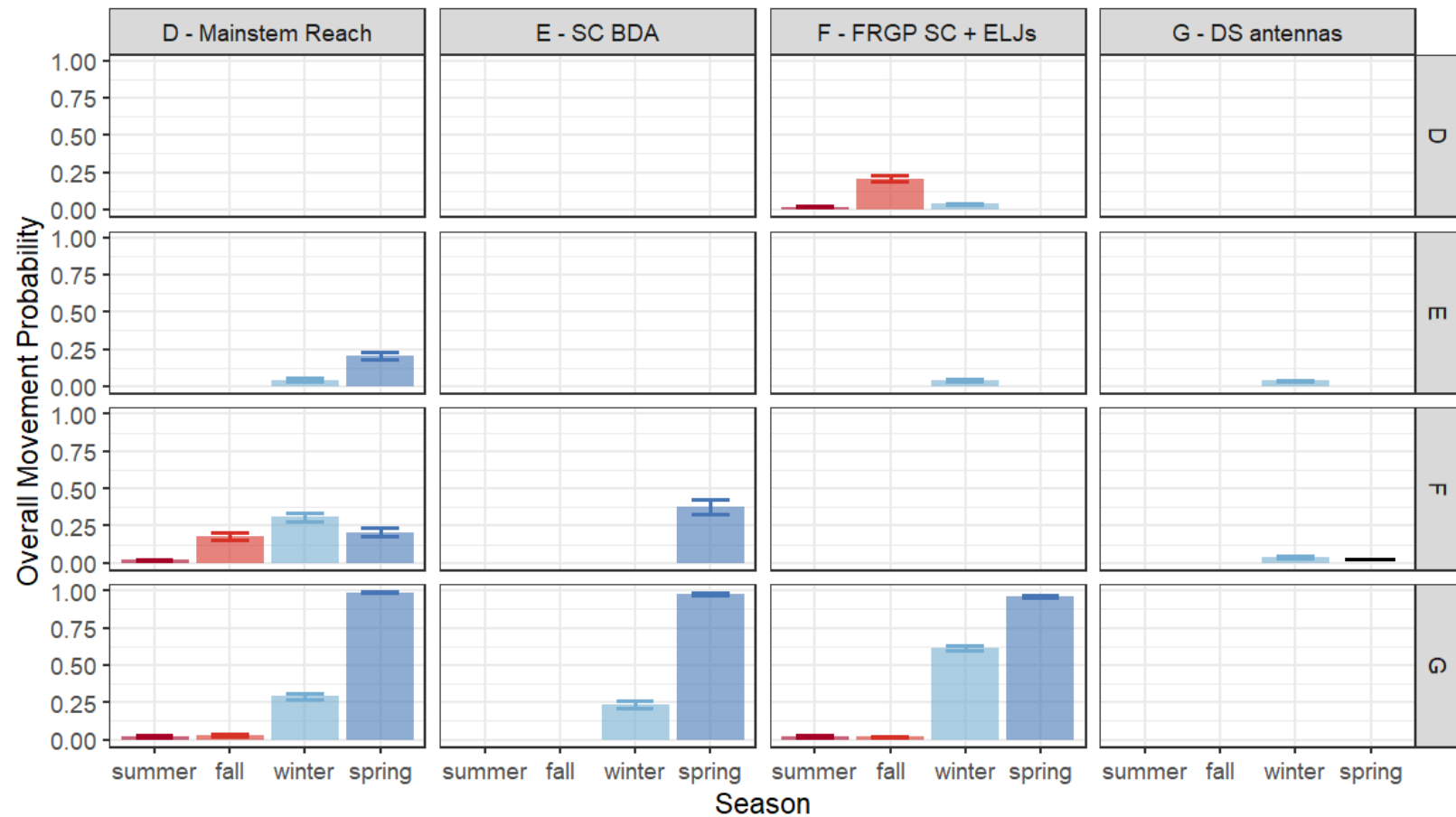
Figure 21. French Creek 2019-2020 median overall movement probability (Ψ) and 95% quantiles for 2000 bootstrap iterations from one state (column) to another state (row): (D) French Untreated Mainstem Reach, (E) Side channel BDA, (F) FRGP Side Channel + ELJs, (G) downstream mainstem antennas aka outmigration state in the spring. Blanks columns indicate the transition was fixed to 0. Single line at 0 indicates transition occurred, but estimate did not converge.
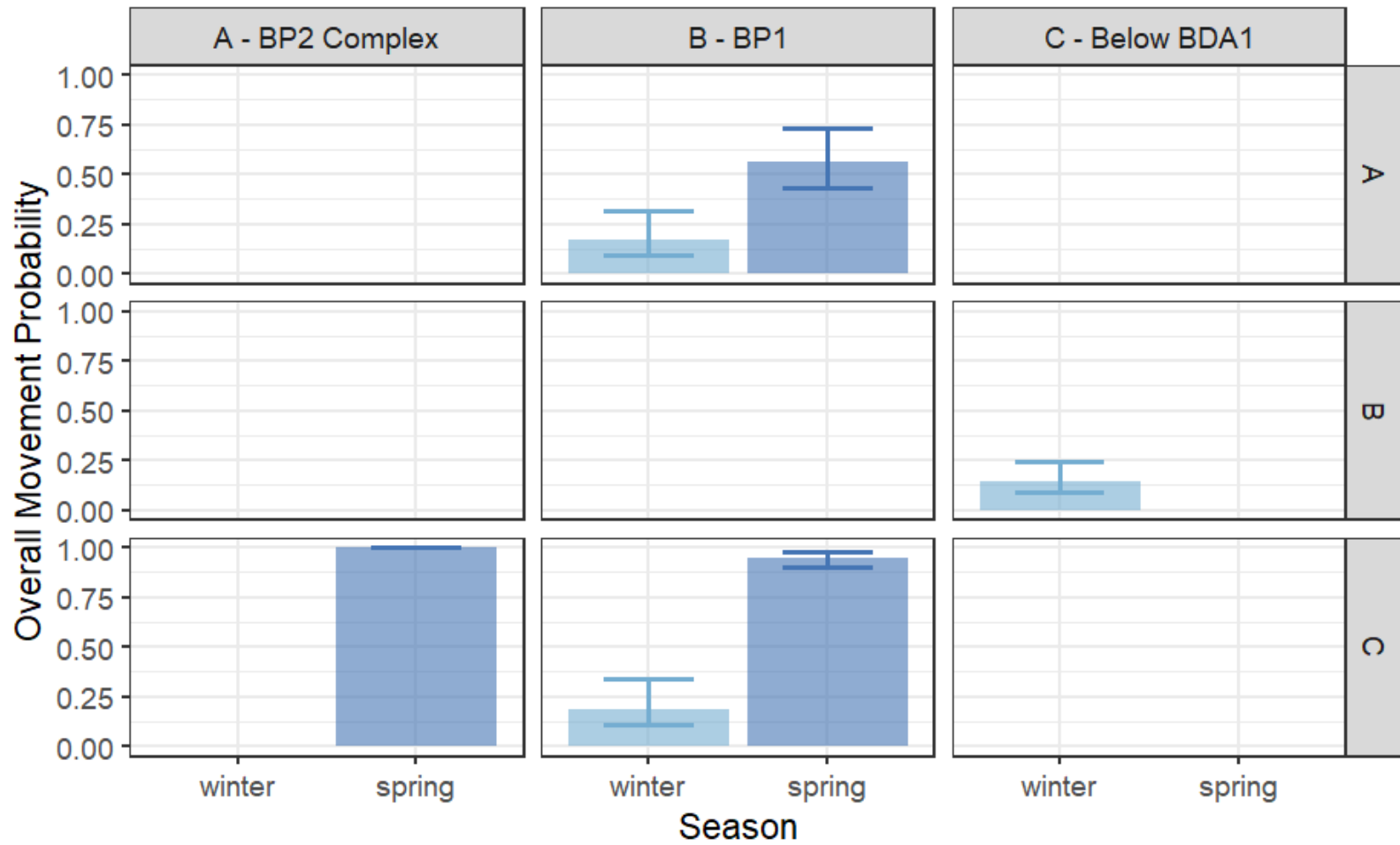
Figure 22. Sugar Creek 2020-2021 overall movement probability (Ψ) and bootstrapped 95% confidence intervals from one state (column) to another state (row): (A) Sugar BP2, (B) Sugar BP1, (C) Sugar below BDA1. Blanks indicate the transition was fixed to 0.
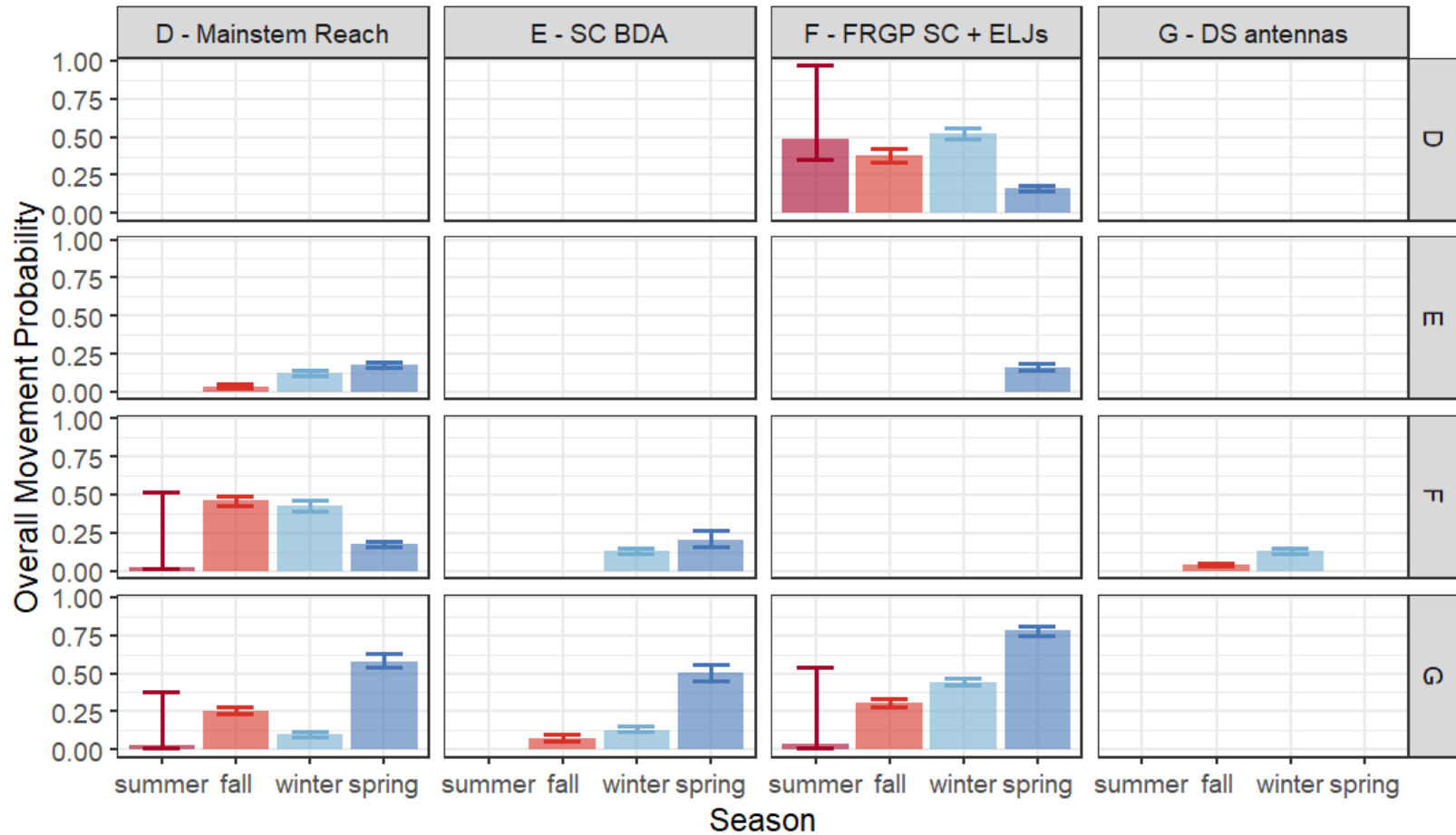
Figure 23. French Creek 2020-2021 overall movement probability (Ψ) and bootstrapped 95% confidence intervals from one state (column) to another state (row): (D) French Untreated Mainstem Reach, (E) Side channel BDA, (F) FRGP Side Channel + ELJs, (G) downstream mainstem antennas. Blanks indicate the transition was fixed to 0. Only ELJ reach was surveyed in state F in summer-fall due to poor water quality in FRGP SC.
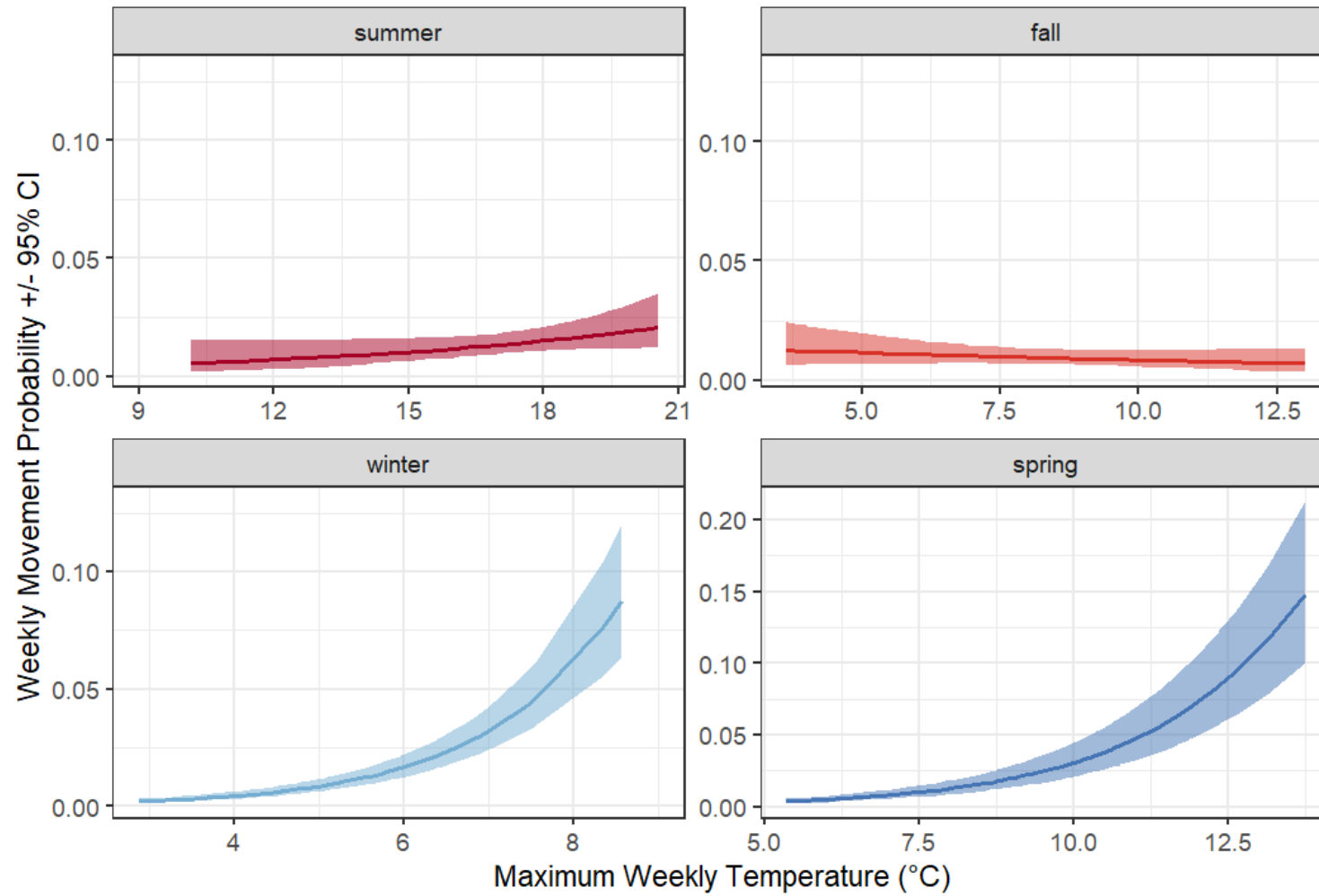
Figure 24. 2019-2020 model predicted relationship between weekly movement probability and maximum weekly temperature by season.
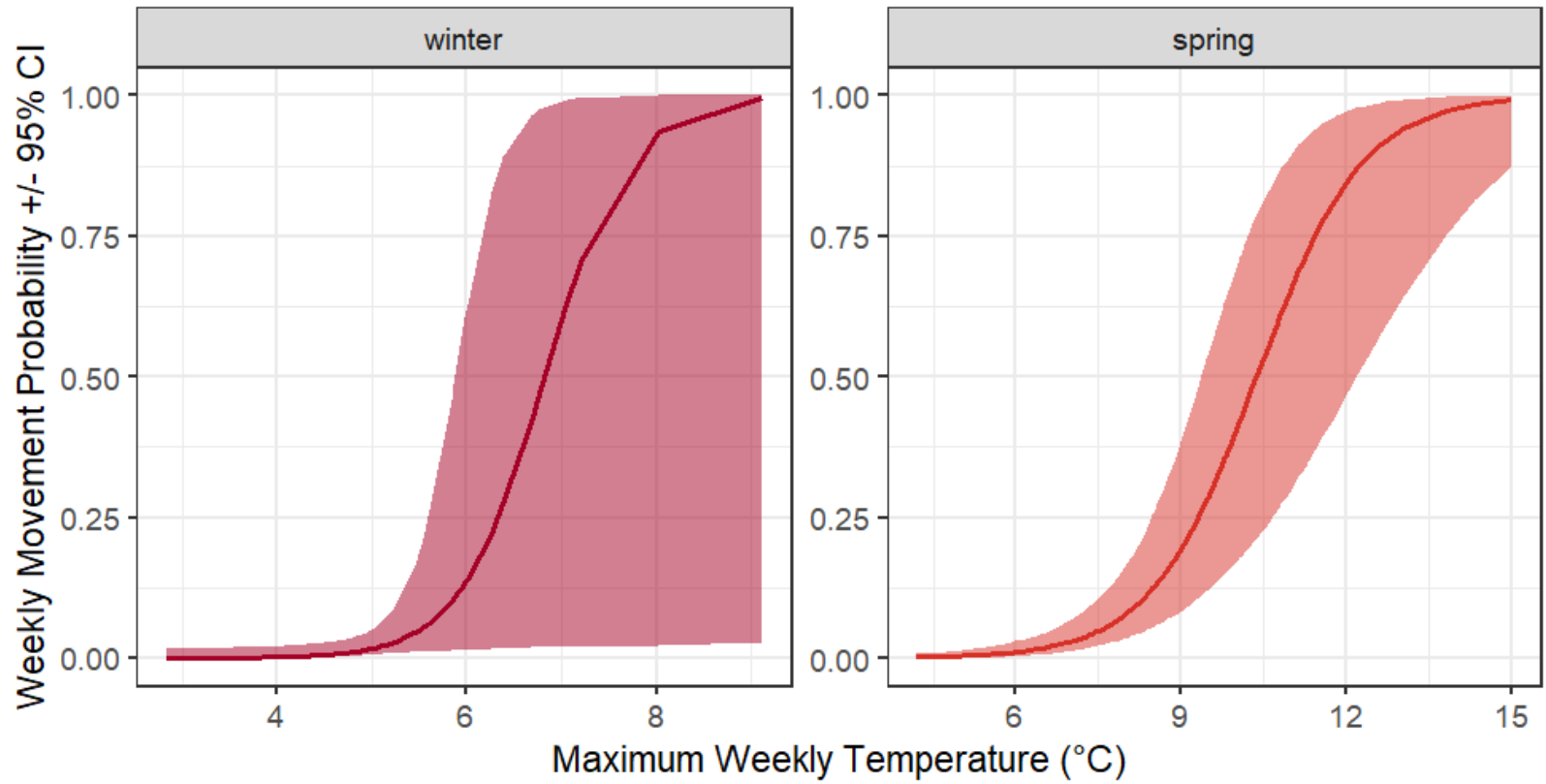
Figure 25. 2020-2021 Sugar Creek model predicted relationship between weekly movement probability and maximum weekly temperature by season.
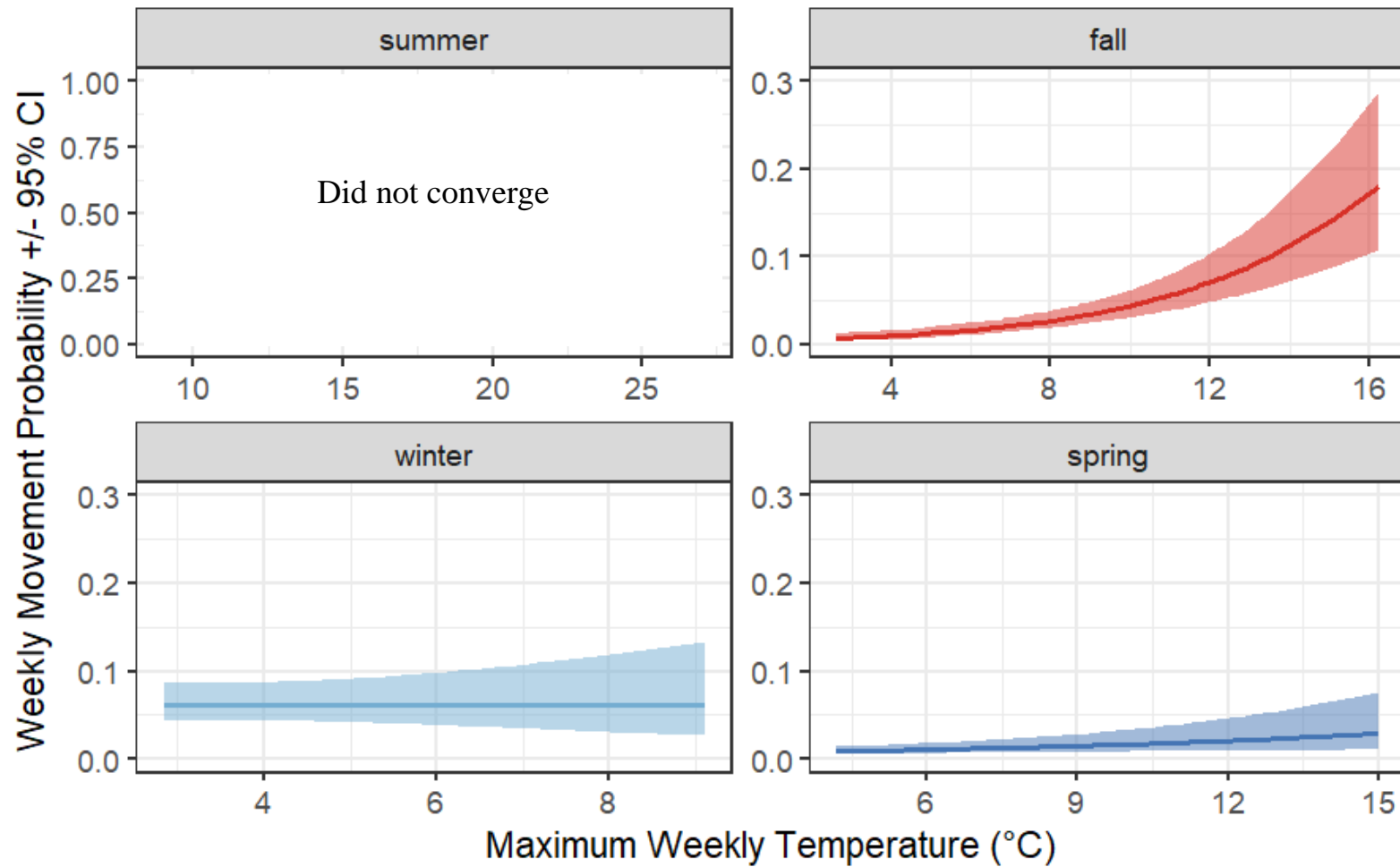
Figure 26. 2020-2021 French Creek model predicted relationship between weekly movement probability and maximum weekly temperature by season.
