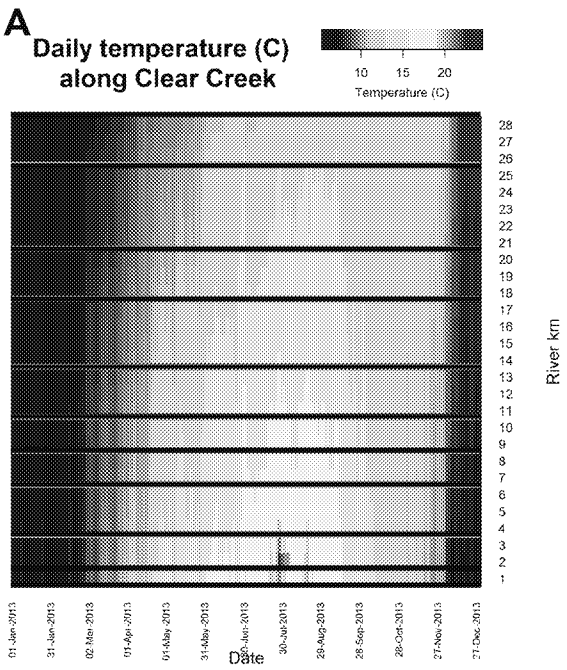
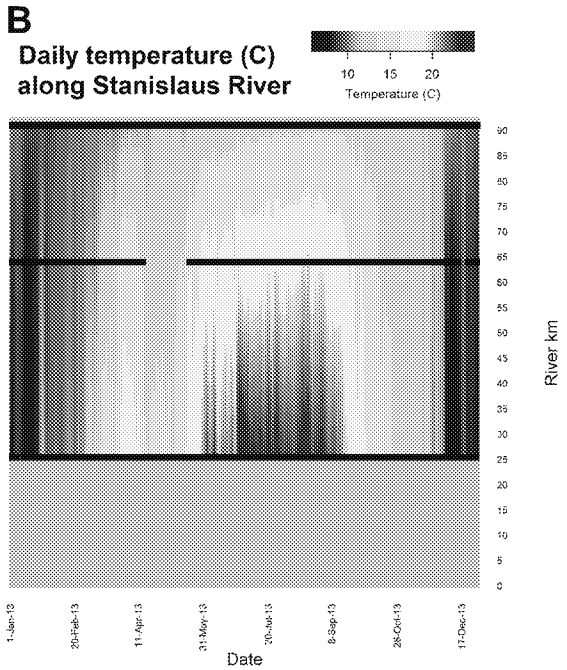

A
Daily temperature (C)
along Clear Creek
10 15 20
Temperature (C)
River km
Date


B
Daily temperature (C)
along Stanislaus River
10 15 20
Temperature (C)
River km
Date

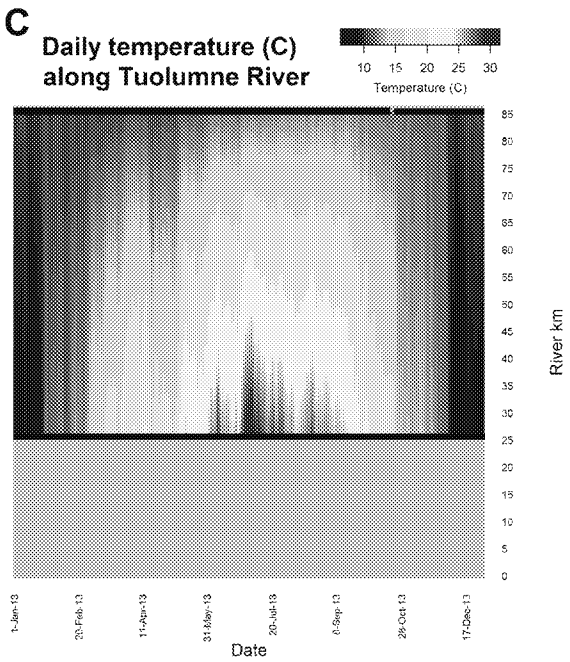

C
Daily temperature (C)
along Tuolumne River
10 15 20 25 30
Temperature (C)
River km
Date

Figure 2. Interpolated temperatures along A) Clear Creek, B) Stanislaus River, and C) Tuolumne River from 2013. The black dots show locations of temperature monitors (vertical axis) and availability of temperatures (horizontal axis). Temporal gaps of less than 30 days were filled in prior to spatial interpolation. Gray pixels are areas with no data. The vertical axis shows river km number from the confluence (river km 0) upstream to an impassible dam; Clear Creek: Sacramento River upstream to the Whiskeytown Dam (river km 28); Stanislaus River: San Joaquin River upstream to the Goodwin Dam (river km 92); Tuolumne River: San Joaquin River upstream to LaGrange Dam (river km 86).

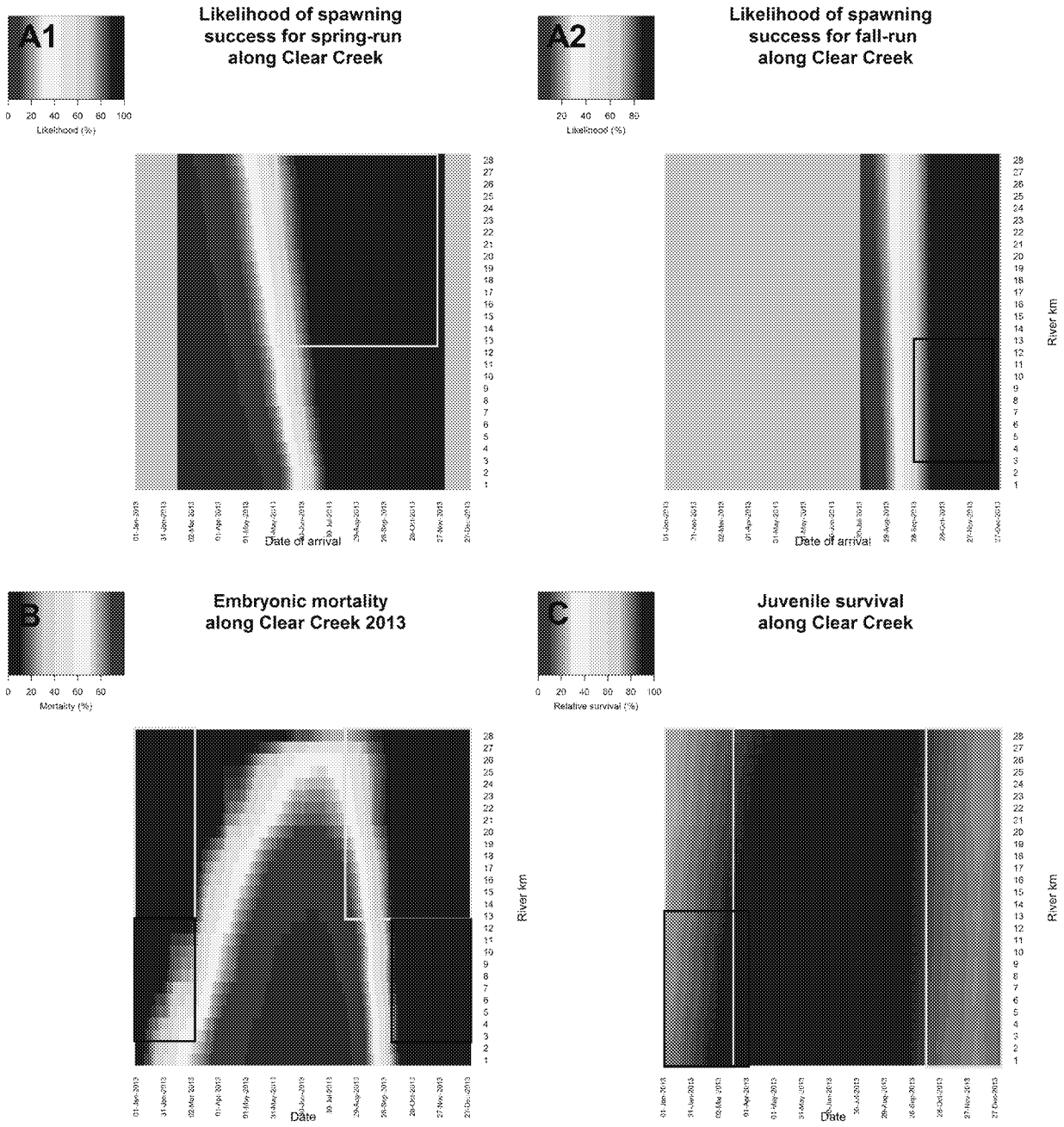


Figure 3. Application of temperature-dependent models to Clear Creek for 2013. The boxes show the approximate spatial/temporal extent of each life stage (i.e. holding, incubation, early rearing) for spring-run (gray) and fall-run (black). A) Likelihood of spawning success based on metabolic expenditure of adults during holding (A1 is spring-run, A2 is fall-run) from arrival date (x-axis) to a randomized spawning date based on a weighted distribution over 1000 replicates (see text). Each location in space and time (pixel) indicates the likelihood that an adult arriving at that point in time and space will have enough energy to spawn. Gray areas were outside of the temporal buffer zone and were not run (see text). B) Egg-to-fry mortality. Each location in space and time (pixel) indicates that percentage of eggs spawned at that spatial location that would experience temperature-dependent mortality prior to emergence. The length of the embryonic period was determined by the temperature-dependent maturation function. C)

Likelihood of juvenile survival to smolt size. Each location in space and time (pixel) is the calculated relative smolt likelihood based on the temperatures experienced relative to the optimum temperature producing maximum growth rate and a daily background mortality (see text).