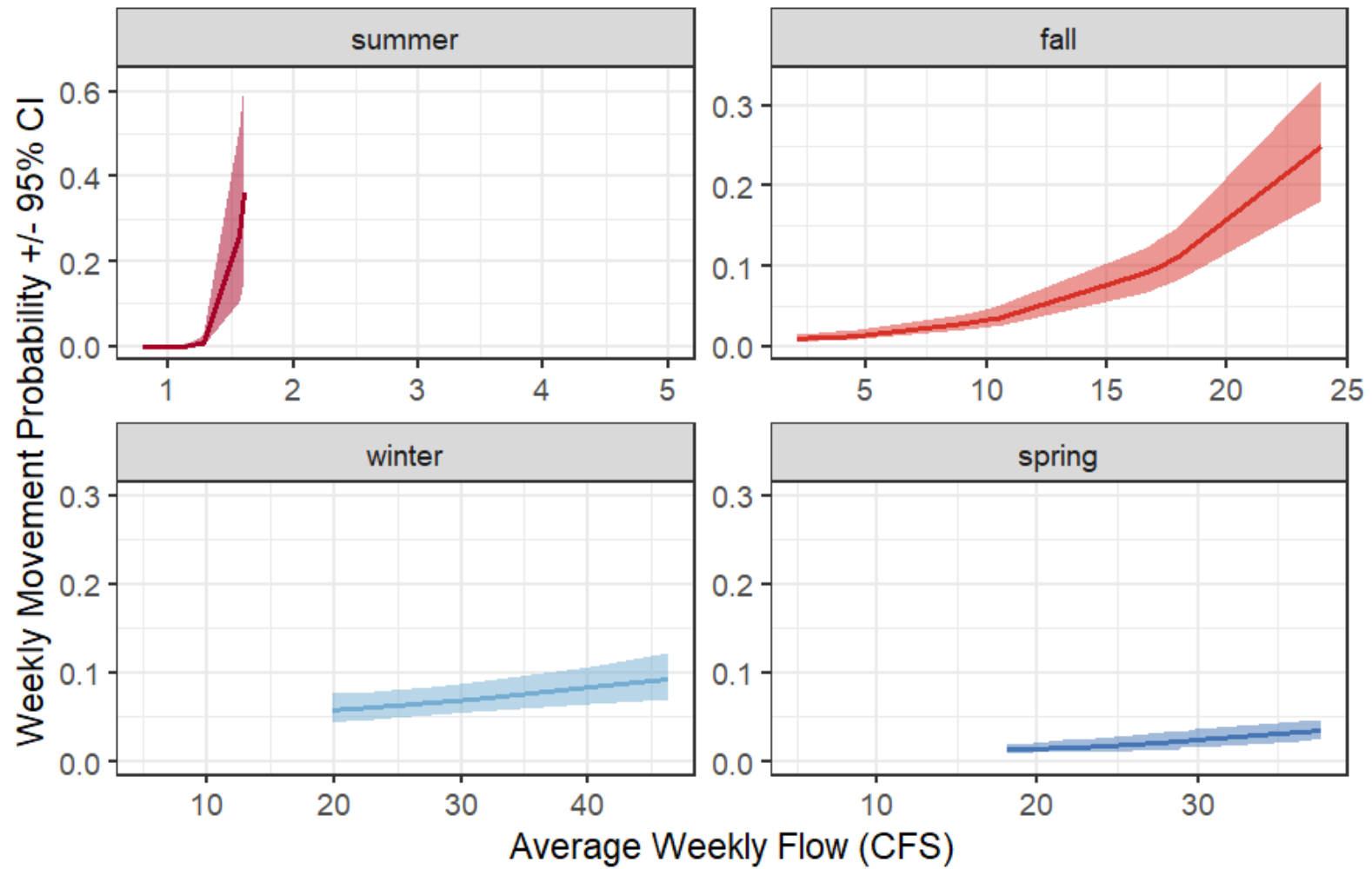
Figure 27. 2020-2021 French Creek model predicted relationship between weekly movement probability and average weekly flow (CFS).
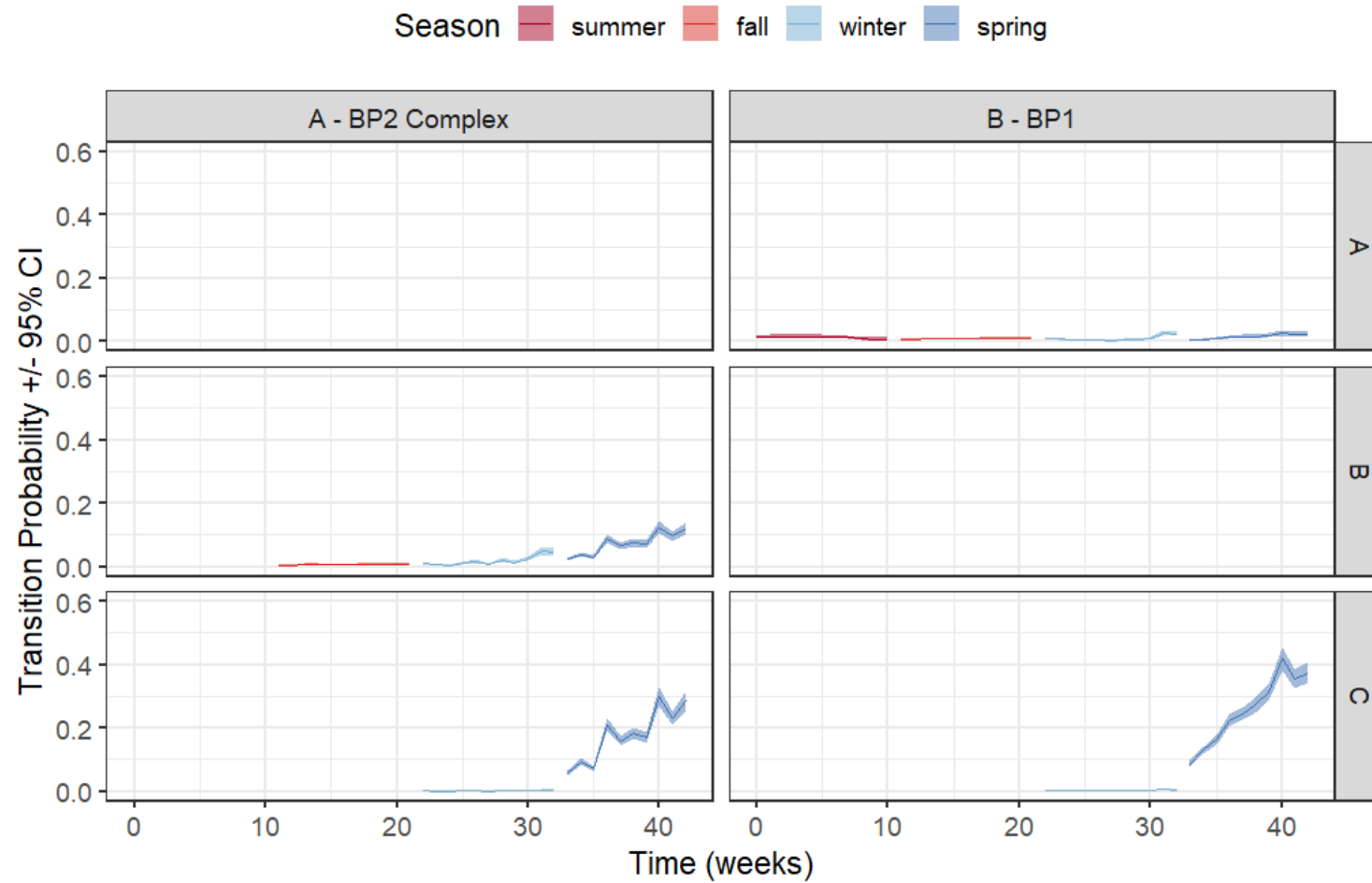
Figure 28. 2019-2020 weekly movement probability (Ψ) and 95% confidence intervals from one state (column) to another state (row): (A) Sugar BP2, (B) Sugar BP1, (C) Sugar below BDA1. Figure shows model that used estimated detection probability (p) = 0.60 for state C. Results shown after accounting for passage experiment. Summer, fall, winter, and spring spanned weeks: 1-11, 12-22, 23-33, and 34-44, respectively.
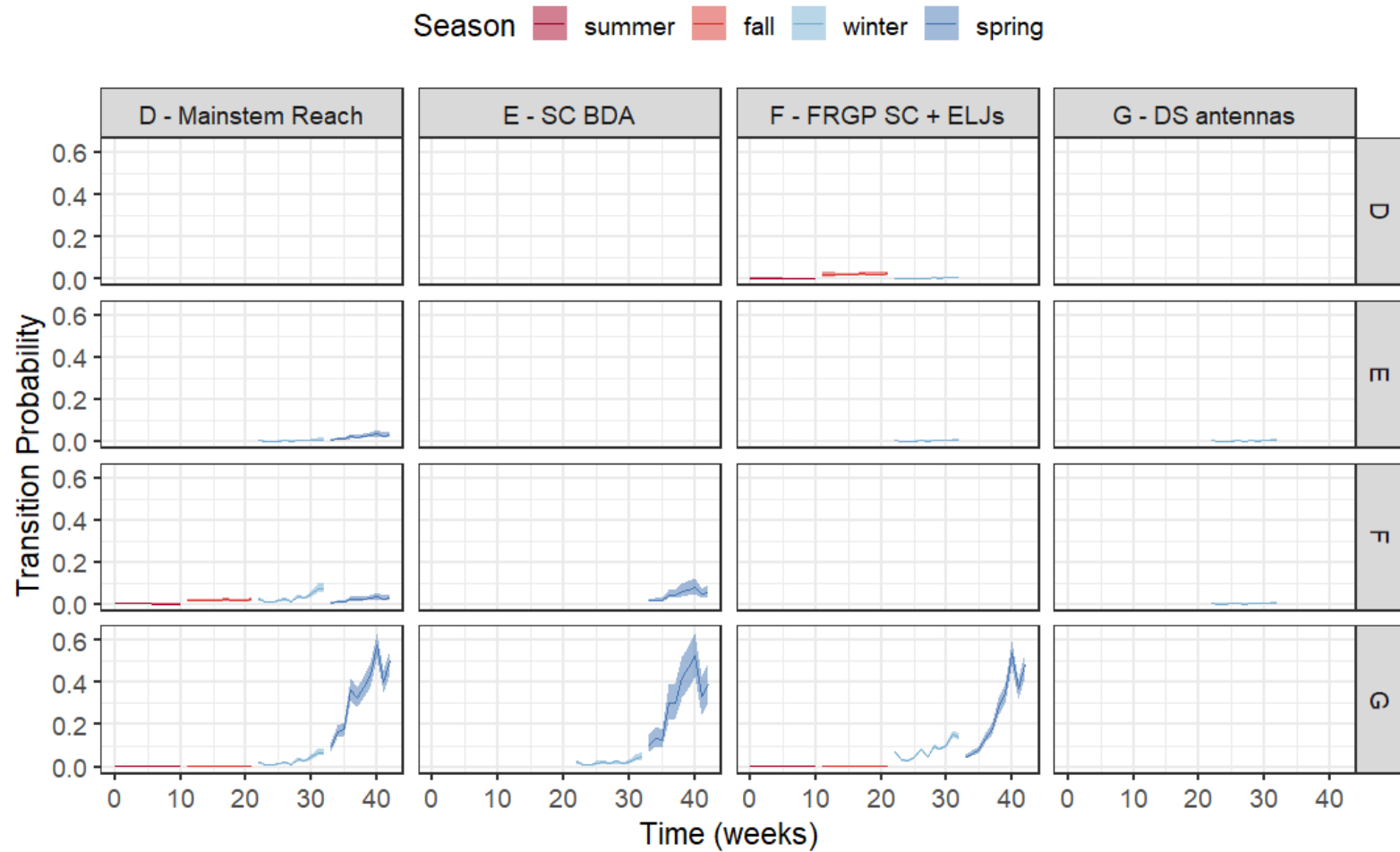
Figure 29. 2019-2020 weekly movement probability (Ψ) and 95% confidence intervals from one state (column) to another state (row): (D) French Untreated Mainstem Reach, (E) Side channel BDA, (F) FRGP Side Channel + ELJs, (G) downstream mainstem antennas. Summer, fall, winter, and spring spanned weeks: 1-11, 12-22, 23-33, and 34-44, respectively.
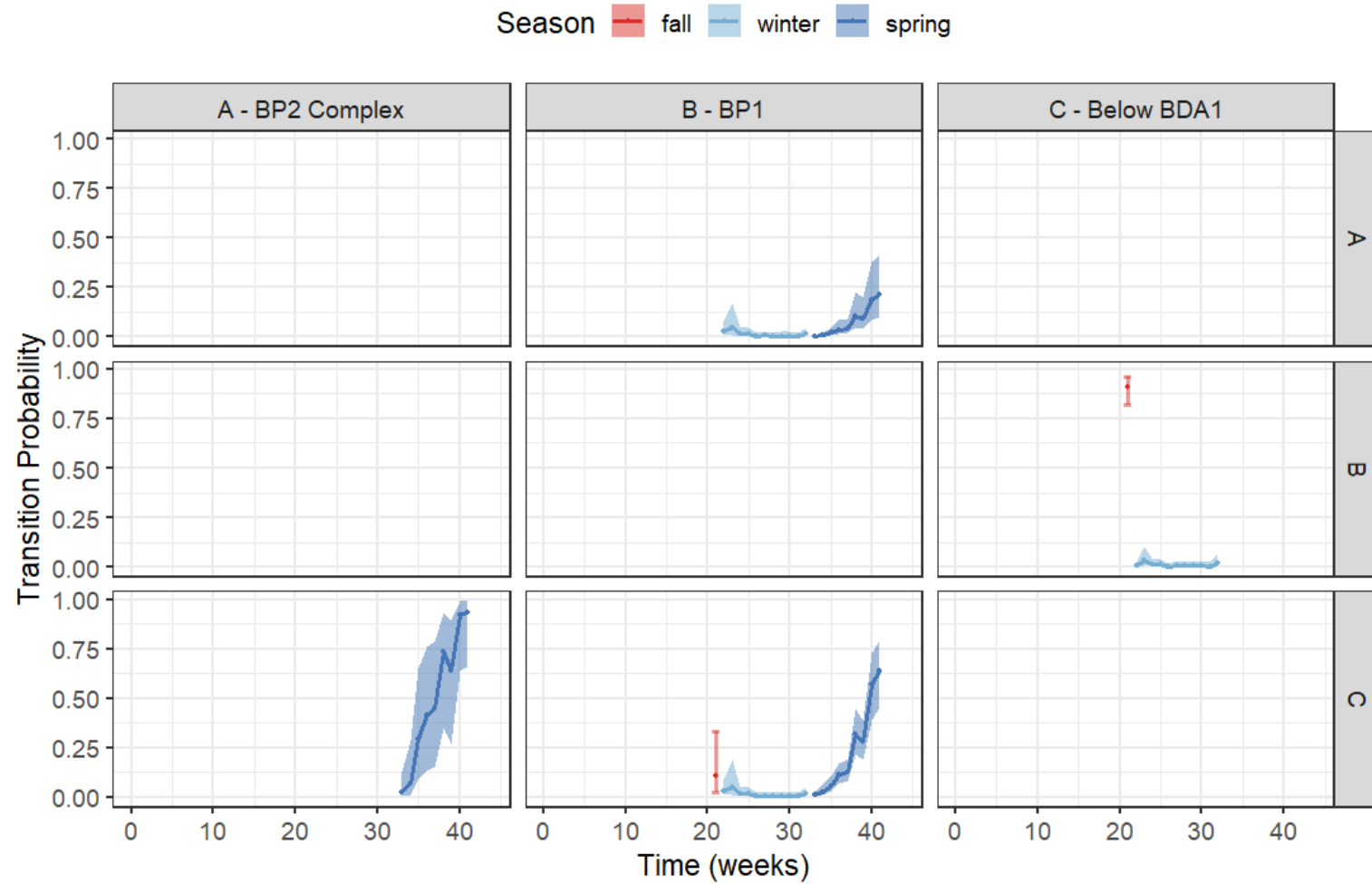
Figure 30. 2020-2021 weekly movement probability (Ψ) and 95% confidence intervals from one state (column) to another state (row): (A) Sugar BP2, (B) Sugar BP1, (C) Sugar below BDA1. Summer, fall, winter, and spring spanned weeks: 1-11, 12-22, 23-33, and 34-44, respectively.
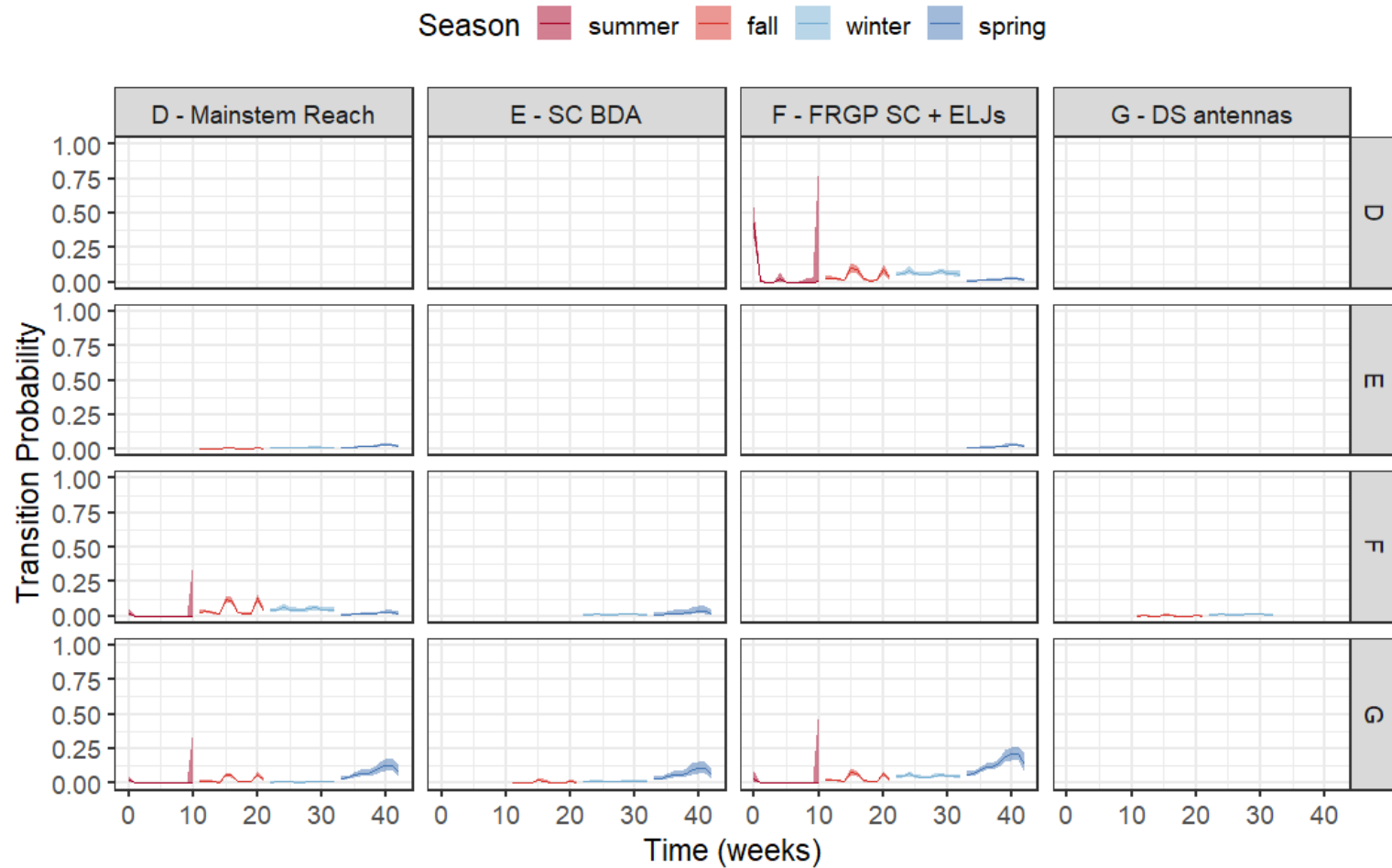
Figure 31. 2020-2021 weekly movement probability (Ψ) and 95% confidence intervals from one state (column) to another state (row): (D) French Untreated Mainstem Reach, (E) Side channel BDA, (F) FRGP Side Channel + ELJs, (G) downstream mainstem antennas. Only ELJ reach was surveyed in state F in summer-fall due to poor water quality in FRGP SC. Summer, fall, winter, and spring spanned weeks: 1-11, 12-22, 23-33, and 34-44, respectively.

DISCUSSION

The restoration community in CA is particularly interested in the performance of BDA habitat restoration relative to other techniques. My results have implications for those considering using BDAs to restore coho juvenile rearing habitat. To assess BDA sites in comparison to other types of restored and existing habitat, I compared juvenile coho abundance, survival, and growth between sites in Scott River tributaries. I analyzed these metrics by season to determine if some sites performed better during certain seasons and not others. I found that juvenile coho grew and survived at similar rates in BDA sites as they did in the other rearing sites, albeit with annual variation in relative performance. Locations and time periods when the sites were not occupied were associated with larger-scale drought and flow conditions that affected the system beyond the restoration area.

Abundance and density estimates allow comparisons of Coho Salmon habitat selection. However, changes in abundance could represent a shift in fish distribution rather than increased survival and recruitment (Roni et al. 2008). I was not able to estimate abundance in every site and season as planned, so density could not be compared between all sites and seasons in this study. Abundance estimates were not effective in the winter due to violating the equal catchability assumption of closed-mark-recapture models. There appeared to be a trap-avoidance on the second day of sampling and a subset of fish moved in and out of the habitat regularly. In the sites where I estimated abundance, the summer-fall linear density was consistently higher in one of the

beaver dam analog sites than all other sites (Sugar BP1). Beaver dam analog ponds likely increase production in part by increasing the habitat width compared to free-flowing reaches.