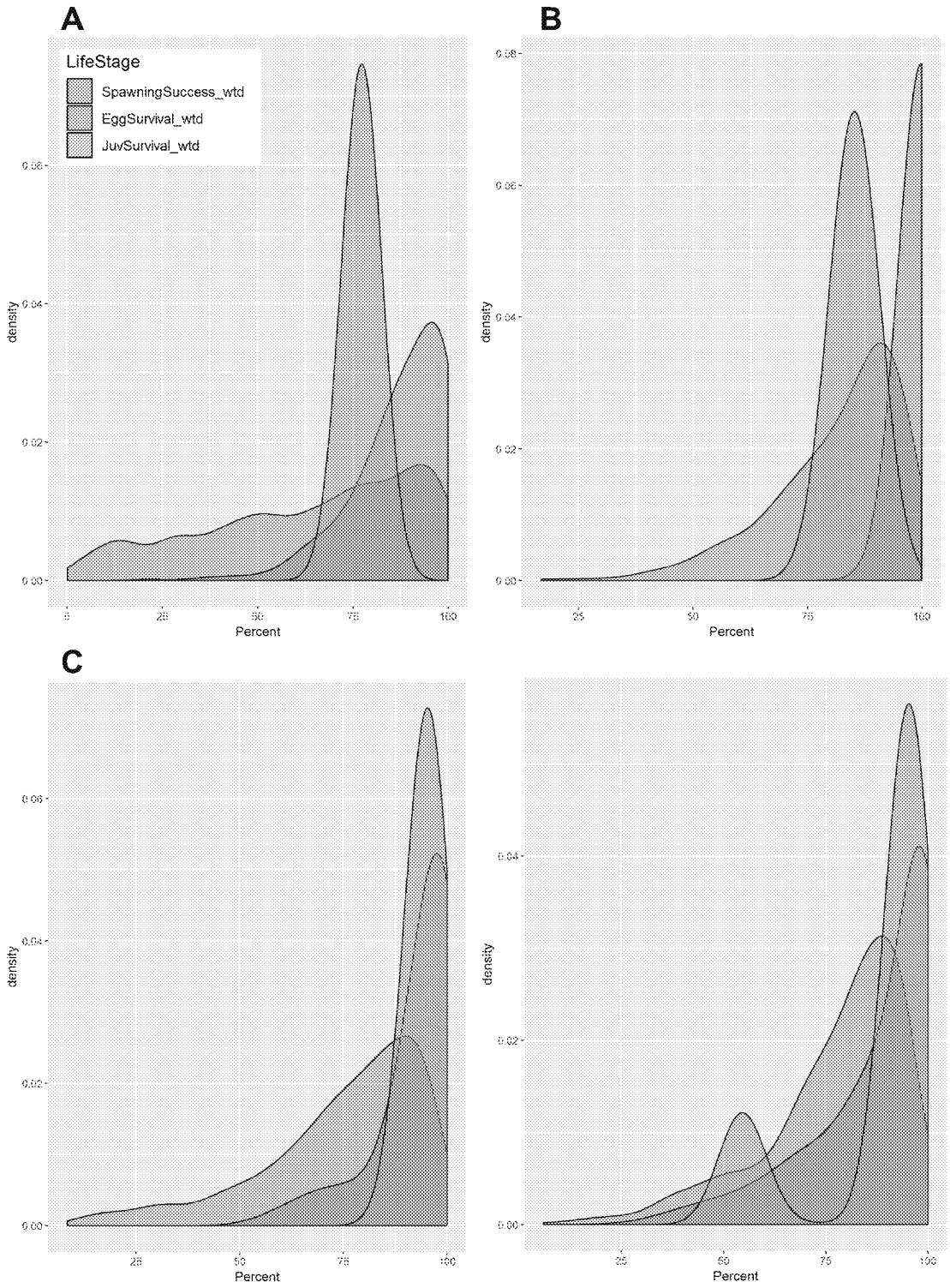
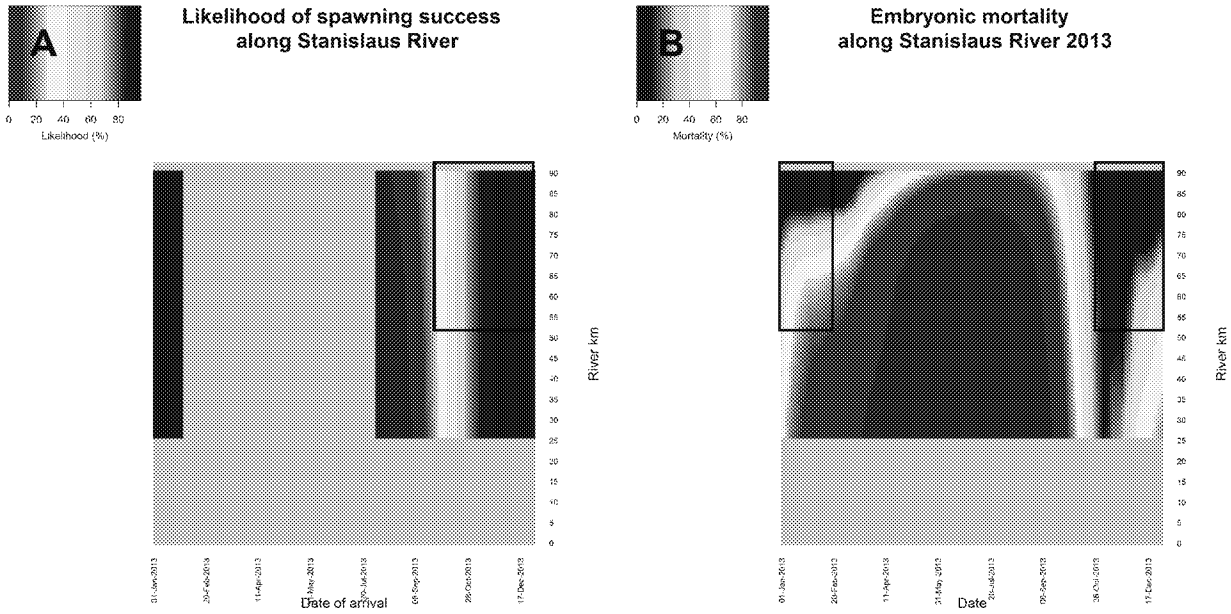

A
LifeStage
SpawningSuccess_wtd
EggSurvival_wtd
JuvSurvival_wtd
density
Percent
B
density
Percent
C
density
Percent
density
Percent

Figure 4. Comparison of thermal effects on different life stages along rivers during 2013. A) Clear Creek spring-run, B) Clear Creek fall-run, C) Stanislaus River fall-run, and D) Tuolumne River fall-run. The results are weighted based on the spatial and phenological distributions.



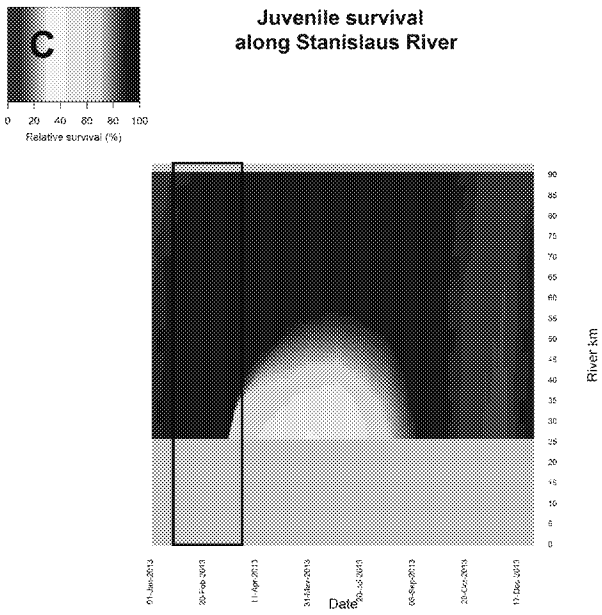


Figure 5. Application of temperature-dependent models to the Stanislaus River for 2013. The black boxes show the approximate spatial/temporal extent of each life stage (i.e. holding, incubation, early rearing) for fall-run. A) Likelihood of spawning success based on metabolic expenditure of adults during holding from arrival date (x-axis) to a randomized spawning date based on a weighted distribution over 1000 replicates (see text). Each location in space and time (pixel) indicates the likelihood that an adult arriving at that point in time and space will have enough energy to spawn. Gray areas were outside of the temporal buffer zone and were not run (see text). B) Egg-to-fry mortality. Each location in space and time (pixel) indicates that percentage of eggs spawned at that spatial location that would experience temperature-dependent mortality prior to emergence. The length of the embryonic period was determined by the temperature-dependent maturation function. C) Likelihood of juvenile survival to smolt size. Each location in space and time (pixel) is the calculated relative smolt likelihood based on the temperatures experienced relative to the optimum temperature producing maximum growth rate and a daily background mortality (see text).

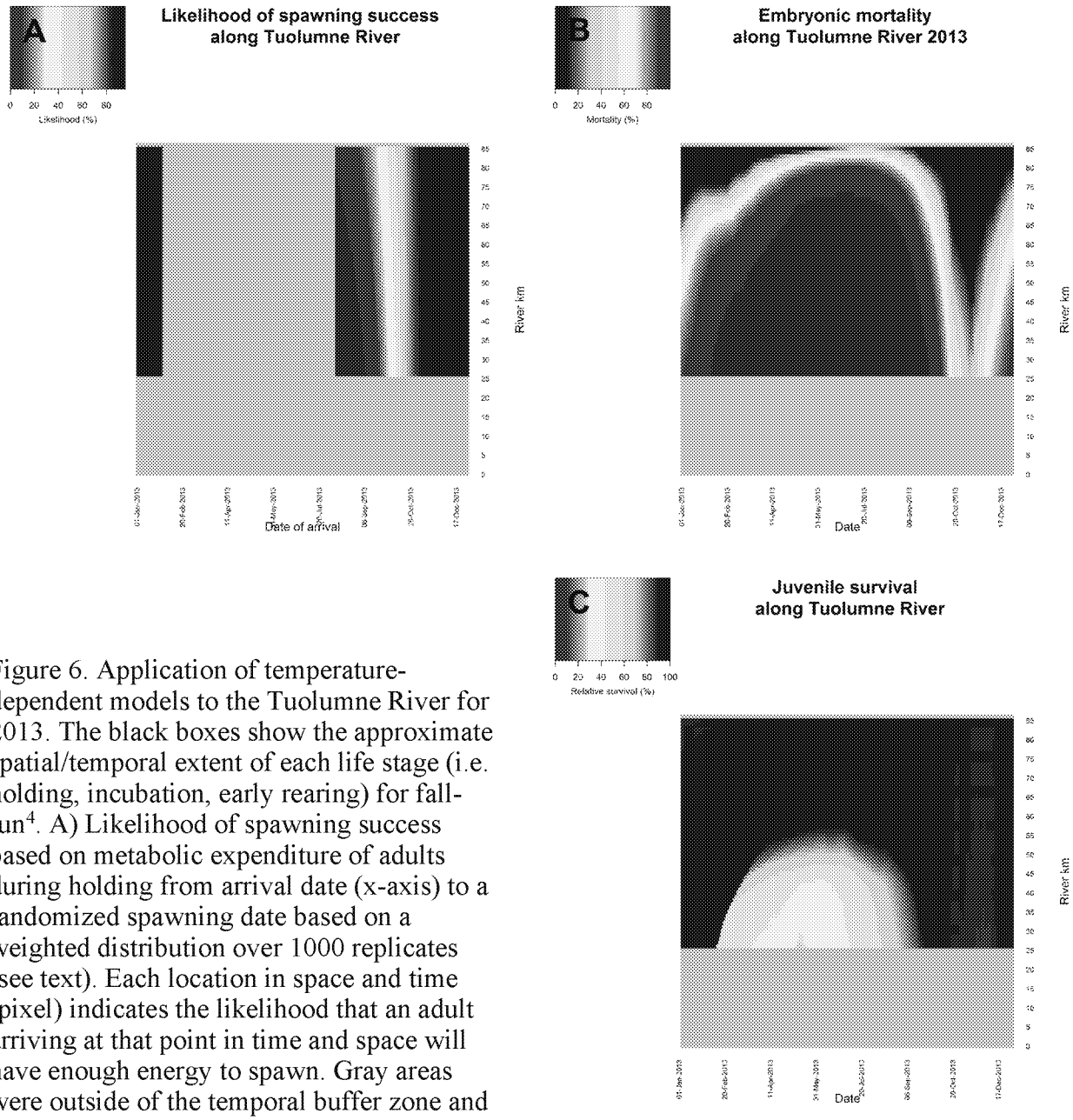


Figure 6. Application of temperature-dependent models to the Tuolumne River for 2013. The black boxes show the approximate spatial/temporal extent of each life stage (i.e. holding, incubation, early rearing) for fall-run[4]. A) Likelihood of spawning success based on metabolic expenditure of adults during holding from arrival date (x-axis) to a randomized spawning date based on a weighted distribution over 1000 replicates (see text). Each location in space and time (pixel) indicates the likelihood that an adult arriving at that point in time and space will have enough energy to spawn. Gray areas were outside of the temporal buffer zone and were not run (see text). B) Egg-to-fry mortality. Each location in space and time (pixel) indicates that percentage of eggs spawned at that spatial location that would experience temperature-dependent mortality prior to emergence. The length of the embryonic period was determined by the temperature-dependent maturation function. C) Likelihood of juvenile survival to smolt size. Each location in space and time (pixel) is the calculated relative smolt likelihood based on the temperatures experienced relative to the optimum temperature producing maximum growth rate and a daily background mortality (see text).

[4] For this Draft, we applied Stanislaus River phenology to the Tuolumne River.

Part 3: What additional studies are needed in order to develop specific thermal thresholds for the different life stages of salmonids in the Central Valley?

INTRODUCTION

Salmon in California are consistently exposed to river temperatures well above the Region 10 thresholds. Although many rivers are managed, in some drought years there is not enough cool water to keep river temperatures below the Region 10 levels. There is therefore an immediate need to determine 1) if Region 10 thresholds are applicable to California salmon, and 2) develop new thermal criteria, if required. In Parts 1 and 2, we quantified the thermal exposure of Central Valley Chinook salmon and illustrated a framework that estimates thermal effects of salmonids for different life stages. We developed these models in a way that converts thermal performance into a common currency: survival. Ultimately, our framework can be used to derive either river- or Central Valley-specific temperature criteria by identifying temperature thresholds that are required for a given level of survival through each life stage, relative to optimal temperatures. For example, we could calculate the temperature threshold needed for a relative survival $\geq$ 80% (% survival relative to survival at optimal temperatures) for each life stage.

To ensure that these temperature-dependent survival estimates are accurate for Central Valley populations, we need more work in two areas. First, our models are based off of the current best-available estimates of thermal performance for Chinook salmon, but some of these studies come from populations outside of the Central Valley. Over time, natural selection tunes a population's thermal physiology to maximize performance in the environmental conditions, as shown by studies on brook trout (*Salvelinus fontinalis*; Stitt et al. 2014) and sockeye salmon (*O. nerka*; Eliason et al. 2011, Chen et al. 2013); in other words, a population is adapted to the long-time environmental average (Quinn 2005). Thermal performance, therefore, is also likely population-specific. Conducting experiments with Central Valley populations to estimate thermal performance would determine how parameters from other populations apply to Central Valley salmonids and allow for the incorporation of local adaptation into our model predictions.

Second, some of our models are based on laboratory experiments, and field testing of the models is needed to make sure the models are accurately estimating thermal impacts in the wild. The strength of a laboratory experimental approach is the ability to determine the effects of varying a single variable, i.e. temperature, while keeping all other variables (e.g. flow, photoperiod) constant, usually in the absence of biotic interference. However, laboratory conditions are often not representative of field conditions (e.g. food *ad libitum*), and so can overestimate thermal performance (Childress and Letcher 2017, Martin et al. 2017).

Below, we discuss several studies that will improve the framework we developed in Part 2 for site-specific management of salmonids. These studies will test the accuracy of the models we applied, and also provide a basis in determining if Region 10 thresholds are appropriate for California salmonids. If Region 10 thermal criteria are not appropriate for California, these studies will be the first steps in establishing California-specific criteria.

Energy use by adults during migration/holding/spawning

We applied a temperature-dependent energy expenditure model to calculate how much energy adults expend while holding. This model was parameterized from respirometry studies on hatchery Chinook from British Columbia and the Columbia River basin (Geist et al. 2000, Gallaugher et al. 2001, Geist et al. 2003). In bioenergetics modeling, parameters are often borrowed from other populations or species if they are not directly measured, despite not

knowing how appropriate those parameters are for other populations (Johnson et al. 2017). We recommend conducting respirometry experiments to measure resting metabolic of holding adults as a function of temperature on Central Valley salmonids. Furthermore, respirometry studies that measure oxygen consumption as a function of swim speed would help inform a mechanistic model of migration costs (e.g. Geist et al. 2000, Gallaugher et al. 2001, Geist et al. 2003).

The metabolic maintenance model could also be expanded to incorporate other variables. As used here, the only variables are mass (M) and temperature (T), but water velocity and fish swim speed are important factors that affect energy consumption (Martin et al. 2015). A mark-recapture study and/or a telemetry study of migrating salmon to calculate migration speed and energy expenditure as a function of flow and temperature of a river could better calculate how much energy an adult expends during migration based on field conditions.

To calculate likelihood of spawning success, we needed to know how much energy (energy density) salmon had at the start of migration (E_I), how much energy they used during migration (E_M), holding (E_H), spawning (E_S), and for gonad allocation (E_G), and how much energy was left when they died (E_D). E_D has been measured for multiple populations and salmonid species, with values around 4 MJ/kg (see Plumb 2017). The other parameters, however, are less well-studied. Bowerman et al. (2017) has the most complete energy study of Chinook, capturing Columbia/Snake River spring-run Chinook at the start of migration, upon arrival to the spawning grounds, immediately before spawning, and after spawning. We borrowed some of these parameters for our model because there has not yet been an energy study on Central Valley salmonids. An energetics study on several sockeye salmon populations found significant differences in energy density at the start of migration dependent on the migration difficulty (distance and elevation) (Crossin et al. 2004). Energy density differences between populations, therefore, are likely, but as yet untested. In Part 2 for Clear Creek, we found that many early-arriving spring-run holding adults expend too much energy holding to spawn successfully. However, if some parameters were relaxed or recalibrated for spring-run specifically, our results may change. We recommend an energy density study on Central Valley populations to evaluate the energy density at different stages of migration and spawning for each run using a non-lethal method to estimate proximate composition and energy density (Crossin & Hinch 2005, Klefoth et al. 2013).

Our results are dependent on the accuracy of the spatial distribution of each life stage. If holding adults are found in cold water pools not accounted for by linear interpolation, our model may overestimate mortality. If cold water pools are used by adults, monitoring programs should put into place to measure the use (the fraction of the populations that uses the pool), the duration of use (how much of the holding period is spent in the pool), and the temperature of the pool. More temperature monitors will also increase the accuracy of the linear interpolation. For example, we interpolate at a 1 km scale, but Fullerton et al. (2017) determined that smaller scales will better account for cold water refugia.

Embryonic mortality

Very little direct evidence exists to determine if thermal tolerance of Chinook embryos is population-specific. Thermal tolerance studies are often conducted on a single population, so any comparisons between populations are made retrospectively. One of the few multi-population comparative studies is from Seymour (1956), who found that Central Valley chinook eggs develop faster than eggs from the Puget Sound ESU and Upper Columbia River Summer/Fall-run ESU at the same experimental temperatures. However, his sample sizes were too small to make any broad conclusions regarding thermal adaptation during the embryonic stage. Some laboratory studies instead suggest that the thermal tolerance of Central Valley Chinook salmonid

embryos may be similar to more northerly distributed populations. For example, Martin et al (2015) found that the same thermal performance model was able to accurately predict survival as a function of temperature in laboratory studies for both Central Valley (fall- and winter-run, USFWS 1995) and British Columbia populations (Jensen and Groot 1991). Other studies on embryonic survival have found similar patterns, where survival is relatively high up to ~14-15C (Alderdice and Velsen 1978, Healey 1979, Heming 1982, Bell 1991).

Although laboratory studies suggest a similar maximum thermal tolerance among widely distributed Chinook populations, there does appear to be a large difference in thermal tolerance in lab and field settings (Martin et al. 2017). For example, a lab-derived model of temperature-dependent embryo survival applied to field data significantly underestimated actual mortality due to differences in field and lab flow velocities (Martin et al. 2017). To account for differences between the laboratory and the field, we apply a 3C laboratory correction factor, which was calculated by Martin et al. (2017) based on work on Central Valley fall-run embryonic survival and by Childress and Letcher (2017) based on juvenile growth rates of multiple Chinook populations. However, it is likely that a 3C correction factor is not appropriate for all lab models applied to the field. Certain models and/or specific populations may require a different correction factor. Lab-based models should be tested against field-derived measurements to determine the accuracy of model prediction.