The performance of BDA sites compared to other sites in terms of growth varied by season and year. In most seasons, growth was 36-67% higher in BDA sites than other sites that were sampled (summer 2016, summer 2017, fall 2018, winter 2018-19, fall 2019, winter 2020-21), but in some seasons, growth was 5-22% lower at some BDA sites than other sites (summer 2019, winter 2019-20). In winter 2019-2020 when Sugar BDA Pond 1 population was high, growth rates were lower in Sugar BDA Pond 1 than other sites. However, in 2020-2021, when the Sugar BDA Pond 1 population was low after the 2020 summer drying event, growth rates were much higher than other sites. This suggests density-dependent factors affect growth rates in Sugar BDA Pond 1, which is consistent with Bouwes et al. (2016) who found density-dependent decreases in growth in Bridge Creek juvenile steelhead post BDA-treatment. Density-dependent factors may have also influenced low grow rates in Sugar BP1 in summer of 2019 in comparison to summer of 2016 and 2017. The estimated abundance was much higher in late summer 2019 compared to 2016 and 2017.

The performance of BDA sites compared to other sites in terms of survival also varied by season and year. BDA sites had similar or higher survival in fall (92-93%), winter (83-91%) and spring (33-59%) compared to non-BDA sites (64-87%, 65-81%, 23-55%). BDA sites had lower survival (0 -67%) than non-BDA sites (13-88%) in the

summer, except in 2016 and 2017 in Sugar BDA Pond 1 (45-49%) compared to French

Untreated Mainstem Reach (12-14%).

Drought likely impacted growth and survival in my study. The summer of 2020

was characterized as D3 – extreme drought. Sugar BDA Pond 1 dried completely by

September. In normal-moderate drought (D2 or lower), fish had higher or similar survival

and/or growth in BDA-formed sites in all seasons. However, during the extreme drought,

BDA-formed sites performed worse than mainstem sites in summer, but comparable or

better in the winter and spring. The combination of low winter flows in 2019-2020

followed by extreme drought the following summer greatly impacted the survival of the

Sugar Creek 2020-2021 cohort. If winter flows had been higher, adult salmon would

likely have spawned above the Sugar Creek BDAs and juvenile Coho Salmon would

have reared the following summer in Sugar Creek BDA Pond 2, which stayed wet and

had good water quality. In the sites that stayed wetted and had fish in summer of 2020,

the French untreated mainstem reach and ELJ reach, summer survival was relatively

high, but growth was much lower compared to all other summers in French Untreated

reach and the ELJ reach.   Under drought conditions, previously perennial streams may

become intermittent, resulting in disconnected pools that trap fish and cause mortality

(Vander Vorste et al. 2020). BDAs placed in these reaches also suffer from this problem,

although under some conditions wetted habitat may persist longer in BDA reaches

(Munir and Westbrook 2021; Pearce et al. 2021). Further, under some conditions the

BDAs offer the opportunity for higher growth and survival. Due to their ability to

increase water storage, SRWC preferentially selected reaches for BDA construction that

were already subject to seasonal drying. Comparing BDAs in losing reaches that would otherwise have been dry, to sites that consistently stay wet, like the French Untreated Mainstem Reach, may be misleading. There was initially an additional control site that represented a typical reach in Sugar Creek, but abundance of fish was so low, there was nothing to compare. This study confirms the importance of having a variety of habitats to support Coho Salmon in variable conditions year-to-year and between seasons within a year.

Another goal of this study was to characterize the spatial scale at which fish use the restoration sites. I found that juvenile coho commonly reared in multiple study sites within the same tributary, even if separated by a BDA. Fish passage through beaver dam analogs has been a general concern, but studies to date indicate the BDAs are rarely passage barriers for seasonal dispersal (Bouwes et al. 2016, O'Keefe 2021, Pollock et al 2022). In my study, juvenile fish passage over BDAs did occur during the low flow season in a normal water year, but not during a drought year.

The probability of moving between sites in the same tributary varied from 0-48% in the summer, 0-46% in the fall, and 4-52% in the winter, not including fish migrating to the downstream antenna sites (C or G). Summer movement between sites was low in French Creek (<3%), except from the ELJ reach to the mainstem pool reach between the first and second occasion in 2020 (43%). Movement from the ELJ reach to the mainstem pool reach was low the rest of the summer, so the higher movement in early summer was possibly a flight response due to tagging. Formal multistate analysis of summer movement in Sugar Creek was limited to 2019, when movement rates were relatively

high between Sugar BP1 and Sugar BP2 (13%). In 2016-2017, I did not perform a

multistate movement and survival analysis, but summer abundance estimates in 2016-

2017 suggest movement from Sugar BP1 to Sugar BP2. As the subsequent abundance

estimate decreased in Sugar BP1, abundance estimates in Sugar BP2 increased (Figure 5).

These were both higher flow summers with high summer abundance in Sugar BP1.

Perhaps these were exploratory movements, or perhaps fish were avoiding competition

and seeking less densely populated habitat (Kahler et al. 2001). Including early summer

fish density in the multistate model would be one way to explore this question.

Regardless of the reason, this suggests that monitoring individual restoration sites,

without monitoring nearby habitat in the same tributary excludes important information,

even in the summer.

I also found that juvenile coho were very unlikely to move between tributaries.

They did not move between tributaries often enough for between-tributary movement to

be included in the multistate model, but several fish were detected moving downstream to

rear in Scott River habitats outside of my study area (Table 12; Table 24). Seven fish

moved from Sugar Creek to French Creek, five individuals in 2019-2020 and two

individuals in 2020-2021. Only two fish moved from French Creek to Sugar Creek, one

each year.

A few factors distinguish this study from previous studies evaluating survival and

growth:

1) I estimated survival and growth for each Coho Salmon rearing season, unlike

most studies that only estimate one season (Witmore 2014; Malison et al. 2015; Vander

Vorste et al. 2020) or combine all seasons and estimate survival to smolt stage (Ebersole

et al. 2006; Roni et al. 2012; Weybright & Giannico 2017). This allows us to better

understand when periods of high growth/survival occur and how that differs between

different habitats. Sampling over a longer period also increases recapture probability of

fish, which affects survival estimates. For example, the CJS estimates of apparent

survival for summer 2016 and 2017 were very low compared to the 2019 and 2020

multistate model estimates. This was not likely due to environmental conditions, as

summer of 2020 had much worse drought conditions (D3) than the summers of 2016

(D0) and 2017 (none) (Table 7). I suspect that this difference is caused by some fish

moving temporarily to areas with low detection probability or no sampling in the

summer, then moving back into the study area in the winter. These fish would be

considered mortalities in the summer-only model, but not in the longer-term multistate

model.

2) CJS apparent survival estimates are substantially lower than true survival when

sampling is confined to a single season, as mentioned above, but also when movement

between different states is not incorporated. I utilized continuous antenna data to account

for movement between sites, rather than just discrete sampling events. I also incorporated

a downstream antenna in each tributary that represented outmigration. My multistate

model winter survival estimates from 62% (95% CI 57-66%) to 91% (95% CI 90-92%)

were much higher than previous studies that did not incorporate early emigration by

using a downstream antenna, 3-49% in Freshwater Creek (Rebenack et al. 2015) 5-15%

in Prairie Creek (Brakensiek and Hankin 2007). Van Vleet (2019) estimated similar

winter survival (87-90%) in Freshwater Creek using a similar multistate model design that incorporated antenna detections and in-hand data into weekly occasions. This study shows the importance of sampling over multiple seasons and locations and incorporating antennas downstream of sites to increase the accuracy of site-specific survival estimates.

(3) I focused on an inland California snow-melt system, where Coho Salmon likely have different periods of low survival and high growth than more commonly studied coastal watersheds (Ebersole et al. 2006; Roni et al. 2012; Weybright & Giannico 2018; Vander Vorste et al. 2020). It is difficult to compare juvenile salmon growth data due to differences in metrics used to report growth, as well as low recaptures across the same time periods. Where I could find comparable data over similar time periods, growth rates at coastal sites were very different from my sites. I estimated lower winter growth, ranging from 0.02 mm/day (95% CI 0.1-0.03) to 0.20 mm/day (95% CI 0.15-0.24), than previous estimates in Northern California coastal streams, which ranged from 0.1-0.36 mm/day (Faukner 2022; Pagliucco 2019; Taylor 2020; Taylor 2021). Spring growth was also much lower in my sites 0.06 mm/day (95% CI 0.04-0.09) to 0.21 mm/day (95% CI 0.18-0.24), compared to 0.29-0.51 mm/day in Freshwater and McGarvey Creeks (Faukner 2022; Taylor 2020; Taylor 2021). My summer growth estimates of 0.04 (95% CI 0.03-0.06)-0.24 (95% CI 0.22-0.27) were comparable to previous estimates of 0.09-0.18 mm/day (Faukner 2022; Taylor 2020; Taylor 2021). Lastly, my fall estimates of 0.03 mm/day (95% CI 0.00-0.06) to 0.17 mm/day (95% CI 0.12-0.22), were similar to 2020-2021 growth in Freshwater Creek of 0.08 mm/day (Taylor 2021). I did not incorporate the mainstem Scott River outmigrant trap, operated by CDFW, in my models

because of the low number of recaptures, but out of nine PIT recaptures, one fish suggests that growth in the spring after outmigration to the mainstem (0.57 mm/day) is similar to spring growth in Freshwater and McGarvey creeks. Three fish captured in January in my sites and then again in May in the Scott River outmigrant trap also suggest a period of high growth not accounted for in my winter and spring estimates (0.19 mm/day, 0.30 mm/day, 0.36 mm/day). Monthly average FL was usually lower in all of my Scott River sites than in freshwater coastal sites, except for Sugar BP1. Sugar BP1 monthly average fork length was usually similar to coastal sites (**Error! Reference source not found.**). This suggests Coho Salmon Scott River fish are smaller than those at coastal sites when leaving their natal streams, but compensatory growth occurs after outmigrating from tributaries.

Mean summer survival rates in my sites that stayed wet in 2019 (71%) and 2020 (77%) were higher than those estimated in the coastal Russian River basin. The Russian River streams, which are often intermittent in the summer, had a mean summer survival of 52% during drought years and 56% during non-drought years, in sites that stayed wet when standardized to 11-weeks (Vander Vorste et al 2020). Bouwes et al. (2016) found similar summer (72-93%), fall (64-97%), and winter survival (68-72%) when standardized to 11-weeks, for steelhead in a BDA reach in a similar climate as the Scott River watershed in north central Oregon. The previously mentioned study in Freshwater Creek, a coastal stream in northern California had similar winter survival estimates as my study (Van Vleet 2019).

Recommendations for Sampling Design to Evaluate Restoration

To improve and simplify studies comparing growth, movement, and survival, such as this one, a very structured study design can make growth rate calculations and multistate model structuring easier. I recommend regular sampling intervals and methods be followed as much as possible, such as once a month, once every other month, etc. and between years. PIT antennas at every site can fill in data from missing inhand surveys for survival estimates, but a missing survey makes growth comparisons between sites difficult. Because sampling intervals were so different year to year, I ran separate multistate models. This means the modeled relationship between survival and the environmental covariates could not include the larger differences in environmental conditions that occurred across years.

I also recommend consistently running multiple downstream capture points. Even with unequal sample intervals and tagging effort at rearing locations upstream, downstream locations allow you to estimate survival to smolt outmigration. If they are in-hand capture points, like an outmigrant trap, total growth can be calculated, or spring growth estimates can be improved. The downstream most capture point should have two paired antennas or one antenna and one smolt trap, so detection efficiency can be easily calculated from PIT detections. Even with two antennas, spring survival estimates may not represent true survival, if fish are missed on both antennas due to antenna malfunction or high flows. Spring survival estimates appeared low in my study, but I suspect that many fish were missed on both French Creek downstream antennas during

periods of high outmigration, which would bias survival low. Therefore, the decline in apparent survival in late spring would represent that more fish have left the study area as smolts and were not detected leaving, rather than an actual decline in survival. Cutting off my capture histories to 11 occasions per season also missed some of the later outmigrants. CDFW ran a downstream smolt trap in some years of this study, but recapture of PIT-tagged fish was very low. Only nine and three PIT-tagged smolts were recaptured in the smolt trap in 2020 and 2021. They estimated a trap efficiency of 2.61% and 2.92% for coho smolts respectively. I did not include this data in my model. Scott River Watershed Council expanded their PIT antenna network in 2020-2021 to include a mainstem Scott River antenna (rKm 28.9). I did not include this antenna in my model, but 109 of the 1944 fish detected in 2020-2021 were detected on this antenna while outmigrating.

One of the goals of this study was to relate changes in abundance to movement, growth, and survival. Achieving this goal would require population estimates at the same site in at least two different seasons in the same year. I found that methods for abundance estimates in winter need refinement. Perhaps waiting 2-3 days instead of just one day between the first and second sampling occasion could decrease the trap-shyness effect I observed with baited minnow traps. Installing temporary block nets could decrease short-term diel movement or flight response, which likely affected my winter abundance estimates.

Selecting control sites is a challenge in field studies. My study did not have a true control because the French Untreated Mainstem Reach was not independent from the

treated sites. It was still useful for comparison but having multiple controls in addition to

French Mainstem reach would be better in lieu of a perfect control site. The French

Mainstem Reach represented a high-quality control reach that retained suitable habitat

year-round even in drought conditions. Originally there was an additional control site on

Sugar Creek that represented a typical reach, but abundance of fish was so low, there was

not anything to compare. Ideally restoration sites would be monitored for a few years

prior to treatments, in a before-after-control-impact (BACI) design, but many of the sites

I sampled likely had very few fish prior to the treatment. An alternative restoration

evaluation framework was recently proposed by Polivka (2022) where two types of

references are compared to treatments: (1) untreated pools in the same treated reaches,

and (2) in untreated pools in untreated reference reaches. This is a good study design

option when pre-restoration monitoring is not feasible.

I used a novel approach to estimate growth. Using a GAMM that predicted fork

length on a specific date for each individual allowed me to utilize all available recapture

data instead of just recaptures that fit into specific time intervals. I then extracted slopes

from specific time intervals as a "growth" estimate. This approach also has potential

issues. It still does not help me predict size confidently within large chunks of time

without data. However, my 2019-2020 GAM results were similar to a strict interval

individual growth rate calculation I did for 2019-2020 (**Error! Reference source not

found.**). One example of where they differ is Sugar BP1 in 2018-2019. The GAMM

estimates a winter growth rate by creating a smoothed curve connecting data from

surveys on 9/27/18 and 3/8/19, with no surveys in between, while the other method does

not generate a winter growth rate. The GAMM includes data outside of each season to help inform the shape of the smoothed line, but in this case, September and March data is the only data informing the shape during winter because there is no data in between. This is accounted for in the GAM by having larger confidence intervals around periods with no data.

I did not have enough data to say if movement between sites or diel movement is important to growth or survival rates. To address diel movement behavior, a targeted study is necessary. I attempted to sample for diel movers using a fyke net that was deployed just before sunrise, with the opening oriented so fish returning after feeding would be captured. To be included in analysis, a fish would need to be PIT tagged, display diel movement on antennas, and be recaptured after showing diel movement to estimate how the diel movement effected growth. After two attempts in Sugar Off-Channel Pond and three attempts in French FRGP SC, the sample size was not large enough to do any meaningful diet or growth analysis.

Though I was not able to do a strict comparison of the growth of diel movers vs non-diel movers, MultiDate30 was a binomial variable used in the GAM growth model to pick up on diel movement. Fish detected on antennas more than three times in the last 30 days were designated as a "mover" and everyone else was designated a "stayer", however fish that live permanently near an antenna would also be categorized as a "mover". The best model showed stayers had significantly higher mean FL. This aligns with Chapman (1962) observation that competition forced out smaller individuals. However, it is unclear if stayers had a higher mean FL because stayers grow faster, or larger fish are more likely

to stay put. Because of the way the MultiDate30 variable was defined, it could also be that fish living permanently near antennas that got lumped in as "movers", were smaller or had lower growth rates. Armstrong et al. (2013) found diel movement at very low temperatures (6-7°C), but in contrast to my results, diel-movers had faster growth rates and were larger on average than individuals with other behavioral strategies, perhaps because they were seeking out more optimal warmer temperatures. Temperatures at my sites in Sugar and French creeks reached even lower temperatures (2°C) in the winter.

By incorporating movement between multiple sites in a reach, this project assessed a restoration project at a larger scale than just looking at sites individually (Bryant 1988; Giannico and Hinch 2003; Henning et al 2006), but a smaller scale than the entire watershed, which is only occasionally done (Solazzi et al. 2000; Bouwes et al. 2016; Okun 2021). This intermediate approach generated more accurate site-specific survival estimates than if I had just estimated survival at an individual site without incorporating movement. Higher survival estimates suggest increased production, which could lead to population level impacts. Survival is more useful than examining changes in local site abundance alone, which can be due to a shift in fish distribution or recruitment (Roni et al. 2008). Based on movement in my study area, at a minimum, adjacent slow and fast habitats, such as the French Creek mainstem engineered log jam reach and the FRGP side channel, or the Sugar Off-channel pond and outlet channel, should be assessed in conjunction. On the other end of the spectrum of assessing restoration effectiveness, estimating population changes at the watershed scale, is very labor and resource intensive. For example, Solazzi et al. (2000) monitored four different streams,

two treatment streams and two reference streams, for eight years using a before-after-control-impact (BACI) design. This study design allowed them to account for changes in fish population parameters due to factors other than the restoration treatment. My study had a posttreatment design, where restoration sites were compared to a reference site, over five years. In terms of days of field work, my study took 4-8 weeks per year. Solazzi et al. (2000) ran a smolt trap in each stream every day in the spring (~13 weeks), to estimate overwinter survival and smolt abundance, and electrofished and snorkeled four stream reaches in the summer (~1 week), to estimate summer abundance. My results suggest Coho Salmon production might increase due to higher survival and growth in restored sites compared to the French mainstem reach, while Solazzi et al. (2000) were able to quantify the change in production with more than twice the field effort.

My study shows promising evidence that beaver dam analogs support juvenile Coho Salmon as well as other types of restoration and high-quality untreated habitats. More targeted evaluations of beaver dam analog sites that compare juvenile Coho Salmon responses associated with production (growth, survival, and abundance) will strengthen the case that beaver dam analogs can help to improve imperiled Coho Salmon populations. By evaluating different sites, this research will help restoration practitioners decide when to apply this relatively affordable restoration technique.

REFERENCES

Armstrong, J. B., Schindler, D. E., Ruff, C. P., Brooks, G. T., Bentley, K. E., & Torgersen, C. E. (2013). Diel horizontal migration in streams: Juvenile fish exploit spatial heterogeneity in thermal and trophic resources. *Ecology*, 94(9), 2066–2075.

Baldock, J. R., Armstrong, J. B., Schindler, D. E., & Carter, J. L. (2016). Juvenile Coho Salmon track a seasonally shifting thermal mosaic across a river floodplain. *Freshwater Biology*, 61(9), 1454–1465. https://doi.org/10.1111/fwb.12784

Bobst, A. L., Payn, R. A., & Shaw, G. D. (2022). Groundwater-mediated influences of beaver-mimicry stream restoration: a modeling analysis. *J Am Water Resour Assoc*, 58, 1388-1406. https://doi.org/10.1111/1752-1688.13044

Bouwes, N., Weber, N., Jordan, C. E., Saunders, W. C., Tattam, I. A., Volk, C., Wheaton, J. M., & Pollock, M. M. (2016). Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Scientific Reports*, 28581. https://doi.org/10.1038/srep28581

Brakensiek, K. E., & Hankin, D. G. (2007). Estimating overwinter survival of juvenile Coho Salmon in a northern California stream: accounting for effects of passive integrated transponder tagging mortality and size-dependent survival. *Transactions of the American Fisheries Society*, 136(5), 1423–1437. https://doi.org/10.1577/T06-211.1

Bryant, M. (1988). Gravel pit ponds as habitat enhancement for juvenile coho salmon (General Technical Report PNW-GTR-212; p. 10). U.S. Department of Agriculture, Forest Service. https://www.fs.usda.gov/pnw/pubs/pnw_gtr212.pdf

Calvert, A. M., Bonner, S. J., Jonsen, I. D., Flemming, J. M., Walde, S. J., & Taylor, P. D. (2009). A hierarchical Bayesian approach to multistate mark–recapture: simulations and applications. *Journal of Applied Ecology*, 46(3), 610–620. https://doi.org/10.1111/j.1365-2664.2009.01636.x

Carlson, S. M., Hendry, A. P., & Letcher, B. H. (2007). Growth rate differences between resident native Brook Trout and non-native Brown Trout. *Journal of Fish Biology*, 71(5), 1430–1447. https://doi.org/10.1111/j.1095-8649.2007.01615.x

Chapman, D. G., & Robbins, H. (1951). Minimum variance estimation without regularity assumptions. The Annals of Mathematical Statistics, 22(4), 581–586.

Chapman, D. W. (1962). Aggressive behavior in juvenile Coho Salmon as a cause of emigration. *Journal of the Fisheries Research Board of Canada*, 19(6), 1047–1080. https://doi.org/10.1139/f62-069

Cochran, S. M. (2015). *Marine survival of coho salmon (Oncorhynchus kisutch) from small coastal watersheds in Northern California*. (Cal State) [Masters Thesis]. California State Polytechnic University, Humboldt.

Connolly, P. J. (2010). Guidelines for calculating and enhancing detection efficiency of PIT tag interrogation systems. Pages 119–125 PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations - A compendium of new and recent science for use in informing technique and decision modalities, Chapter 7.

Cooch, E., & White, G. (2019). Using MARK—a gentle introduction. Cornell University, Ithaca.

Ebersole, J. L., Wigington Jr, P. J., Baker, J. P., Cairns, M. A., Church, M. R., Hansen, B. P., Miller, B. A., LaVigne, H. R., Compton, J. E., & Leibowitz, S. G. (2006). Juvenile coho salmon growth and survival across stream network seasonal habitats. *Transactions of the American Fisheries Society*, 135(6), 1681–1697.

Everest, F. H., Reeves, G. H., & Hohler, D. B. (1987). Effects of habitat enhancement on steelhead trout and Coho Salmon smolt production, habitat utilization, and habitat availability in Fish Creek, Oregon, 1986 Annual Report. Oregon State University, Pacific Northwest Forest and Range Experiment.

Faukner, J. (2022). McGarvey Creek master data. Yurok Tribal Fisheries (Unpublished Raw Data).

Ford, J. H., Bravington, M. V., & Robbins, J. (2012). Incorporating individual variability into mark–recapture models. *Methods in Ecology and Evolution*, 3(6), 1047–1054.

Giannico, G., & Healey, M. (1998). NOTES Effects of flow and food on winter movements of juvenile Coho Salmon. *Transactions of the American Fisheries Society*, 127, 645–651. https://doi.org/10.1577/1548-8659(1998)127<0645:EOFAFO>2.0.CO;2

Giannico, G. R., & Hinch, S. G. (2003). The effect of wood and temperature on juvenile Coho Salmon winter movement, growth, density and survival in side-channels. River Research and Applications, 19(3), 219–231. https://doi.org/10.1002/rra.723

Hartman, G. F., Andersen, B. C., & Scrivener, J. C. (1982). Seaward movement of Coho Salmon (*Oncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal

stream in British Colombia. *Canadian Journal of Fisheries and Aquatic Sciences*, 39(4), 588–597. https://doi.org/10.1139/f82-083

Henning, J. A., Gresswell, R. E., & Fleming, I. A. (2006). Juvenile salmonid use of freshwater emergent wetlands in the floodplain and its implications for conservation management. *North American Journal of Fisheries Management*, 26(2), 367–376. https://doi.org/10.1577/M05-057.1

Holtby, L. B., Andersen, B. C., & Kadowaki, R. K. (1990). Importance of smolt size and early ocean growth to interannual variability in marine survival of Coho Salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences*, 47(11), 2181–2194. https://doi.org/10.1139/f90-243

Irvine, J. R., O'Neill, M., Godbout, L., & Schnute, J. (2013). Effects of smolt release timing and size on the survival of hatchery-origin coho salmon in the Strait of Georgia. *Progress in Oceanography*, 115, 111–118. https://doi.org/10.1016/j.pocean.2013.05.014

James, G., Witten, D., Hastie, T., & Tibshirani, R. (2013). *An introduction to statistical learning* (Vol. 112). New York: springer.

Kahler, T. H., Roni, P., & Quinn, T. P. (2001). Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. *Canadian Journal of Fisheries and Aquatic Sciences,* 58(10), 1947–1956.

Laake, J.L. (2013). RMark: An R interface for analysis of capture-recapture data with MARK. AFSC Processed Rep 2013-01, 25p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Lebreton, J. D., & Cefe, R. P. (2002). Multistate recapture models: Modelling incomplete individual histories. *Journal of Applied Statistics*, *29*(1–4), 353–369. https://doi.org/10.1080/02664760120108638

Lestelle, L. C. (2007). Coho Salmon (*Oncorhynchus kisutch*) life history patterns in the Pacific Northwest and California. Prepared for US Bureau of Reclamation, Klamath Area Office. Final Report, March.

Liermann, M., & Roni, P. (2008). More sites or more years? Optimal study design for monitoring fish response to watershed restoration. *North American Journal of Fisheries Management*, *28*(3), 935–943.

Lusardi, R. A., Hammock, B. G., Jeffres, C. A., Dahlgren, R. A., & Kiernan, J. D. (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(2), 413–424. https://doi.org/10.1139/cjfas-2018-0484

Malison, R. L., Eby, L. A., & Stanford, J. A. (2015). Juvenile salmonid growth, survival, and production in a large river floodplain modified by beavers (Castor canadensis). *Canadian Journal of Fisheries and Aquatic Sciences*, 72(11), 1639–1651.

Mason, J. C. (1976). Response of underyearling Coho Salmon to supplemental feeding in a natural stream. *The Journal of Wildlife Management*, 40(4), 775–788. JSTOR. https://doi.org/10.2307/3800576

Massie, M., & Morrow, H. (2020). Scott River juvenile salmonid outmigrant study. California Department of Fish and Wildlife.

Morrow, H., Bachteler, A., Claire, T., & Gaines, M. (2021). Scott River juvenile salmonid outmigrant study. California Department of Fish and Wildlife.

Munir, T. M., & Westbrook, C. J. (2021). Beaver dam analogue configurations influence stream and riparian water table dynamics of a degraded spring-fed creek in the Canadian Rockies. *River Research and Applications*, 37(3), 330–342. https://doi.org/10.1002/rra.3753

Murphy, M. L., Heifetz, J., Thedinga, J. F., Johnson, S. W., & Koski, K. V. (1989). Habitat utilization by juvenile pacific salmon (*Oncorhynchus*) in the glacial Taku River, Southeast Alaska. *Canadian Journal of Fisheries and Aquatic Sciences*, 46(10), 1677–1685.

National Marine Fisheries Service. (2014). Final Recovery Plan for the Southern Oregon/Northern California Coast Evolutionarily Significant Unit of Coho Salmon (*Oncorhynchus kisutch*). National Marine Fisheries Service. Arcata, CA.

Nickelson, T. E., Rodgers, J. D., Johnson, S. L., & Solazzi, M. F. (1992). Seasonal changes in habitat use by juvenile Coho Salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. *Canadian Journal of Fisheries and Aquatic Sciences*, *49*(4), 783–789.

Nehlsen, W., Williams, J. E., & Lichatowich, J. A. (1991). Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries*, 16(2), 4–21.

Obedzinski, M., Nossaman Pierce, S., Horton, G. E., & Deitch, M. J. (2018). Effects of Flow-Related Variables on Oversummer Survival of Juvenile Coho Salmon in Intermittent Streams. *Transactions of the American Fisheries Society*, 147(3), 588–605. https://doi.org/10.1002/tafs.10057 o

O'Keefe, C. G. (2021). *Do beaver dam analogues act as passage barriers to juvenile Coho Salmon and juvenile steelhead trout?* (508) [Theses and Projects, Cal Poly Humboldt]. https://digitalcommons.humboldt.edu/etd/508

Okun, N. B. (2021). *Effects of large wood restoration on coho salmon in a northern California watershed: A before-after-control-impact experiment* (518) [Theses and projects, Cal Poly Humboldt]. https://digitalcommons.humboldt.edu/etd/518

Pagliuco, B. National Oceanic and Atmospheric Administration. (2019). Strawberry Creek, Martin Slough, Lawrence Creek Master Data (Unpublished Raw Data).

Pearce, C., Vidon, P., Lautz, L., Kelleher, C., & Davis, J. (2021). Impact of beaver dam analogues on hydrology in a semi-arid floodplain. *Hydrological Processes*, 35(7), e14275. https://doi.org/10.1002/hyp.14275

Polivka, C. M. (2022). "If You Build It…": Methodological Approaches to Detect Postrestoration Responses in Stream Fishes. *Fisheries*, 47(8), 346–355. https://doi.org/10.1002/fsh.10745

Pollock, M. M., Lewallen, G., Woodruff, K., Jordan, C. E., & Castro, J. M. (2015). The beaver restoration guidebook: Working with beaver to restore streams, wetlands, and floodplains (Version 1.02). Retrieved from https://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Documents/BRG%20v.1.0%20final%20reduced.pdf

Pollock, M. M., Witmore, S., & Yokel, E. (2022). Field experiments to assess passage of juvenile salmonids across beaver dams during low flow conditions in a tributary to the Klamath River, California, USA. *PLOS ONE*, 17(5), e0268088. https://doi.org/10.1371/journal.pone.0268088

Quinn, T.P. (2005). The Behavior and Ecology of Pacific Salmon and Trout. American Fisheries Society and University of Washington Press, Seattle and London.

Quinn, T. P., & Peterson, N. P. (1996). The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile Coho Salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. *Canadian Journal of Fisheries and Aquatic Sciences,* 53(7), 1555–1564. https://doi.org/10.1139/f96-092

Rebenack, J. J., Ricker, S., Anderson, C., Wallace, M., & Ward, D. M. (2015). Early Emigration of Juvenile Coho Salmon: Implications for Population Monitoring. *Transactions of the American Fisheries Society*, 144(1), 163–172. https://doi.org/10.1080/00028487.2014.982258

Rice, R. J. (2019). Annual Costs of Wild Salmon Restoration Efforts in the Columbia River Basin. Capstone Project Paper, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon. 24 pp.

Roni, P., Hanson, K., & Beechie, T. (2008). Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques. North *American Journal of Fisheries Management*, 28(3), 856–890. https://doi.org/10.1577/M06-169.1

Roni, P., Bennett, T., Holland, R., Pess, G., Hanson, K., Moses, R., McHenry, M., Ehinger, W., & Walter, J. (2012). Factors affecting migration timing, growth, and survival of juvenile Coho Salmon in two coastal Washington watersheds. *Transactions of the American Fisheries Society*, 141(4), 890–906.