The temperature-dependent embryonic survival model we employ was developed and parameterized with field data on endangered Sacramento River winter-run Chinook (Martin et al. 2017). We use these parameters in our framework, but it's unclear if these parameters are appropriate for other runs. An important caveat when applying the winter-run model to other runs is that the temporal pattern of temperature variation for different runs can be very different. For example, temperatures during winter run development tend to increase with time, while for spring- and fall-run they tend to start high and then decrease as winter approaches. Our thermal performance model assumes that the thermal tolerance of eggs is constant throughout the embryonic development period. However, the oxygen limitation mechanism hypothesized by Martin et al. (2015) suggests that thermal tolerance may be lowest during the late egg stage when oxygen demand of eggs is highest. If thermal tolerance varies through embryonic development, the thermal tolerance parameters estimated in one thermal regime (e.g. increasing summer temps), may not be predictive in a different regime (decreasing temps). Thus an important next step is to quantify the degree to which thermal tolerance varies throughout the embryonic stage. Thermal performance models parameterized by such datasets should greatly improve the ability of embryonic thermal performance models to predict survival for variable temperature profiles.

An application of this model to spring-run in Clear Creek found substantially different parameter values (Provins, unpublished). However, due to small sample sizes, it is unclear if the original parameters fit with winter-run are really not appropriate for runs with different thermal regimes. This study also examined several other embryonic mortality models and found that the incorporation of a variable T_{crit} midway through development and the incorporation of flow increased the accuracy of the model (Provins, unpublished).

Flow and, importantly, the availability of dissolved oxygen to embryos, is an important yet often neglected factor in assessing egg-to-fry survival (Martin et al. 2017). An important, but currently unknown factor, is how river discharge and above ground flow affects the flow experienced by eggs with redds. To help elucidate this relationship and its consequences for egg-

to-fry survival In rivers where temperature and flow are gauged, dissolved oxygen should also be measured around and within redds.

Juvenile growth

Many studies exist on juvenile salmonid growth. In fact, several models exist for estimating juvenile growth, such as the Ratkowsky model and the Wisconsin bioenergetics model. We chose the Ratkowsky model because it has been parameterized with Chinook populations (Perry et al. 2015), and we added a food-level component. The parameters were fit from multiple populations based on several controlled laboratory experiments measuring growth rate and temperature (Perry et al. 2015). Although there is some variation in growth rates among populations, the analysis of Perry et al (2105) suggest that the temperature-dependence on growth is similar across widely distributed populations. However, the model from Perry et al. (2015) had very little data from Central Valley populations (i.e. one study from the American River). We suggest more studies measuring juvenile growth at multiple temperatures for Central Valley populations.

These laboratory experiments will narrow down the optimum range of a variable that achieves the maximum growth rate. However, results need to be validated in the field because estimates of thermal tolerance generated in controlled laboratory settings may not be applicable to actual conditions if other environmental factors, such as flow velocity, food, predation risk, or oxygen availability, affect thermal sensitivity (Eaton et al. 1995, Pörtner and Knust 2007, Childress and Letcher 2017). These and other factors can influence an individual's actual thermal needs. For example, juvenile sockeye in lakes exhibit maximum growth rates at 15°C, but they prefer cooler temperatures when food is not readily available, indicating that restricted rations influence their thermal preferences (Brett 1971). We recommend a mark-recapture study of Central Valley juveniles study using methods akin to Childress and Letcher (2017) to measure growth and other factors. This study will help validate laboratory-derived thermal optimum and determine site-specific maximum growth rates.

To calculate survival from juvenile growth, we determined the likelihood that juveniles would reach smolt size against a daily background mortality. We borrow size-dependent mortality parameters to relate differences in growth to differences in survival (Peterson and Wroblewski 1984, Lorenzen 1996), but these parameters are not Chinook-specific. Local mortality due to predation likely varies between populations and rivers, and so field studies to measure size- and temperature-dependent predation mortality would help make this model more accurate.

Other life stages

Our framework incorporates three models: energy expenditure of adults during holding, embryonic survival during incubation, and juvenile growth rates. However, the salmonid life cycle is complex, and there are several key components that could be added as information becomes available. For example, the migration model in Martin et al. (2015) predicts energy costs associated with migration based on temperature, flow velocity, swim speed and duration, and mass, and this model may be used in future studies examining energy expenditure of salmonids. With these and other additions, this framework could be converted into a full temperature-dependent life cycle model, such that thermal effects on one life stage could predict future performance of a subsequent life stage.

The major life stage missing from our model is survival in the ocean. Compared to freshwater life stages, oceanic survival is difficult to assess. How temperature affects adult salmon may be particularly challenging to disentangle from other causes of mortality. A correlational study of adults held in multiple offshore farms may give a first look at temperature-dependent mortality in the ocean.

Other species

Our work here has focused on Chinook salmon. Chinook salmon have the most diverse life history of all Pacific salmonids, with multiple runs spawning in ~640 streams and 20 major rivers in the U.S. and Canada (Raleigh et al. 1986), and is the species with the highest risk based on the number of listed populations (Quinn 2005). However, other salmonids in California – notably Steelhead trout (*O. mykiss*) – are also economically important and declining perhaps due to temperature. Future studies should use the framework we illustrate here to examine temperature effects on other salmonid species.

Data accessibility

Due to their incredible economic importance, salmonids are studied by multiple federal researchers and state agencies, nonprofits, concerned citizen groups, and individual naturalists. Unfortunately, much of this research remains disparate and inaccessible. We advocate for transparency in salmonid work and easier access to certain data via a public database, such as GBIF for occurrence data, VertNet for specimen data, and GenBank for DNA sequence data. Our Chinook salmon phenology table (in an ArcGIS shapefile format) will be publically accessible via NOAA.

Conclusions

We have developed a framework that combines modeling, laboratory studies, and field work to predict thermal impacts on the freshwater life stages of anadromous salmonids. Our method requires an iterative feedback loop: laboratory studies parameterize thermal performance models, models provide predictions, and these predictions are tested with field data. For the best predictions, these three components are required. Specific thermal recommendations for Central Valley salmonids cannot be made until we have more laboratory data and field-tested models. Only once we have a thorough understanding of the thermal variability experienced among these life history stages and populations can we begin to define thermal criteria for these critically important salmonids and set new standards (if needed) for California.

SUPPLEMENTAL MATERIALS

Supplement 1 – Chinook phenology

Table S1.1. Phenology of each life stage of Chinook populations in California, Oregon, Washington, and Idaho. The last column lists the number of occurrences procured for the distribution dataset. Spring-run (green), fall-run (blue), late-fall-run (purple), winter-run (red). CV=Central Valley, SONCC=Southern Oregon & Northern California Coast, UKTR=Upper Klamath Trinity Rivers, UC=Upper Columbia, UWR=Upper Willamette River. Note that CA Coastal spring-run is extinct, and SONCC Spring is mostly extinct. A'0' may indicate a negative or a lack of available information. References are listed in Appendix 1 List1.1.

ESU	Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Peak	References
CA Coast Fall	Mig Adult	1	0	0	0	0	0	0	0	1	1	1	1	11	3,10,12,13,14,17
CA Coast Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,10,12,13,14,17
CA Coast Fall	Spawning	1	0	0	0	0	0	0	0	1	1	1	1	11	3,10,12,13,14,17
CA Coast Fall	Incubation	1	1	1	1	1	0	0	0	1	1	1	1	1	3,10,12,13,14,17
CA Coast Fall	Emergence	1	1	1	1	1	0	0	0	0	0	0	1	2.5	3,10,12,13,14,17
CA Coast Fall	Juv Rearing	0	1	1	1	1	1	1	0	0	0	0	0	4.5	3,10,12,13,14,17
CA Coast Fall	Outmig Juv	0	1	1	1	1	1	1	0	0	0	0	0	4.5	3,10,12,13,14,17
CA Coast Fall	Ocean Entry	0	0	0	1	1	1	0	0	0	0	0	0	5	3,10,12,13,14,17
CA Coast Spring-Extinct	Mig Adult	0	0	1	1	1	1	1	1	0	0	0	0	5.5	3,10,12,13,14,17
CA Coast Spring-Extinct	Holding Adult	0	0	1	1	1	1	1	1	0	0	0	0	5.5	3,10,12,13,14,17
CA Coast Spring-Extinct	Spawning	0	0	0	0	0	0	0	0	1	1	1	1	10.5	3,10,12,13,14,17
CA Coast Spring-Extinct	Incubation	1	1	0	0	0	0	0	0	1	1	1	1	11.5	3,10,12,13,14,17
CA Coast Spring-Extinct	Emergence	1	1	0	0	0	0	0	0	0	0	0	1	1	3,10,12,13,14,17
CA Coast Spring-Extinct	Juv Rearing	1	1	1	1	1	1	1	1	1	1	0	1	5	3,10,12,13,14,17
CA Coast Spring-Extinct	Outmig Juv	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,10,12,13,14,17
CA Coast Spring-Extinct	Ocean Entry	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,10,12,13,14,17
CA CV Fall	Mig Adult	1	0	0	0	0	1	1	1	1	1	1	1	10	3,10,12,13,17,26
CA CV Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,10,12,13,17
CA CV Fall	Spawning	1	0	0	0	0	0	0	0	1	1	1	1	10.5	3,10,12,13,17,26
CA CV Fall	Incubation	1	1	1	1	1	0	0	0	1	1	1	1	1	3,10,12,13,17, 19
CA CV Fall	Emergence	1	1	1	1	1	0	0	0	0	0	0	1	2.5	3,10,12,13,17, 19
CA CV Fall	Juv Rearing	1	1	1	1	1	1	0	0	0	0	0	1	3	3,10,12,13,17
CA CV Fall	Outmig Juv	1	1	1	1	1	1	1	0	0	0	0	0	3.5	3,10,12,13,17,28
CA CV Fall	Ocean Entry	0	0	1	1	1	1	1	0	0	0	0	0	5	3,10,12,13,17
CA CV Late-Fall	Mig Adult	1	1	1	1	0	0	0	0	0	1	1	1	12	3,10,12,13,17,26,19