Rosenfeld, J. (2003). Assessing the Habitat Requirements of Stream Fishes: An Overview and Evaluation of Different Approaches. *Transactions of the American Fisheries Society*, 132(5), 953–968. https://doi.org/10.1577/T01-126

Schreck, C. B., Moyle, P. B., & American Fisheries Society (Eds.). (1990). Methods for fish biology. American Fisheries Society.

Scott River Watershed Council. (2021). French Creek Instream and Off Channel Enhancement Project. Report Prepared for California Department of Fish & Wildlife Fisheries Restoration Grant Program. Grant #P1610528.

Solazzi, M. F., Nickelson, T. E., Johnson, S. L., & Rodgers, J. D. (2000). Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 57(5), 906–914.

Staton, J. M. (2017). Baseline characterization of nearshore Rocky reef fishes found in northern California marine protected areas. *Cal Poly Humboldt theses and projects.* 110. https://digitalcommons.humboldt.edu/etd/110

Swales, S., Lauzier, R. B., & Levings, C. D. (1986). Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. *Canadian Journal of Zoology*, *64*(7), 1506–1514.

Taylor, R. (2020). Monitoring of the Freshwater Creek off-channel Coho Salmon enhancement project (Periodic Report Prepared for Redwood Community Action Agency, p. 36).

Taylor, R. (2021). Freshwater Creek: Monitoring of the Off-channel Coho Salmon Enhancement Project Final Report (p. 17). Prepared by Ross Taylor and Assosciates for the Redwood Community Action Agency.

Tschaplinski, P. J., & Hartman, G. F. (1983). Winter Distribution of Juvenile Coho Salmon (*Oncorhynchus kisutch*) Before and After Logging in Carnation Creek, British Columbia, and Some Implications for Overwinter Survival. *Canadian Journal of Fisheries and Aquatic Sciences*, 40(4), 452–461. https://doi.org/10.1139/f83-064

Van Kirk, R. W., & Naman, S. W. (2008). Relative Effects of Climate and Water Use on Base-Flow Trends in the Lower Klamath Basin1. *Journal of the American Water Resources Association*, 44(4), 1035–1052. https://doi.org/10.1111/j.1752-1688.2008.00212.x

Vander Vorste, R., Obedzinski, M., Nossaman Pierce, S., Carlson, S. M., & Grantham, T. E. (2020). Refuges and ecological traps: Extreme drought threatens persistence of an endangered fish in intermittent streams. *Global Change Biology*, 26(7), 3834–3845. https://doi.org/10.1111/gcb.15116

Van Vleet, N. P. (2019). A time- and state-based approach to estimate winter movement and survival of juvenile Coho Salmon (*Oncorhynchus kisutch*) in freshwater creek, California [Master's thesis, Cal Poly Humboldt]. https://digitalcommons.humboldt.edu/etd/299

Wathen, G., Allgeier, J. E., Bouwes, N., Pollock, M. M., Schindler, D. E., & Jordan, C. E. (2019). Beaver activity increases habitat complexity and spatial partitioning by steelhead trout. *Canadian Journal of Fisheries & Aquatic Sciences*, 76(7), 1086–1095. https://doi.org/10.1139/cjfas-2018-0171

Weybright, A. D., & Giannico, G. R. (2018). Juvenile coho salmon movement, growth and survival in a coastal basin of southern Oregon. *Ecology of Freshwater Fish*, 27(1), 170–183. https://doi.org/10.1111/eff.12334

White, G. C., & Burnham, K. P. (1999). Program MARK: Survival estimation from populations of marked animals. Bird Study, 46(sup1), S120–S139. https://doi.org/10.1080/00063659909477239

Winkowski, J. J., & Zimmerman, M. S. (2018). Summer habitat and movements of juvenile salmonids in a coastal river of Washington State. *Ecology of Freshwater Fish*, 27(1), 255–269. https://doi.org/10.1111/eff.12344

Witmore, S. K. (2014). *Seasonal growth, retention and movement of juvenile Coho Salmon in natural and constructed habitats of the mid-Klamath River*. [Theses and Projects, Cal Poly Humboldt]. https://scholarworks.calstate.edu/concern/theses/6d56zz89d

Wood, S. N. (2017). Generalized Additive Models: An Introduction with R, Second Edition. CRC Press.

Yokel, E., Witmore, S., Stapleton, B., Gilmore, C., Pollock., M.M. (2018). Scott River
    Beaver Dam Analogue Coho Salmon Habitat Restoration Program 2017
    Monitoring Report. 57 p. Scott River Watershed Council. Etna, California.

APPENDICES

Appendix A: Comparison of Growth Rates Using Different Methods

In this section, I show the results for individual growth rates calculated with strict

intervals for the 2019-2020 cohort, similar to methods in Carlson et al. (2007), and

compared using ANOVA. Seasonal growth rates were calculated by site when possible,

using absolute change in fork length (mm/day). I wanted to know if some sites had higher

growth rates in some seasons but not others or if some sites had consistently higher

growth rates. I hypothesized that the BDA sites would have higher growth rates in the

winter than other sites. I evaluated the differences in growth between sites and between

seasons and the interaction between sites and seasons using analysis of variance

(ANOVA) followed by a Tukey honestly significant difference test for pairwise

comparisons. Differences were considered significant at P-values equal to 0.05. ANOVA

require similar time intervals for the groups being compared. This made seasonal

comparisons and site comparisons impossible in some cases. For the 2019-2020 cohort it

was possible to do a growth comparison for most of the sites during three 'seasons' of

approximately equal length (66-75 days): summer 2019 (8/23/2019-10/31/2019), fall

2019-2020 (10/31/2019-1/14/2020), and winter 2020 (1/14/2020-3/19/2020). I compared

the results of these growth estimates with growth estimates extracted from my GAM

model (Table 17). Almost all of the estimates fell within the 95% CI of the GAM model

growth rates.

Where there were similar intervals with a large enough sample size to compare, growth rates varied significantly by season ($F_{2,570} = 301.46$, $P < 0.001$) and site ($F_{5,570} = 63.21$, $P < 0.001$). The model with an interaction between season and location had the lowest AIC, residual standard error and adjusted R2, giving support that there was a significant interaction between site and season ($F_{5,570} = 14.46$, $P < 0.001$). During the summer 2019, the French FRGP SC and Sugar BP2 Complex had similarly high growth rates (0.20-0.22 mm/day) while the French Untreated Mainstem Reach and Sugar BP1 had similar growth rates (0.13 mm/day). Overall, summer growth rates were higher than the other seasons ($P<0.001$). In the fall, growth rates were highest in BDA sites, however these differences were only significant in Sugar BP2 complex compared to the French ELJ and French FRGP SC, but not French Control. In winter, growth rates were highest in the French SC BDA, which connected to the mainstem, allowing fish to move in around January. Sugar BP1 and Sugar BP2 Complex did not have significantly different growth rates than French FRGP SC, but Sugar BP2 did have a significantly higher growth rate than Sugar BP1 ($P<0.001$).

As a secondary option to increase sample size, but not do any ANOVA comparisons, I calculated growth rates by averaging all growth rates within two dates for a summer-fall and a winter-spring season (Table 18). For example, if one fish was captured July 15th and recaptured November 15th and another fish was recaptured July 15th and August 15th, their growth rates were both included. The summer-fall season included July 14-Nov 27th and the winter-spring season included Nov 28th-April 30th.

This is similar to methods used by Taylor (2020) in Freshwater Creek, however there they had consistent monthly sampling.

This simpler method of averaging all growth rates with a season works best with monthly sampling, so growth can be divided into four seasons and there is an even distribution of growth rates across each season to average. It also increases the sample size in comparison to using strict intervals that fish were captured and recaptured to calculate average individual growth.

Table 17. 2019-2020 average individual growth rates during three 'seasons' of approximately equal length (66-75 days): summer 2019 (8/23/2019-10/31/2019), fall 2019-2020 (10/31/2019-1/14/2020), and winter 2020 (1/14/2020-3/19/2020). Only individuals caught at both the beginning and end of each interval included. Not all sites had enough recaptures at the beginning and end of each interval to be included. Intervals during which growth was measured, average interval length, and number of individuals included in the growth analysis for each location are also included. The growth rate extracted from the GAM model for the same dates and bootstrapped 2000 iterations is shown for comparison.

Interval (starting sample-ending sample)	Average starting date (range)	Average ending date (range)	Average number of days in interval	Stream	Location	# captured in both starting and ending sample	Avg Growth (mm/day)	SD	GAM Median Growth (mm/day)	Bootstrap 95% CI
Summer 2019 (1-2)	08/26 (08/19-09/06)	10/31 (10/28-11/05)	67	French	Mainstem Reach	88	0.128	0.041	0.124	0.114-0.134
					ELJs	1	-	-	0.132	0.103-0.160
					FRGP SC	8	0.215	0.023	0.194	0.183-0.207
				Sugar	BP1	87	0.125	0.048	0.126	0.122-0.130
					BP2	17	0.200	0.033	0.190	0.179-0.202
Fall 2019-2020 (2-3)	10/31 (10/28-11/05)	01/14 (01/08-02/02)	76	French	Mainstem Reach	37	0.042	0.030	0.038	0.032-0.044
					ELJs	5	0.025	0.030	0.049	0.033-0.065
					FRGP SC	28	0.025	0.020	0.026	0.016-0.036
				Sugar	BP1	83	0.047	0.033	0.051	0.047-0.056
					BP2	40	0.057	0.029	0.074	0.062-0.086
Winter 2020 (3-4)	01/16 (01/08-02/02)	03/20 (03/17-03/26)	64	French	Mainstem Reach	4	-	-	0.082	0.070-0.094
					ELJs	0	-	-	-	-
					FRGP SC	12	0.059	0.034	-	-
					SC BDA	43	0.160	0.039	-	-
				Sugar	BP1	108	0.050	0.034	0.053	0.049-0.057
					BP2	27	0.096	0.046	0.104	0.096-0.112

Table 18. Average individual growth rate (mm/day) and standard deviation (sd) by cohort, season, and location. All growth rates within the min date and max date were averaged. The surveys column displays the number of recapture surveys and does not include initial tagging/measuring events with no recaptures.

Cohort	Season	Location	n	Growth (mm/day)	SD	Min Date	Max Date	Surveys
2016-2017	Summer/Fall	French Mainstem Reach	169	0.067	0.087	8/8/16	9/28/16	4
2016-2017	Summer/Fall	Sugar BP1	160	0.158	0.111	7/19/16	9/30/16	6
2016-2017	Summer/Fall	Sugar BP2 Complex	73	0.156	0.104	7/21/16	10/1/16	5
2017-2018	Summer/Fall	French Mainstem Reach	134	0.105	0.075	7/27/17	9/26/17	4
2017-2018	Summer/Fall	Sugar BP1	226	0.166	0.087	7/24/17	10/25/17	5
2017-2018	Summer/Fall	Sugar BP2 Complex	14	0.192	0.055	7/24/17	10/26/17	3
2018-2019	Summer/Fall	Scott Sugar Confluence	10	0.243	0.09	7/16/18	7/30/18	1
2018-2019	Summer/Fall	Sugar BP1	56	0.076	0.103	7/16/18	9/27/18	3
2019-2020	Summer/Fall	French Mainstem Reach	90	0.126	0.042	8/22/19	10/29/19	2
2019-2020	Summer/Fall	French ELJ	40	0.13	0.035	8/22/19	11/4/19	2
2019-2020	Summer/Fall	French FRGP SC	14	0.192	0.092	8/22/19	11/4/19	1
2019-2020	Summer/Fall	Sugar BP1	359	0.079	0.078	7/31/19	11/1/19	6
2019-2020	Summer/Fall	Sugar BP2 Complex	48	0.181	0.052	8/26/19	11/5/19	2
2020-2021	Summer/Fall	French Mainstem Reach	60	0.051	0.046	7/27/20	10/9/20	2
2020-2021	Summer/Fall	French ELJ	32	0.055	0.042	7/28/20	10/9/20	2
2018-2019	Winter/Spring	French FRGP SC	16	0.098	0.093	1/31/19	4/30/19	2
2019-2020	Winter/Spring	French Mainstem Reach	60	0.054	0.036	10/28/19	3/20/20	2
2019-2020	Winter/Spring	French ELJ	6	0.034	0.036	11/4/19	3/18/20	3
2019-2020	Winter/Spring	French FRGP SC	47	0.035	0.029	11/4/19	3/18/20	3
2019-2020	Winter/Spring	Mid French SC BDA	66	0.177	0.048	2/2/20	4/15/20	2
2019-2020	Winter/Spring	Sugar BP1	249	0.051	0.032	10/31/19	3/19/20	3
2019-2020	Winter/Spring	Sugar BP2 Complex	98	0.075	0.042	11/5/19	3/26/20	5

Cohort	Season	Location	n	Growth (mm/day)	SD	Min Date	Max Date	Surveys
2020-2021	Winter/Spring	French Mainstem Reach	7	0.073	0.047	12/14/20	3/23/21	2
2020-2021	Winter/Spring	French FRGP SC	107	0.053	0.054	12/15/20	3/22/21	4
2020-2021	Winter/Spring	Mid French SC BDA	140	0.152	0.076	1/26/21	4/26/21	4
2020-2021	Winter/Spring	Scott Sugar Confluence	8	0.08	0.043	12/17/20	3/24/21	2
2020-2021	Winter/Spring	Sugar BP1	11	0.155	0.047	12/17/20	3/24/21	2

Table 19. Monthly average fork length (mm) and standard deviation by cohort and location. Includes all fork length data, not just fish that were recaptured. The "Coastal Comparison" column classifies average fork length as lower, similar, or higher than sites in northern California coastal tributaries (Table 20).