ESU	Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Peak	References
CA CV Late-Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,10,12,13,17
CA CV Late-Fall	Spawning	1	1	1	1	0	0	0	0	0	0	0	1	2.5	3,10,12,13,17,26
CA CV Late-Fall	Incubation	1	1	1	1	1	1	0	0	0	0	0	1	5	3,10,12,13,17,19
CA CV Late-Fall	Emergence	0	0	0	1	1	1	0	0	0	0	0	0	5	3,10,12,13,17
CA CV Late-Fall	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	3,10,12,13,17
CA CV Late-Fall	Outmig Juv	0	0	0	1	1	1	1	1	1	1	0	0	5.5	3,10,12,13,17,19
CA CV Late-Fall	Ocean Entry	1	1	1	1	1	0	0	0	0	1	1	1	1.5	3,10,12,13,17
CA CV Spring	Mig Adult	1	1	1	1	1	1	1	1	1	1	1	0	5	3,10,12,13,17, 19
CA CV Spring	Holding Adult	0	0	1	1	1	1	1	1	1	0	0	0	6	3,10,12,13,17
CA CV Spring	Spawning	0	0	0	0	0	0	0	1	1	1	1	1	9	3,10,12,13,17, 19
CA CV Spring	Incubation	1	1	1	1	0	0	0	1	1	1	1	1	12.5	3,10,12,13,17, 19
CA CV Spring	Emergence	1	1	1	1	1	0	0	0	0	1	1	1	1	3,10,12,13,17,27
CA CV Spring	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	3,10,12,13,17
CA CV Spring	Outmig Juv	1	1	1	1	1	1	1	0	0	0	0	1	1.5	3,10,12,13,17,28
CA CV Spring	Ocean Entry	1	1	1	1	1	1	0	0	0	0	1	1	2.5	3,10,12,13,17
CA CV Winter	Mig Adult	1	1	1	1	1	1	1	0	0	0	1	1	3.5	3,10,12,13,17,19
CA CV Winter	Holding Adult	1	1	1	1	0	0	0	0	0	0	0	0	2.5	3,10,12,13,17
CA CV Winter	Spawning	0	0	0	1	1	1	1	1	0	0	0	0	5.5	3,10,12,13,17
CA CV Winter	Incubation	0	0	0	1	1	1	1	1	1	1	0	0	7	3,10,12,13,17
CA CV Winter	Emergence	0	0	0	0	0	0	1	1	1	1	0	0	8.5	3,10,12,13,17
CA CV Winter	Juv Rearing	1	1	1	1	0	0	1	1	1	1	1	1	11.5	3,10,12,13,17
CA CV Winter	Outmig Juv	1	1	1	1	1	1	0	0	1	1	1	1	11	3,10,12,13,17,19
CA CV Winter	Ocean Entry	1	1	1	1	1	0	0	0	0	0	1	1	2	3,10,12,13,17
Deschutes River Fall	Mig Adult	0	0	0	0	0	0	0	1	1	1	0	0	9	3,8,12,15,17,29,30
Deschutes River Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,8,12,15,17,29,30
Deschutes River Fall	Spawning	0	0	0	0	0	0	0	0	0	1	1	1	11	3,8,12,15,17,29,30
Deschutes River Fall	Incubation	1	1	0	0	0	0	0	0	0	1	1	1	12	3,8,12,15,17,29,30
Deschutes River Fall	Emergence	0	1	1	1	0	0	0	0	0	0	0	0	3	3,8,12,15,17,29,30
Deschutes River Fall	Juv Rearing	0	1	1	1	1	1	1	1	0	0	0	0	5	3,8,12,15,17,29,30
Deschutes River Fall	Outmig Juv	0	0	0	0	1	1	1	1	0	0	0	0	6.5	3,8,12,15,17,29,30
Deschutes River Fall	Ocean Entry	0	0	0	0	0	0	1	1	1	1	1	0	9	3,8,12,15,17,29,30
Deschutes River Summer	Mig Adult	0	0	0	0	0	1	1	0	0	0	0	0	6.5	3,8,12,15,17,29,30
Deschutes River Summer	Holding Adult	0	0	0	0	0	0	1	1	1	0	0	0	8	3,8,12,15,17,29,30
Deschutes River Summer	Spawning	0	0	0	0	0	0	0	0	1	1	1	0	10	3,8,12,15,17,29,30
Deschutes River Summer	Incubation	1	1	1	0	0	0	0	0	1	1	1	1	12	3,8,12,15,17,29,30
Deschutes River Summer	Emergence	1	1	1	0	0	0	0	0	0	0	0	1	1.5	3,8,12,15,17,29,30
Deschutes River Summer	Juv Rearing	1	1	1	1	1	1	0	0	0	0	0	1	3	3,8,12,15,17,29,30
Deschutes River Summer	Outmig Juv	0	0	0	0	0	1	1	1	0	0	0	0	7	3,8,12,15,17,29,30
Deschutes River Summer	Ocean Entry	0	0	0	0	0	0	1	1	1	1	1	0	9	3,8,12,15,17,29,30

ESU	Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Peak	References
Lower Columbia Fall Run	Mig Adult	0	0	0	0	0	0	0	1	1	1	1	0	9.5	3,5,11,12,15,17
Lower Columbia Fall Run	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,5,11,12,15,17
Lower Columbia Fall Run	Spawning	0	0	0	0	0	0	0	0	1	1	1	1	10.5	3,5,11,12,15,17,20
Lower Columbia Fall Run	Incubation	1	1	0	0	0	0	0	0	0	1	1	1	12	3,5,11,12,15,17
Lower Columbia Fall Run	Emergence	0	1	1	1	0	0	0	0	0	0	0	0	3	3,5,11,12,15,17
Lower Columbia Fall Run	Juv Rearing	0	1	1	1	1	1	1	1	0	0	0	0	5	3,5,11,12,15,17
Lower Columbia Fall Run	Outmig Juv	0	0	0	0	1	1	1	1	0	0	0	0	6.5	3,5,11,12,15,17
Lower Columbia Fall Run	Ocean Entry	0	0	0	0	0	0	0	1	1	1	1	0	9.5	3,5,11,12,15,17
Lower Columbia Spring Run	Mig Adult	1	1	1	1	1	0	0	0	0	0	0	0	3	3,5,11,12,15,17
Lower Columbia Spring Run	Holding Adult	0	1	1	1	1	1	1	1	0	0	0	0	5	3,5,11,12,15,17
Lower Columbia Spring Run	Spawning	0	0	0	0	0	0	0	1	1	1	0	0	9	3,5,11,12,15,17,20
Lower Columbia Spring Run	Incubation	0	0	0	0	0	0	0	0	1	1	1	0	10	3,5,11,12,15,17
Lower Columbia Spring Run	Emergence	1	0	0	0	0	0	0	0	0	1	1	1	11.5	3,5,11,12,15,17
Lower Columbia Spring Run	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	3,5,11,12,15,17
Lower Columbia Spring Run	Outmig Juv	0	0	1	1	1	1	0	0	0	0	0	0	4.5	3,5,11,12,15,17
Lower Columbia Spring Run	Ocean Entry	0	0	0	0	1	1	1	0	0	0	0	0	6	3,5,11,12,15,17
Mid-Columbia Spring	Mig Adult	0	0	1	1	1	1	0	0	0	0	0	0	5	3,8,12,15,17,21,31
Mid-Columbia Spring	Holding Adult	0	0	0	1	1	1	1	1	1	0	0	0	6.5	3,8,12,15,17,31
Mid-Columbia Spring	Spawning	0	0	0	0	0	0	0	1	1	0	0	0	8.5	3,8,12,15,17
Mid-Columbia Spring	Incubation	1	1	0	0	0	0	0	1	1	1	1	1	11	3,8,12,15,17
Mid-Columbia Spring	Emergence	1	1	0	0	0	0	0	0	0	1	1	1	12	3,8,12,15,17
Mid-Columbia Spring	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	3,8,12,15,17
Mid-Columbia Spring	Outmig Juv	0	0	1	1	1	1	0	0	0	0	0	0	4.5	3,8,12,15,17,18
Mid-Columbia Spring	Ocean Entry	0	0	0	1	1	1	1	0	0	0	0	0	5.5	3,8,12,15,17
Oregon Coast Fall	Mig Adult	0	0	0	0	0	0	1	1	1	1	0	0	8.5	3,12,16,17
Oregon Coast Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,12,16,17
Oregon Coast Fall	Spawning	1	1	1	0	0	0	0	0	1	1	1	1	12	3,12,16,17
Oregon Coast Fall	Incubation	1	1	1	1	1	1	0	0	1	1	1	1	1.5	3,12,16,17
Oregon Coast Fall	Emergence	1	1	1	1	1	1	0	0	0	0	0	1	3	3,12,16,17
Oregon Coast Fall	Juv Rearing	1	1	1	1	1	1	1	1	1	1	0	1	5	3,12,16,17
Oregon Coast Fall	Outmig Juv	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,12,16,17
Oregon Coast Fall	Ocean Entry	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,12,16,17
Oregon Coast Spring	Mig Adult	0	0	1	1	1	1	1	0	0	0	0	0	5	3,12,16,17
Oregon Coast Spring	Holding Adult	0	0	1	1	1	1	1	1	0	0	0	0	5.5	3,12,16,17
Oregon Coast Spring	Spawning	0	0	0	0	0	0	0	0	1	1	1	1	10.5	3,12,16,17
Oregon Coast Spring	Incubation	1	1	1	0	0	0	0	0	1	1	1	1	12	3,12,16,17
Oregon Coast Spring	Emergence	1	1	1	0	0	0	0	0	0	0	0	1	2	3,12,16,17
Oregon Coast Spring	Juv Rearing	1	1	1	1	1	1	1	1	1	1	0	1	5	3,12,16,17
Oregon Coast Spring	Outmig Juv	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,12,16,17

ESU	Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Peak	References
Oregon Coast Spring	Ocean Entry	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,12,16,17
Oregon Coast Summer	Mig Adult	0	0	0	0	0	0	1	1	1	1	0	0	8.5	3,12,16,17
Oregon Coast Summer	Holding Adult	0	0	0	0	0	0	1	1	1	1	0	0	8.5	3,12,16,17
Oregon Coast Summer	Spawning	0	0	0	0	0	0	0	0	0	1	1	0	10.5	3,12,16,17
Oregon Coast Summer	Incubation	1	1	0	0	0	0	0	0	0	1	1	1	12	3,12,16,17
Oregon Coast Summer	Emergence	1	1	1	1	1	0	0	0	0	0	0	0	3	3,12,16,17
Oregon Coast Summer	Juv Rearing	1	1	1	1	1	1	1	1	1	1	0	0	5.5	3,12,16,17
Oregon Coast Summer	Outmig Juv	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,12,16,17
Oregon Coast Summer	Ocean Entry	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,12,16,17
Puget Sound Fall	Mig Adult	0	0	0	0	0	0	1	1	1	0	0	0	8	2,3,12,17
Puget Sound Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	2,3,12,17
Puget Sound Fall	Spawning	0	0	0	0	0	0	0	0	1	1	1	1	10.5	2,3,12,17
Puget Sound Fall	Incubation	1	1	0	0	0	0	0	0	1	1	1	1	11.5	2,3,12,17
Puget Sound Fall	Emergence	1	1	1	0	0	0	0	0	0	0	0	1	2.5	2,3,12,17
Puget Sound Fall	Juv Rearing	1	1	1	1	1	1	1	0	0	0	0	0	4	2,3,12,17
Puget Sound Fall	Outmig Juv	1	1	1	1	1	1	1	0	0	0	0	0	4	2,3,12,17
Puget Sound Fall	Ocean Entry	1	1	1	1	1	1	1	0	0	0	0	0	4	2,3,12,17
Puget Sound Spring	Mig Adult	0	0	1	1	1	1	1	0	0	0	0	0	5	2,3,12,17
Puget Sound Spring	Holding Adult	0	0	1	1	1	1	0	0	0	0	0	0	4.5	2,3,12,17
Puget Sound Spring	Spawning	0	0	0	0	0	0	1	1	1	1	0	0	8.5	2,3,12,17
Puget Sound Spring	Incubation	1	0	0	0	0	0	1	1	1	1	1	1	10	2,3,12,17
Puget Sound Spring	Emergence	1	1	0	0	0	0	0	0	0	1	1	1	12	2,3,12,17
Puget Sound Spring	Juv Rearing	1	1	1	1	1	1	1	0	0	1	1	1	2.5	2,3,12,17
Puget Sound Spring	Outmig Juv	1	1	1	1	1	1	1	0	0	1	1	1	2.5	2,3,12,17
Puget Sound Spring	Ocean Entry	1	1	1	1	1	1	1	0	0	0	0	0	4	2,3,12,17
Puget Sound Summer	Mig Adult	0	0	0	0	0	1	1	1	0	0	0	0	7	2,3,12,17
Puget Sound Summer	Holding Adult	0	0	0	0	0	1	1	0	0	0	0	0	6.5	2,3,12,17
Puget Sound Summer	Spawning	0	0	0	0	0	0	0	1	1	1	0	0	9	2,3,12,17
Puget Sound Summer	Incubation	1	0	0	0	0	0	0	1	1	1	1	1	10.5	2,3,12,17
Puget Sound Summer	Emergence	1	1	0	0	0	0	0	0	0	0	1	1	12.5	2,3,12,17
Puget Sound Summer	Juv Rearing	1	1	1	1	1	1	1	0	0	0	1	1	3	2,3,12,17
Puget Sound Summer	Outmig Juv	1	1	1	1	1	1	1	0	0	0	0	0	4	2,3,12,17
Puget Sound Summer	Ocean Entry	1	1	1	1	1	1	1	0	0	0	0	0	4	2,3,12,17
Snake River Fall	Mig Adult	0	0	0	0	0	0	1	1	1	1	1	1	9	1,3,9,12,15,17,22
Snake River Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	1,3,9,12,15,17
Snake River Fall	Spawning	0	0	0	0	0	0	0	0	0	1	1	1	11	1,3,9,12,15,17,25
Snake River Fall	Incubation	1	1	1	1	0	0	0	0	0	1	1	1	1	1,3,9,12,15,17
Snake River Fall	Emergence	0	0	1	1	0	0	0	0	0	0	0	0	3.5	1,3,9,12,15,17
Snake River Fall	Juv Rearing	0	0	1	1	1	1	1	0	0	0	0	0	5	1,3,9,12,15,17

ESU	Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Peak	References
Snake River Fall	Outmig Juv	0	0	0	1	1	1	1	0	0	0	0	0	5.5	1,3,9,12,15,17
Snake River Fall	Ocean Entry	0	0	0	0	0	0	1	1	1	1	1	0	9	1,3,9,12,15,17
Snake River Spring	Mig Adult	0	0	1	1	1	1	1	1	1	0	0	0	5	1,3,9,12,15,17,22
Snake River Spring	Holding Adult	0	0	0	1	1	1	1	0	0	0	0	0	5.5	1,3,9,12,15,17
Snake River Spring	Spawning	0	0	0	0	0	0	1	1	1	0	0	0	9	1,3,9,12,15,17,22
Snake River Spring	Incubation	0	0	0	0	0	0	1	1	1	1	1	1	9.5	1,3,9,12,15,17
Snake River Spring	Emergence	0	0	0	0	0	0	0	0	0	1	1	1	11	1,3,9,12,15,17
Snake River Spring	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	1,3,9,12,15,17
Snake River Spring	Outmig Juv	0	0	1	1	1	1	0	0	0	0	0	0	4.5	1,3,9,12,15,17
Snake River Spring	Ocean Entry	0	0	0	1	1	1	1	0	0	0	0	0	5.5	1,3,9,12,15,17
Snake River Summer	Mig Adult	0	0	0	0	1	1	1	0	0	0	0	0	6	1,3,9,12,15,17,22
Snake River Summer	Holding Adult	0	0	0	0	1	1	1	0	0	0	0	0	6	1,3,9,12,15,17
Snake River Summer	Spawning	0	0	0	0	0	0	0	1	1	1	0	0	9	1,3,9,12,15,17,22
Snake River Summer	Incubation	0	0	0	0	0	0	0	1	1	1	1	1	10	1,3,9,12,15,17
Snake River Summer	Emergence	0	0	0	0	0	0	0	0	0	1	1	1	11	1,3,9,12,15,17
Snake River Summer	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	1,3,9,12,15,17
Snake River Summer	Outmig Juv	0	0	1	1	1	1	0	0	0	0	0	0	4.5	1,3,9,12,15,17
Snake River Summer	Ocean Entry	0	0	0	1	1	1	1	0	0	0	0	0	5.5	1,3,9,12,15,17
SONCC Fall	Mig Adult	1	1	0	0	0	0	0	1	1	1	1	1	11	3,7,10,12,13,14,17
SONCC Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,7,10,12,13,14,17
SONCC Fall	Spawning	1	1	0	0	0	0	0	0	0	1	1	1	12	3,7,10,12,13,14,17,24
SONCC Fall	Incubation	1	1	1	1	0	0	0	0	0	1	1	1	1	3,7,10,12,13,14,17
SONCC Fall	Emergence	1	1	1	1	1	0	0	0	0	0	1	1	2	3,7,10,12,13,14,17
SONCC Fall	Juv Rearing	0	1	1	1	1	1	1	1	0	0	0	0	5	3,7,10,12,13,14,17
SONCC Fall	Outmig Juv	0	1	1	1	1	1	1	1	0	0	0	0	4.5	3,7,10,12,13,14,17,24
SONCC Fall	Ocean Entry	0	0	1	1	1	1	1	1	0	0	0	0	5.5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Mig Adult	0	0	1	1	1	1	1	0	0	0	0	0	5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Holding Adult	0	0	1	1	1	1	1	1	0	0	0	0	5.5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Spawning	0	0	0	0	0	0	0	0	1	1	1	1	10.5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Incubation	1	1	0	0	0	0	0	0	1	1	1	1	11.5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Emergence	1	1	0	0	0	0	0	0	0	0	0	1	1.5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Juv Rearing	1	1	1	1	1	1	1	1	1	1	0	1	5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Outmig Juv	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,7,10,12,13,14,17
SONCC Spring-Mostly Extinct	Ocean Entry	0	0	0	0	1	1	1	1	1	1	0	0	7.5	3,7,10,12,13,14,17
UKTR Fall	Mig Adult	0	0	0	0	0	0	1	1	1	1	1	1	9.5	3,10,12,13,14,17
UKTR Fall	Holding Adult	0	0	0	0	0	0	1	1	1	1	0	0	8.5	3,10,12,13,14,17
UKTR Fall	Spawning	1	0	0	0	0	0	0	0	1	1	1	1	11.5	3,10,12,13,14,17
UKTR Fall	Incubation	1	1	1	1	0	0	0	0	1	1	1	1	12.5	3,10,12,13,14,17
UKTR Fall	Emergence	1	1	1	1	1	0	0	0	0	0	1	1	2	3,10,12,13,14,17