Cohort	Month	Location	Avg FL	SD FL	n	Coastal Comparison
2016-2017	7	Sugar BP2 Complex	62	7	183	
2016-2017	7	Sugar BP1	68	7	275	
2016-2017	7	Scott Sugar Confluence	65	9	5	
2016-2017	8	Sugar BP2 Complex	69	7	454	Lower
2016-2017	8	Sugar BP1	71	7	485	Lower
2016-2017	8	French Mainstem Reach	71	7	367	Lower
2016-2017	9	Sugar BP2 Complex	75	9	265	
2016-2017	9	Sugar BP1	80	8	282	
2016-2017	9	French Mainstem Reach	73	7	591	
2016-2017	10	Sugar BP2 Complex	74	7	333	Lower
2016-2017	4	Sugar BP2 Complex	115	8	91	
2016-2017	5	Sugar BP2 Complex	118	5	9	
2016-2017	6	Sugar BP2 Complex	78	37	7	
2017-2018	7	Sugar BP2 Complex	59	8	155	
2017-2018	7	Sugar BP1	68	6	399	

Cohort	Month	Location	Avg FL	SD FL	n	Coastal Comparison
2017-2018	7	Scott Sugar Confluence	69	3	12	
2017-2018	7	French Mainstem Reach	70	9	237	
2017-2018	8	Sugar BP2 Complex	61	7	166	
2017-2018	8	Sugar BP1	73	6	307	
2017-2018	8	Scott Sugar Confluence	69	4	7	
2017-2018	8	French Mainstem Reach	72	6	264	
2017-2018	9	Sugar BP2 Complex	72	8	219	
2017-2018	9	Sugar BP1	81	6	312	
2017-2018	9	Scott Sugar Confluence	73	4	46	
2017-2018	9	French Mainstem Reach	76	5	238	
2017-2018	10	Sugar BP2 Complex	83	9	43	
2017-2018	10	Sugar BP1	86	6	158	
2017-2018	2	Sugar BP1	95	6	18	
2017-2018	4	Sugar BP2 Complex	102	9	101	
2017-2018	4	Sugar BP1	97	7	90	
2018-2019	7	Sugar BP2 Complex	52	8	152	
2018-2019	7	Sugar BP1	70	7	163	
2018-2019	7	Scott Sugar Confluence	67	5	162	
2018-2019	8	Sugar BP2 Complex	56	6	53	
2018-2019	9	Sugar BP1	74	5	415	
2018-2019	9	French Mainstem Reach	69	6	570	
2018-2019	1	French FRGP SC	82	7	138	Lower
2018-2019	3	Sugar BP2 Complex	88	12	35	Similar
2018-2019	3	Sugar BP1	96	7	26	Similar
2018-2019	3	French Mainstem Reach	83	8	23	Lower
2018-2019	3	Mid French SC BDA	89	10	132	Similar
2018-2019	3	French ELJ	81	7	11	Lower

Cohort	Month	Location	Avg FL	SD FL	n	Coastal Comparison
2018-2019	3	French FRGP SC	85	7	283	Lower
2018-2019	4	Mid French SC BDA	103	11	19	Lower
2018-2019	4	French FRGP SC	98	10	19	Lower
2019-2020	7	Sugar BP1	70	7	365	
2019-2020	8	Sugar BP2 Complex	64	5	104	Lower
2019-2020	8	Sugar BP1	71	7	371	Similar
2019-2020	8	French Mainstem Reach	67	9	448	Lower
2019-2020	8	French ELJ	67	6	151	Similar
2019-2020	8	French FRGP SC	75	8	84	Higher
2019-2020	9	Sugar BP2 Complex	75	10	121	
2019-2020	9	Sugar BP1	73	7	551	
2019-2020	9	French ELJ	72	5	234	
2019-2020	9	French FRGP SC	81	8	23	
2019-2020	10	Sugar BP1	80	6	413	Similar
2019-2020	10	French Mainstem Reach	76	9	579	Lower
2019-2020	11	Sugar BP2 Complex	80	8	234	
2019-2020	11	Sugar BP1	80	7	450	
2019-2020	11	French ELJ	75	6	129	
2019-2020	11	French FRGP SC	91	10	172	
2019-2020	1	Sugar BP2 Complex	85	6	372	Similar
2019-2020	1	Sugar BP1	84	6	486	Similar
2019-2020	1	French Mainstem Reach	78	9	133	Lower
2019-2020	1	French ELJ	78	6	110	Lower
2019-2020	1	French FRGP SC	87	11	567	Similar
2019-2020	2	Mid French SC BDA	79	8	82	Lower
2019-2020	3	Sugar BP2 Complex	95	7	190	Similar
2019-2020	3	Sugar BP1	88	6	571	Lower

Cohort	Month	Location	Avg FL	SD FL	n	Coastal Comparison
2019-2020	3	French Mainstem Reach	87	10	55	Lower
2019-2020	3	Mid French SC BDA	86	7	80	Lower
2019-2020	3	French ELJ	83	8	59	Lower
2019-2020	3	French FRGP SC	90	12	230	Similar
2019-2020	4	Mid French SC BDA	89	9	64	Lower
2020-2021	7	Sugar BP1	67	9	369	Similar
2020-2021	7	Scott Sugar Confluence	62	6	58	Lower
2020-2021	7	French Mainstem Reach	65	10	576	Lower
2020-2021	7	French ELJ	61	6	720	Lower
2020-2021	10	Scott Sugar Confluence	70	5	78	Lower
2020-2021	10	French Mainstem Reach	70	7	739	Lower
2020-2021	10	French ELJ	67	5	660	Lower
2020-2021	12	Sugar BP1	85	9	28	Similar
2020-2021	12	Scott Sugar Confluence	78	5	70	Lower
2020-2021	12	French Mainstem Reach	75	11	39	Lower
2020-2021	12	French ELJ	73	4	15	Lower
2020-2021	12	French FRGP SC	74	8	440	Lower
2020-2021	1	Mid French SC BDA	76	9	79	Lower
2020-2021	1	French ELJ	70	5	55	Lower
2020-2021	1	French FRGP SC	77	9	224	Lower
2020-2021	2	Sugar BP1	96	9	17	Similar
2020-2021	2	Scott Sugar Confluence	82	4	8	Similar
2020-2021	2	French Mainstem Reach	77	8	68	Lower
2020-2021	2	Mid French SC BDA	80	9	138	Lower
2020-2021	2	French ELJ	73	5	80	Lower
2020-2021	2	French FRGP SC	78	9	544	Lower
2020-2021	3	Sugar BP1	102	8	22	Similar

Cohort	Month	Location	Avg FL	SD FL	n	Coastal Comparison
2020-2021	3	Scott Sugar Confluence	88	5	18	Lower
2020-2021	3	French Mainstem Reach	81	8	24	Lower
2020-2021	3	Mid French SC BDA	84	8	54	Lower
2020-2021	3	French ELJ	74	7	23	
2020-2021	3	French FRGP SC	79	9	209	
2020-2021	4	Mid French SC BDA	91	10	128	

Table 20. Monthly average forklength (mm) and standard deviation in coastal tributaries in Northern California provided for comparison to my sites (Faukner 2022; Pagliucco 2019; Taylor 2020; Taylor 2021).

Years	Date	Tributary	Avg FL	SD FL	n
2016	Aug	Lawrence Creek	84.75	4.35	4
		Strawberry Creek	85.00	29.02	8
	Oct	Strawberry Creek	90.15	6.45	13
	Nov	Lawrence Creek	102.00	2.00	3
		Strawberry Creek	90.12	14.74	17
	Dec	Lawrence Creek	88.29	7.65	7
		Strawberry Creek	97.81	6.50	16
2017	Jan	Lawrence Creek	93.86	7.84	7
	Feb	Lawrence Creek	91.00	9.80	5
		Strawberry Creek	117.00	7.84	5
	Mar	Lawrence Creek	96.50	9.08	14
2018	Dec	McGarvey Creek	94.00	NA	1
2019	Jan	Lawrence Creek	83.76	9.53	17
		Martin Slough	64.67	5.86	3
		McGarvey Creek	94.49	11.69	65

Years	Date	Tributary	Avg FL	SD FL	n
	Feb	Martin Slough	75.39	8.34	18
	Mar	Lawrence Creek	96.00	7.90	6
		Martin Slough	84.94	8.14	16
		McGarvey Creek	114.74	12.14	112
	Apr	McGarvey Creek	132.36	12.01	25
	May	McGarvey Creek	137.33	12.79	24
	Jun	McGarvey Creek	145.00	NA	1
	Aug	McGarvey Creek	67.22	3.36	23
	Oct	McGarvey Creek	79.43	5.20	23
	Dec	Freshwater Creek	79.90	9.86	100
2020	Jan	Freshwater Creek	85.59	10.81	128
	Feb	Freshwater Creek	88.39	10.85	143
	Mar	Freshwater Creek	92.53	9.87	118
	Apr	Freshwater Creek	108.31	6.23	26
	May	Freshwater Creek	61.13	19.41	23
	Jun	Freshwater Creek	64.19	6.94	59
	Jul	Freshwater Creek	69.78	5.53	37
	Aug	McGarvey Creek	79.43	5.35	42
	Sep	Freshwater Creek	78.57	5.63	23
		McGarvey Creek	80.27	9.57	11
	Oct	Freshwater Creek	84.75	5.97	8
		McGarvey Creek	87.43	6.20	58
	Nov	Freshwater Creek	83.19	5.01	16
	Dec	Freshwater Creek	82.65	8.82	52
2021	Jan	McGarvey Creek	103.82	8.53	11
	Feb	Freshwater Creek	83.00	8.64	32
		McGarvey Creek	103.09	8.35	11

Years	Date	Tributary	Avg FL	SD FL	n
	Mar	Freshwater Creek	92.00	7.66	26
		McGarvey Creek	121.44	10.78	9
	Apr	Freshwater Creek	96.76	9.61	17
		McGarvey Creek	128.00	16.97	2
	May	Freshwater Creek	107.39	8.68	18
2022	Aug	McGarvey Creek	73.95	8.57	58
	Oct	McGarvey Creek	80.22	8.81	58

Table 21. Summary results from the global Generalized Additive Model (GAM) describing juvenile coho fork length through time for 2016-2021. Table values indicate the effective degrees of freedom (edf), F-statistic (F), and the standard error (SE) associated with each non-linear explanatory variable. FL ~ s(DaySinceOct1, by = Cohort_Location, k = 7, sp = 0.08) + Cohort +Location + s(PIT, bs = "re").

Predictor	Edf	Ref.df	F	P
s(DaySinceOct1):2016-2017_Sugar BP2 Complex	2.15	2.32	674.48	<0.001
s(DaySinceOct1):2016-2017_French Mainstem Reach	2.23	2.50	66.71	<0.001
s(DaySinceOct1):2016-2017_Sugar BP1	2.42	2.72	250.33	<0.001
s(DaySinceOct1):2018-2019_French Mainstem Reach	1.08	1.10	34.91	0.004
s(DaySinceOct1):2018-2019_French FRGP SC	2.09	2.43	89.03	<0.001
s(DaySinceOct1):2018-2019_Sugar BP1	2.18	2.39	369.19	<0.001
s(DaySinceOct1):2017-2018_Sugar BP1	3.75	4.39	1098.10	<0.001
s(DaySinceOct1):2017-2018_Sugar BP2 Complex	2.08	2.31	383.53	<0.001
s(DaySinceOct1):2017-2018_French Mainstem Reach	2.26	2.52	133.99	<0.001
s(DaySinceOct1):2019-2020_Sugar BP1	4.17	4.56	1135.89	<0.001
s(DaySinceOct1):2019-2020_Sugar BP2 Complex	3.26	3.63	629.54	<0.001
s(DaySinceOct1):2019-2020_French FRGP SC	2.94	3.22	332.81	<0.001
s(DaySinceOct1):2019-2020_French Mainstem Reach	2.85	3.00	471.87	<0.001
s(DaySinceOct1):2020-2021_French Mainstem Reach	3.02	3.41	61.94	<0.001

Predictor	Edf	Ref.df	F	P
s(DaySinceOct1):2020-2021_French FRGP SC	2.84	3.19	61.13	<0.001
s(DaySinceOct1):2020-2021_French ELJ	2.66	3.06	54.97	<0.001
s(DaySinceOct1):2020-2021_Mid French SC BDA	2.30	2.56	414.61	<0.001
s(DaySinceOct1):2020-2021_Scott Sugar Confluence	1.89	2.15	49.75	<0.001
s(DaySinceOct1):2020-2021_Sugar BP1	1.81	2.04	153.41	<0.001
s(DaySinceOct1):2019-2020_French ELJ	2.99	3.53	130.87	<0.001
s(DaySinceOct1):2019-2020_Mid French SC BDA	1.90	2.15	426.46	<0.001
s(PIT)	2096.53	2182.00	17.73	<0.001

Appendix B. Multistate Model Supporting Data

Table 22. Summary of number of tagged fish by Cohort, Location, and Season.

Cohort	Tributary	Location	Season	# Tagged
2016-2017	French Creek	French Mainstem Reach	Summer	315
2016-2017	Sugar Creek	Sugar BP1	Summer	386
2016-2017	Sugar Creek	Sugar BP2 Complex	Summer	345
2017-2018	French Creek	French Mainstem Reach	Summer	319
2017-2018	Miners Creek	Miners US Control Pools	Summer	69
2017-2018	Scott River	Scott Sugar Confluence	Summer	61
2017-2018	Sugar Creek	Sugar BP1	Summer	684
2017-2018	Sugar Creek	Sugar BP1	Fall	84
2017-2018	Sugar Creek	Sugar BP2 Complex	Summer	206
2017-2018	Sugar Creek	Sugar BP2 Complex	Fall	40
2018-2019	French Creek	DS pre ELJs	Summer	30
2018-2019	French Creek	French Mainstem Reach	Summer	369
2018-2019	French Creek	French ELJ	Winter	11
2018-2019	French Creek	French FRGP SC	Winter	308
2018-2019	French Creek	Mid French SC BDA	Spring	42
2018-2019	French Creek	Pre ELJs	Summer	4
2018-2019	Miners Creek	Miners US Control Pools	Summer	33
2018-2019	Scott River	Scott Sugar Confluence	Summer	93
2018-2019	Sugar Creek	Sugar BP1	Summer	259
2018-2019	Sugar Creek	Sugar BP2 Complex	Summer	7
2018-2019	Sugar Creek	Sugar BP2 Complex	Winter	4

Cohort	Tributary	Location	Season	# Tagged
2019-2020	French Creek	French Mainstem Reach	Summer	233
2019-2020	French Creek	French Mainstem Reach	Fall	310
2019-2020	French Creek	French Mainstem Reach	Winter	83
2019-2020	French Creek	French ELJ	Summer	286
2019-2020	French Creek	French ELJ	Fall	50
2019-2020	French Creek	French ELJ	Winter	43
2019-2020	French Creek	French FRGP SC	Summer	103
2019-2020	French Creek	French FRGP SC	Fall	152
2019-2020	French Creek	French FRGP SC	Winter	170
2019-2020	French Creek	French Gravel Wood	Winter	12
2019-2020	French Creek	Mid French SC BDA	Winter	71
2019-2020	Sugar Creek	SugarBelowBDA1	Summer	12
2019-2020	Sugar Creek	Sugar BP1	Summer	691
2019-2020	Sugar Creek	Sugar BP1	Fall	300
2019-2020	Sugar Creek	Sugar BP1	Winter	336
2019-2020	Sugar Creek	Sugar BP2 Complex	Summer	147
2019-2020	Sugar Creek	Sugar BP2 Complex	Fall	151
2019-2020	Sugar Creek	Sugar BP2 Complex	Winter	263
2019-2020	Sugar Creek	Sugar Control	Summer	70
2019-2020	Sugar Creek	Sugar Control	Fall	8
2020-2021	French Creek	French Below Miners	Summer	59
2020-2021	French Creek	French Below Miners	Fall	98
2020-2021	French Creek	French Mainstem Reach	Summer	206
2020-2021	French Creek	French Mainstem Reach	Fall	306
2020-2021	French Creek	French Mainstem Reach	Winter	37

Cohort	Tributary	Location	Season	# Tagged
2020-2021	French Creek	French ELJ	Summer	135
2020-2021	French Creek	French ELJ	Fall	210
2020-2021	French Creek	French ELJ	Winter	54
2020-2021	French Creek	French FRGP SC	Fall	206
2020-2021	French Creek	French FRGP SC	Winter	237
2020-2021	French Creek	French Gravel Wood	Fall	13
2020-2021	French Creek	French Gravel Wood	Winter	22
2020-2021	French Creek	Mid French SC BDA	Winter	101
2020-2021	French Creek	US ELJs	Fall	24
2020-2021	Miners Creek	Miners Above French	Summer	39
2020-2021	Miners Creek	Miners Above French	Fall	8
2020-2021	Miners Creek	Miners BDAs	Summer	28
2020-2021	Miners Creek	Miners BDAs	Fall	55
2020-2021	Miners Creek	Miners BDAs	Winter	89
2020-2021	Miners Creek	Miners US Control Pools	Summer	2
2020-2021	Miners Creek	Miners US Control Pools	Fall	24
2020-2021	Miners Creek	Miners US Control Pools	Winter	33
2020-2021	Scott River	Scott Sugar Confluence	Summer	70
2020-2021	Scott River	Scott Sugar Confluence	Fall	63
2020-2021	Scott River	Scott Sugar Confluence	Winter	3
2020-2021	Sugar Creek	Sugar BP1	Summer	165
2020-2021	Sugar Creek	Sugar BP1	Fall	27
2020-2021	Sugar Creek	Sugar BP1	Winter	10

132

Table 23. 2019-2020 count of unique individuals detected on PIT antenna or inhand scanner by season and location.