ESU	Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Peak	References
UKTR Fall	Juv Rearing	1	1	1	1	1	1	0	0	0	0	1	1	2.5	3,10,12,13,14,17
UKTR Fall	Outmig Juv	1	1	1	1	1	1	1	0	0	0	0	0	5	3,10,12,13,14,17
UKTR Fall	Ocean Entry	0	0	1	1	1	1	1	0	0	0	0	0	5	3,10,12,13,14,17
UKTR Spring	Mig Adult	0	0	1	1	1	1	1	1	0	0	0	0	5.5	3,10,12,13,14,17
UKTR Spring	Holding Adult	0	0	1	1	1	1	1	1	0	0	0	0	5.5	3,10,12,13,14,17
UKTR Spring	Spawning	0	0	0	0	0	0	0	1	1	1	0	0	10	3,10,12,13,14,17
UKTR Spring	Incubation	1	1	1	1	1	0	0	1	1	1	1	1	12.5	3,10,12,13,14,17
UKTR Spring	Emergence	1	1	1	1	1	1	0	0	0	0	1	1	2.5	3,10,12,13,14,17
UKTR Spring	Juv Rearing	1	1	1	1	1	1	1	0	0	0	1	1	3	3,10,12,13,14,17
UKTR Spring	Outmig Juv	0	1	1	1	1	1	1	0	0	0	0	0	4.5	3,10,12,13,14,17
UKTR Spring	Ocean Entry	0	0	0	1	1	1	1	1	0	0	0	0	6	3,10,12,13,14,17
Upper Columbia Fall	Mig Adult	0	0	0	0	0	0	0	1	1	1	0	0	9	3,4,12,15,17
Upper Columbia Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,4,12,15,17
Upper Columbia Fall	Spawning	0	0	0	0	0	0	0	0	0	1	1	1	11	3,4,12,15,17,23
Upper Columbia Fall	Incubation	1	1	0	0	0	0	0	0	0	1	1	1	12	3,4,12,15,17
Upper Columbia Fall	Emergence	0	1	1	1	0	0	0	0	0	0	0	0	3	3,4,12,15,17
Upper Columbia Fall	Juv Rearing	0	1	1	1	1	1	1	1	0	0	0	0	5	3,4,12,15,17
Upper Columbia Fall	Outmig Juv	0	0	0	0	1	1	1	1	0	0	0	0	6.5	3,4,12,15,17
Upper Columbia Fall	Ocean Entry	0	0	0	0	0	0	1	1	1	1	1	0	9	3,4,12,15,17
Upper Columbia Spring	Mig Adult	0	0	1	1	1	1	1	0	0	0	0	0	5	3,4,12,15,17
Upper Columbia Spring	Holding Adult	0	0	0	1	1	1	1	0	0	0	0	0	5.5	3,4,12,15,17
Upper Columbia Spring	Spawning	0	0	0	0	0	0	1	1	1	0	0	0	8	3,4,12,15,17,20
Upper Columbia Spring	Incubation	0	0	0	0	0	0	1	1	1	1	1	1	9.5	3,4,12,15,17
Upper Columbia Spring	Emergence	0	0	0	0	0	0	0	0	0	1	1	1	11	3,4,12,15,17
Upper Columbia Spring	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	3,4,12,15,17
Upper Columbia Spring	Outmig Juv	0	0	1	1	1	1	0	0	0	0	0	0	4.5	3,4,12,15,17
Upper Columbia Spring	Ocean Entry	0	0	0	1	1	1	1	0	0	0	0	0	5.5	3,4,12,15,17
Upper Columbia Summer	Mig Adult	0	0	0	0	0	1	1	0	0	0	0	0	6.5	3,4,12,15,17
Upper Columbia Summer	Holding Adult	0	0	0	0	0	0	1	1	1	0	0	0	8	3,4,12,15,17
Upper Columbia Summer	Spawning	0	0	0	0	0	0	0	0	1	1	1	0	10	3,4,12,15,17
Upper Columbia Summer	Incubation	1	1	1	0	0	0	0	0	1	1	1	1	12	3,4,12,15,17
Upper Columbia Summer	Emergence	1	1	1	0	0	0	0	0	0	0	0	1	1.5	3,4,12,15,17
Upper Columbia Summer	Juv Rearing	1	1	1	1	1	1	0	0	0	0	0	1	3	3,4,12,15,17
Upper Columbia Summer	Outmig Juv	0	0	0	0	0	1	1	1	0	0	0	0	7	3,4,12,15,17
Upper Columbia Summer	Ocean Entry	0	0	0	0	0	0	1	1	1	1	1	0	9	3,4,12,15,17
UWR Spring	Mig Adult	1	1	1	1	1	1	1	1	0	0	0	0	4.5	3,6,12,15,17
UWR Spring	Holding Adult	1	1	1	1	1	1	1	1	0	0	0	0	4.5	3,6,12,15,17
UWR Spring	Spawning	0	0	0	0	0	0	0	1	1	1	0	0	9	3,6,12,15,17
UWR Spring	Incubation	1	1	1	0	0	0	0	1	1	1	1	1	11.5	3,6,12,15,17

ESU	Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Peak	References
UWR Spring	Emergence	1	1	1	0	0	0	0	0	0	0	0	1	1.5	3,6,12,15,17
UWR Spring	Juv Rearing	1	1	1	1	1	1	1	1	1	1	1	1	NA	3,6,12,15,17
UWR Spring	Outmig Juv	1	1	1	1	1	0	0	0	0	1	1	1	1.5	3,6,12,15,17
UWR Spring	Ocean Entry	0	0	0	0	1	1	1	0	0	0	0	0	6	3,6,12,15,17
Washington Coast Fall	Mig Adult	0	0	0	0	0	0	1	1	1	0	0	0	8	3,12,17
Washington Coast Fall	Holding Adult	0	0	0	0	0	0	0	0	0	0	0	0	NA	3,12,17
Washington Coast Fall	Spawning	0	0	0	0	0	0	0	0	1	1	1	1	10.5	3,12,17
Washington Coast Fall	Incubation	1	1	1	0	0	0	0	0	1	1	1	1	12	3,12,17
Washington Coast Fall	Emergence	1	1	1	0	0	0	0	0	0	0	0	1	1.5	3,12,17
Washington Coast Fall	Juv Rearing	1	1	1	1	1	1	1	0	0	0	0	1	3.5	3,12,17
Washington Coast Fall	Outmig Juv	1	1	1	1	1	1	1	0	0	0	0	0	4	3,12,17
Washington Coast Fall	Ocean Entry	1	1	1	1	1	1	1	0	0	0	0	0	4	3,12,17
Washington Coast Spring	Mig Adult	0	0	0	1	1	1	1	1	0	0	0	0	6	3,12,17
Washington Coast Spring	Holding Adult	0	0	0	1	1	1	1	1	0	0	0	0	6	3,12,17
Washington Coast Spring	Spawning	0	0	0	0	0	0	0	1	1	1	0	0	9	3,12,17
Washington Coast Spring	Incubation	1	1	0	0	0	0	0	1	1	1	1	1	11	3,12,17
Washington Coast Spring	Emergence	1	1	0	0	0	0	0	0	0	0	1	1	12.5	3,12,17
Washington Coast Spring	Juv Rearing	1	1	1	1	1	1	1	0	0	0	1	1	3	3,12,17
Washington Coast Spring	Outmig Juv	1	1	1	1	1	1	1	0	0	0	1	1	3	3,12,17
Washington Coast Spring	Ocean Entry	1	1	1	1	1	1	1	0	0	0	1	1	3	3,12,17
Washington Coast Summer	Mig Adult	0	0	0	1	1	1	1	1	0	0	0	0	6	3,12,17
Washington Coast Summer	Holding Adult	0	0	0	1	1	1	1	1	0	0	0	0	6	3,12,17
Washington Coast Summer	Spawning	0	0	0	0	0	0	0	1	1	1	0	0	9	3,12,17
Washington Coast Summer	Incubation	1	1	0	0	0	0	0	1	1	1	1	1	11	3,12,17
Washington Coast Summer	Emergence	1	1	0	0	0	0	0	0	0	0	1	1	12.5	3,12,17
Washington Coast Summer	Juv Rearing	1	1	1	1	1	1	1	0	0	0	1	1	3	3,12,17
Washington Coast Summer	Outmig Juv	1	1	1	1	1	1	1	0	0	0	1	1	3	3,12,17
Washington Coast Summer	Ocean Entry	1	1	1	1	1	1	1	0	0	0	1	1	3	3,12,17

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Supplement 2 – Fitting phenological distribution models

General procedure

Survey dates were changed to Julian day and converted into a representative bin size; for example, we used a 14 day bin for surveys completed 1+ times every 2 weeks. Raw counts were converted into percentages based on the total count for that year to weight all years equally regardless of that year's population size. Percentages were rounded to the nearest integer to obtain whole numbers, and observations were multiplied by the integer for a total number of observations of 100*n, where n is the number of years in a dataset, resulting in a relative count per binsize by year. We first graphed each dataset using a histogram and fit a Gaussian (normal) distribution unless otherwise stated. To show goodness of fit, we graphed the empirical and theoretical densities. Once the best fitting distribution was determined, we converted all models into a daily model by multiplying by the bin size.

Clear Creek

Arrival time for SCS was determined from video monitoring near the junction with the Sacramento River. The proportion of annual passage from 2013-2016 was digitized from CCTT (2017) so we did not have to calculate the frequency distribution from raw counts. For this dataset, frequency was listed by month, so we first fit a normal monthly distribution and then multiplied results by the average numbers of days in a month (30.4375).

For Clear Creek spawning phenology, multiple redd surveys from raw, published, and technical reports were aggregated for the years 2003-2016. A temporary picket weir is installed annually at the boundary of reach 5a/5b to help separate SCS and FCS; occasionally, two weirs are installed. Prior to weir installation, all fish in the creek are classified as SCS. After installation, all live fish and redds upstream of the picket weir were assigned as SCS, whereas all live fish and redds downstream of the weir were assigned as FCS after installation. Although the Gorge Cascade (demarcating the downstream boundary of reach 5b) is a partial barrier to FCS (Provins, pers. comm.), peak spawning in reach 5b occurs in early October, whereas 95% of SCS spawning occurs during September (Giovannetti and Brown 2008). Ambiguous live fish or redds in this reach were therefore removed from the dataset. Years with fewer than 10 redds reported (2010, 2017) were also removed. A biweekly normal distribution was fit, and then results were multiplied by 14.

Daily video counts of fall-run arrivals on Clear Creek were obtained from 2012-2016 (). To avoid misclassifications, we removed all arrivals before September 1, by which time the weir is closed. Arrivals past the last recorded day of new redds were also removed. We fit the dataset to a normal distribution.

An accurate count of fall-run redds along Clear Creek is difficult because of the high density of spawners – sometimes over 8,000 adults in a ~12 km reach (Earley et al. 2013), so we used the distribution of fall spawn timings from nearby Scott River as a proxy. Although Scott River is not classified as a Central Valley population, spawn timing seems similar, peaking in mid-October or early November (Meneks 2017, 2018). In contrast, fall-run in the San Joaquin begin spawning in early November, peak in December, and can spawn into early January (Castle et al. 2016). Along Scott River, surveys were run 1+ times per week, so we used a 7-day bin to

fit the spawning distribution. We used 2017 data only because the surveys in 2016 appeared to miss the beginning of spawning (Meneks 2017, 2018).