Cohort	Tributary	State	Location	Season	nPit
2016-2017	French Creek	NA	French Mainstem Reach	summer	317
2016-2017	Sugar Creek	NA	Sugar BP1	summer	387
2016-2017	Sugar Creek	NA	Sugar BP2 Complex	summer	334
2017-2018	French Creek	NA	French Mainstem Reach	summer	323
2017-2018	Sugar Creek	NA	Sugar BP1	summer	687
2017-2018	Sugar Creek	NA	Sugar BP2 Complex	summer	207
2018-2019	Sugar Creek	NA	Sugar BP1	summer	479
2019-2020	Sugar Creek	A	Sugar BP2	summer	154
2019-2020	Sugar Creek	A	Sugar BP2	fall	246
2019-2020	Sugar Creek	A	Sugar BP2	winter	499
2019-2020	Sugar Creek	A	Sugar BP2	spring	388
2019-2020	Sugar Creek	B	Sugar BP1	summer	699
2019-2020	Sugar Creek	B	Sugar BP1	fall	653
2019-2020	Sugar Creek	B	Sugar BP1	winter	971
2019-2020	Sugar Creek	B	Sugar BP1	spring	961
2019-2020	Sugar Creek	C	Sugar Below BDA1	summer	19
2019-2020	Sugar Creek	C	Sugar Below BDA1	fall	1
2019-2020	Sugar Creek	C	Sugar Below BDA1	winter	11
2019-2020	Sugar Creek	C	Sugar Below BDA1	spring	718
2019-2020	French Creek	D	French Mainstem Reach	summer	233
2019-2020	French Creek	D	French Mainstem Reach	fall	406
2019-2020	French Creek	D	French Mainstem Reach	winter	126
2019-2020	French Creek	D	French Mainstem Reach	spring	26
2019-2020	French Creek	E	French SC BDA	winter	85
2019-2020	French Creek	E	French SC BDA	spring	83

Cohort	Tributary	State	Location	Season	nPit
2019-2020	French Creek	F	French FRGP SC + ELJ	summer	391
2019-2020	French Creek	F	French FRGP SC + ELJ	fall	396
2019-2020	French Creek	F	French FRGP SC + ELJ	winter	730
2019-2020	French Creek	F	French FRGP SC + ELJ	spring	189
2019-2020	French Creek	G	French DS mainstem antenna	summer	4
2019-2020	French Creek	G	French DS mainstem antenna	fall	24
2019-2020	French Creek	G	French DS mainstem antenna	winter	551
2019-2020	French Creek	G	French DS mainstem antenna	spring	417
2020-2021	Sugar Creek	A	Sugar BP2 Complex	summer	3
2020-2021	Sugar Creek	A	Sugar BP2 Complex	winter	3
2020-2021	Sugar Creek	A	Sugar BP2 Complex	spring	11
2020-2021	Sugar Creek	B	Sugar BP1	summer	447
2020-2021	Sugar Creek	B	Sugar BP1	fall	30
2020-2021	Sugar Creek	B	Sugar BP1	winter	49
2020-2021	Sugar Creek	B	Sugar BP1	spring	39
2020-2021	Sugar Creek	C	Sugar Below BDA1	fall	22
2020-2021	Sugar Creek	C	Sugar Below BDA1	winter	8
2020-2021	Sugar Creek	C	Sugar Below BDA1	spring	31
2020-2021	French Creek	D	French Mainstem Reach	summer	216
2020-2021	French Creek	D	French Mainstem Reach	fall	460
2020-2021	French Creek	D	French Mainstem Reach	winter	101
2020-2021	French Creek	D	French Mainstem Reach	spring	17
2020-2021	French Creek	E	French SC BDA	winter	122
2020-2021	French Creek	E	French SC BDA	spring	113
2020-2021	French Creek	F	French FRGP SC + ELJ	summer	152
2020-2021	French Creek	F	French FRGP SC + ELJ	fall	838
2020-2021	French Creek	F	French FRGP SC + ELJ	winter	793

Cohort	Tributary	State	Location	Season	nPit
2020-2021	French Creek	F	French FRGP SC + ELJ	spring	449
2020-2021	French Creek	G	French DS mainstem antenna	summer	7
2020-2021	French Creek	G	French DS mainstem antenna	fall	230
2020-2021	French Creek	G	French DS mainstem antenna	winter	221
2020-2021	French Creek	G	French DS mainstem antenna	spring	433

Table 24. 2019-2020 and 2020-2021 transition counts prior to manually editing capture histories by season. The fix column designates if a transition was grouped into a seasonal "background transition rate", fixed to 0, not fixed, or censored. State Z represents out of basin and was included to show fish that outmigrated but were not detected on a downstream antenna in Sugar or French.

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2019-2020	Sugar	summer	spring	A	B	1	fix
2019-2020	Sugar	fall	fall	A	B	1	group
2019-2020	Sugar	fall	spring	A	B	1	group
2019-2020	Sugar	winter	spring	A	B	15	no fix
2019-2020	Sugar	winter	winter	A	B	6	no fix
2019-2020	Sugar	spring	spring	A	B	75	no fix
2019-2020	Sugar	summer	spring	A	C	2	fix
2019-2020	Sugar	summer	winter	A	C	2	fix
2019-2020	Sugar	fall	spring	A	C	1	fix
2019-2020	Sugar	winter	spring	A	C	26	group
2019-2020	Sugar	winter	winter	A	C	1	group
2019-2020	Sugar	spring	spring	A	C	241	no fix
2019-2020	Sugar	spring	summer1+	A	C	2	
2019-2020	Sugar	winter	spring	A	G	1	censor
2019-2020	Sugar	spring	spring	A	G	10	censor
2019-2020	Sugar	summer	fall	B	A	2	no fix

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2019-2020	Sugar	summer	summer	B	A	7	no fix
2019-2020	Sugar	fall	fall	B	A	4	no fix
2019-2020	Sugar	winter	spring	B	A	1	no fix
2019-2020	Sugar	winter	winter	B	A	9	no fix
2019-2020	Sugar	spring	spring	B	A	11	no fix
2019-2020	Sugar	summer	spring	B	C	4	no fix
2019-2020	Sugar	summer	summer	B	C	7	no fix
2019-2020	Sugar	summer	winter	B	C	1	no fix
2019-2020	Sugar	winter	spring	B	C	5	no fix
2019-2020	Sugar	winter	winter	B	C	7	no fix
2019-2020	Sugar	spring	spring	B	C	439	no fix
2019-2020	Sugar	spring	summer1+	B	C	6	no fix
2019-2020	Sugar	spring	spring	B	G	26	censor
2019-2020	Sugar	summer	summer	C	A	0	fix
2019-2020	Sugar	spring	spring	C	A	0	fix
2019-2020	Sugar	fall	fall	C	all	0	fix
2019-2020	Sugar	winter	winter	C	all	0	fix
2019-2020	Sugar	summer	summer	C	B	8	fix
2019-2020	Sugar	spring	spring	C	G	5	censor
2019-2020	Sugar	spring	spring	C	B	1	fix
2019-2020	French	summer	winter	D	E	2	fix
2019-2020	French	fall	spring	D	E	2	fix
2019-2020	French	fall	winter	D	E	4	fix
2019-2020	French	winter	spring	D	E	2	no fix
2019-2020	French	winter	winter	D	E	4	no fix
2019-2020	French	spring	spring	D	E	0	group
2019-2020	French	summer	fall	D	F	4	group

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2019-2020	French	summer	spring	D	F	2	group
2019-2020	French	summer	summer	D	F	2	group
2019-2020	French	summer	winter	D	F	21	group
2019-2020	French	fall	fall	D	F	14	no fix
2019-2020	French	fall	spring	D	F	9	no fix
2019-2020	French	fall	winter	D	F	55	no fix
2019-2020	French	winter	spring	D	F	5	no fix
2019-2020	French	winter	winter	D	F	22	no fix
2019-2020	French	spring	spring	D	F	1	group
2019-2020	French	summer	fall	D	G	2	group
2019-2020	French	summer	spring	D	G	20	group
2019-2020	French	summer	winter	D	G	7	group
2019-2020	French	fall	fall	D	G	11	no fix
2019-2020	French	fall	spring	D	G	57	no fix
2019-2020	French	fall	winter	D	G	35	no fix
2019-2020	French	winter	spring	D	G	39	no fix
2019-2020	French	winter	summer1+	D	G	3	no fix
2019-2020	French	winter	winter	D	G	23	no fix
2019-2020	French	spring	spring	D	G	19	no fix
2019-2020	French	winter	winter	E	D	0	fix
2019-2020	French	spring	spring	E	D	0	fix
2019-2020	French	winter	spring	E	F	0	fix
2019-2020	French	spring	spring	E	F	2	group
2019-2020	French	winter	winter	E	G	1	group
2019-2020	French	spring	spring	E	G	72	no fix
2019-2020	French	summer	fall	F	D	4	group
2019-2020	French	fall	winter	F	D	1	group

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2019-2020	French	spring	spring	F	D	0	fix
2019-2020	French	summer	winter	F	E	2	fix
2019-2020	French	fall	winter	F	E	1	fix
2019-2020	French	spring	spring	F	E	0	fix
2019-2020	French	summer	fall	F	G	6	group
2019-2020	French	summer	spring	F	G	12	group
2019-2020	French	summer	summer	F	G	4	group
2019-2020	French	summer	winter	F	G	18	group
2019-2020	French	fall	fall	F	G	4	no fix
2019-2020	French	fall	spring	F	G	8	no fix
2019-2020	French	fall	winter	F	G	21	no fix
2019-2020	French	winter	spring	F	G	31	no fix
2019-2020	French	winter	winter	F	G	446	no fix
2019-2020	French	spring	spring	F	G	150	no fix
2019-2020	French	fall	fall	G	all	0	fix
2019-2020	French	spring	spring	G	D, E	0	fix
2019-2020	French	winter	spring	G	E	1	group
2019-2020	French	winter	spring	G	F	8	group
2019-2020	French	spring	spring	G	F	6	fix
2020-2021	Sugar	all		A	B	0	fix
2020-2021	Sugar	spring	spring	A	C	2	group
2020-2021	Sugar	summer, fall, winter		A	C	0	fix
2020-2021	Sugar	summer	summer	B	A	2	group
2020-2021	Sugar	fall	winter	B	A	2	group
2020-2021	Sugar	winter	winter	B	A	1	group
2020-2021	Sugar	spring	spring	B	A	7	no fix
2020-2021	Sugar	summer		B	C	0	fix

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2020-2021	Sugar	fall	spring	B	C	2	group
2020-2021	Sugar	fall	winter	B	C	3	
2020-2021	Sugar	winter	spring	B	C	3	
2020-2021	Sugar	winter	winter	B	C	1	group
2020-2021	Sugar	spring	spring	B	C	19	no fix
2020-2021	Sugar	fall	winter	B	Z	1	
2020-2021	Sugar	spring	spring	B	Z	5	
2020-2021	Sugar	all		C	A	0	fix
2020-2021	Sugar	summer		C	B	0	fix
2020-2021	Sugar	fall	fall	C	B	2	group
2020-2021	Sugar	fall	winter	C	B	10	group
2020-2021	Sugar	winter	winter	C	B	1	group
2020-2021	Sugar	spring		C	B	0	fix
2020-2021	French	summer	winter	D	E	2	fix
2020-2021	French	fall	spring	D	E	3	group
2020-2021	French	fall	winter	D	E	18	group
2020-2021	French	winter	winter	D	E	0	group
2020-2021	French	spring	spring	D	E	0	group
2020-2021	French	summer	fall	D	F	28	
2020-2021	French	summer	spring	D	F	3	
2020-2021	French	summer	summer	D	F	3	group
2020-2021	French	summer	winter	D	F	3	
2020-2021	French	fall	fall	D	F	129	no fix
2020-2021	French	fall	spring	D	F	13	
2020-2021	French	fall	winter	D	F	24	
2020-2021	French	winter	spring	D	F	7	
2020-2021	French	winter	winter	D	F	13	no fix

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2020-2021	French	spring	spring	D	F	2	group
2020-2021	French	summer	fall	D	G	20	
2020-2021	French	summer	spring	D	G	9	
2020-2021	French	summer	summer	D	G	3	group
2020-2021	French	summer	winter	D	G	2	
2020-2021	French	fall	fall	D	G	79	no fix
2020-2021	French	fall	spring	D	G	32	
2020-2021	French	fall	summer1+	D	G	4	
2020-2021	French	fall	winter	D	G	19	
2020-2021	French	winter	spring	D	G	44	
2020-2021	French	winter	summer1+	D	G	5	
2020-2021	French	winter	winter	D	G	8	no fix
2020-2021	French	spring	spring	D	G	10	no fix
2020-2021	French	fall	summer1+	D	Z	1	
2020-2021	French	all		E	D	0	fix
2020-2021	French	summer		E	F	0	fix
2020-2021	French	fall		E	F	0	fix
2020-2021	French	winter	winter	E	F	2	group
2020-2021	French	spring	spring	E	F	10	no fix
2020-2021	French	summer		E	G	0	fix
2020-2021	French	fall	fall	E	G	1	group
2020-2021	French	winter	spring	E	G	4	group
2020-2021	French	spring	spring	E	G	69	no fix
2020-2021	French	spring	summer1+	E	G	1	
2020-2021	French	summer	fall	F	D	11	
2020-2021	French	summer	summer	F	D	9	no fix
2020-2021	French	fall	fall	F	D	28	no fix

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2020-2021	French	fall	winter	F	D	2	
2020-2021	French	winter	spring	F	D	1	
2020-2021	French	winter	winter	F	D	4	no fix
2020-2021	French	spring	spring	F	D	1	group
2020-2021	French	spring	spring	F	E	1	group
2020-2021	French	summer, fall, winter		F	E	0	fix
2020-2021	French	summer	fall	F	G	8	
2020-2021	French	summer	spring	F	G	1	
2020-2021	French	summer	summer	F	G	4	no fix
2020-2021	French	summer	summer1+	F	G	1	
2020-2021	French	fall	fall	F	G	94	no fix
2020-2021	French	fall	spring	F	G	9	
2020-2021	French	fall	winter	F	G	24	
2020-2021	French	winter	spring	F	G	78	
2020-2021	French	winter	summer1+	F	G	1	
2020-2021	French	winter	winter	F	G	165	no fix
2020-2021	French	spring	spring	F	G	175	no fix
2020-2021	French	spring	summer1+	F	G	21	
2020-2021	French	winter	summer1+	F	Z	2	
2020-2021	French	spring	spring	F	Z	1	
2020-2021	French	spring	summer1+	F	Z	2	
2020-2021	French	all		G	D	0	fix
2020-2021	French	all		G	E	0	fix
2020-2021	French	summer		G	F	0	fix
2020-2021	French	fall	fall	G	F	1	group
2020-2021	French	fall	spring	G	F	9	
2020-2021	French	fall	winter	G	F	1	

Cohort	Tributary	Season 1	Season 2	State 1	State 2	nPIT	Fix?
2020-2021	French	winter	spring	G	F	5	
2020-2021	French	winter	winter	G	F	2	group
2020-2021	French	spring	spring	G	F	15	fix