Stanislaus River

Video observations of fall-run passing the weir on the Stanislaus River were obtained for 2003-2018 (S. Tsao and G. Murphy, pers. comm., 2018). Although salmon were observed swimming upstream year-round, two peaks occurred, a small peak near the end of May and a predominant peak in November. The late-May peak may represent spring-run Chinook based on arrival timing, although it is currently unclear if spring-run spawn successfully along the Stanislaus. Observations prior to September 1 were not included in the model due to potential misclassification. Observations past the last reported date of spawning were also removed. We fit a normal distribution to weekly count data. The year 2011 had 776 arrivals, but the mean arrival date was ~3 weeks later than average, so this year was not included when fitting an arrival distribution.

Spawn timing was based on weekly surveys of redds in 2018 (S. Tsao and G. Murphy, pers. comm., 2018). Redd surveys began October 1 and ended mid-January. A total of 3,344 redds were counted in 2018. We fit a normal distribution to the weekly data. More years of data may be added to this dataset if obtained.

Tuolumne River

For this Draft, we applied arrival and spawning phenology from the Stanislaus River to our modeling on the Tuolumne River. For the Final project, we will use Tuolumne phenology based on arrival data from 2009-2018 (S. Tsao and G. Murphy, pers. comm., 2018) and at least one season of redd surveys (FISHBIO 2013).

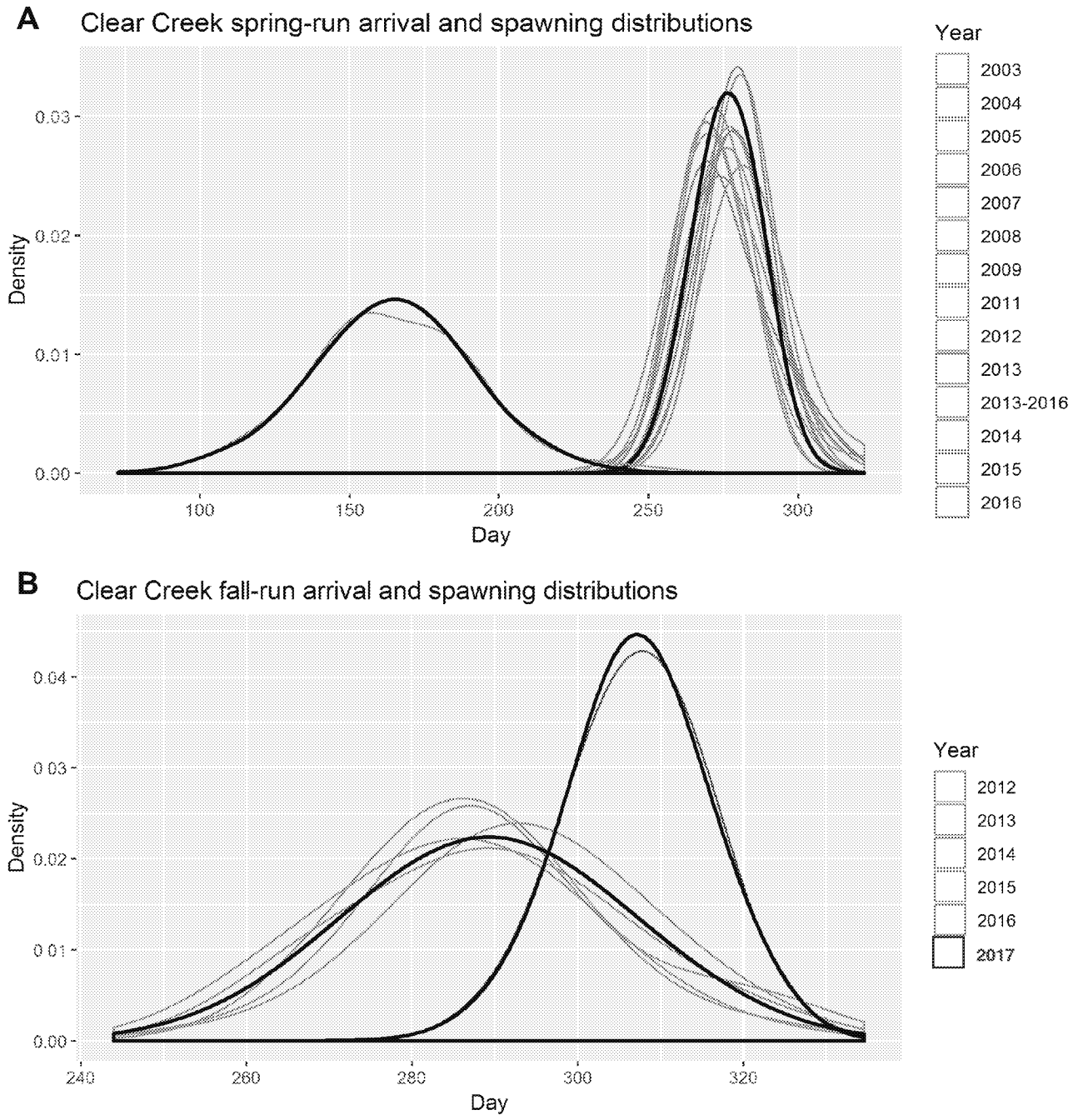

Figure S2.1. Empirical and fitted distributions of arrival and spawning phenology of A) spring-run and B) fall-run on Clear Creek. The x-axis shows Julian day.

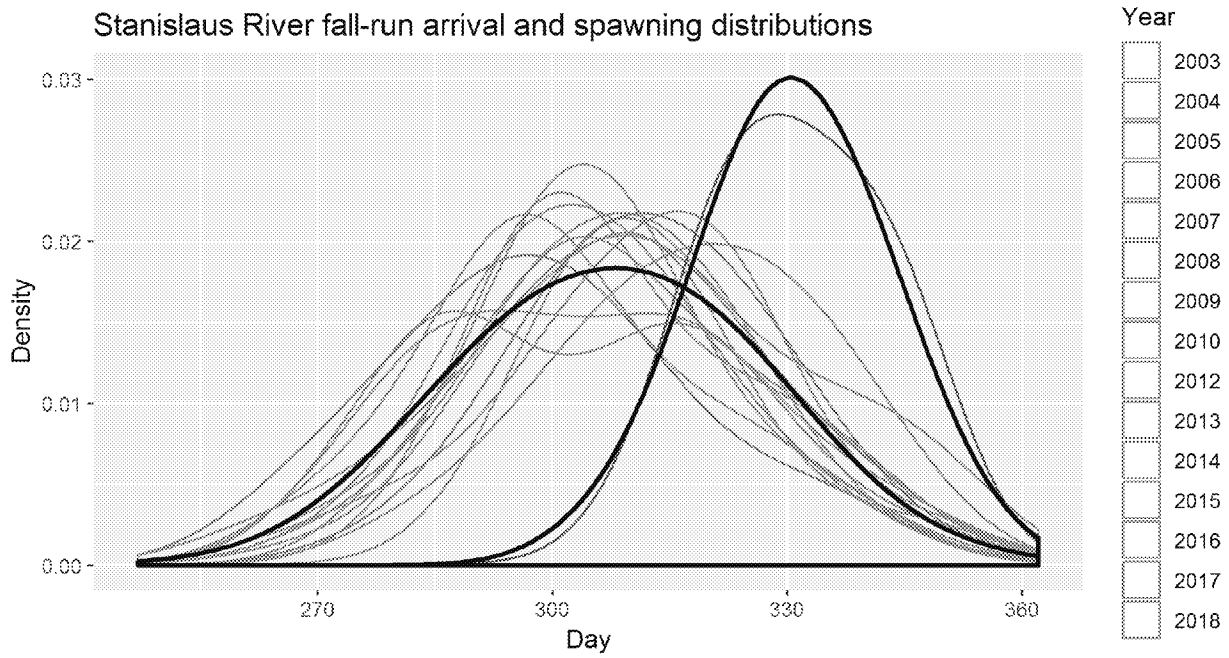

Figure S2.2. Empirical and fitted distributions of arrival and spawning phenology of fall-run on the Stanislaus River. The x-axis shows Julian day.

Supplement 3 – Fitting spatial distribution models

General Procedure

We standardized survey counts to number of observations per 1 river km to match the spatial resolution of the temperature data. In most cases this resulted in the total counts per reach averaged per km. Raw counts were converted into percentages based on the total count for that year to weight all years equally regardless of that year's population size. Percentages were rounded to the nearest integer to obtain whole numbers, and observations were multiplied by the integer for a total number of observations of 100*n, where n is the number of years in a dataset, resulting in a relative count per river km by year (Fig. S3.1).

Clear Creek

Spring-run redd surveys are completed ~biweekly by the USFWS Red Bluff Office; we obtained redd locations from 2003-2017 (S. Provins, personal communication). Redds found downstream of river km 12 (the approximate location of the temporary segregation weir) after September 1 (the weir is set up at the end of August) were removed because they may have been late-arriving spring-run or early spawning fall-run. The years 2010 and 2017 were removed because fewer than 10 redds were reported. The spatial dataset was not normal ($p < 0.001$), and the best fitting distribution was uniform (Fig. S3.1).

Because estimating fall-run redd counts is difficult due to the high density of spawners (Earley et al. 2013), spawning area mapping (SAM) documents the spatial locations and quantity of spawning habitat use (SHU) via counts of redds in October and December. SHU quantities were reported every 1,000 ft reach from 2000-2007 (mean) and annually from 2008-2012 (Earley et al. 2013). We converted reaches to 1 km, and used the SHU quantities to fit a normal distribution (Fig. S3.1).

Spring-run juveniles rear throughout the entirety of Clear Creek (AFRP 2015), so we sampled from a uniform distribution from river km 0 to 29. Fall-run juveniles, on the other hand, rear only in the downstream sections of Clear Creek below the Clear Creek Road gravel site (AFRP 2015), so we employed a uniform distribution from river km 0 to 13.5.

Stanislaus River

Based on verbal descriptions of habitat use by spawners, we sampled from a uniform distribution from river km 52.6, the location of the Stanislaus River weir, to Goodwin Dam at river km 96.9 (Peterson et al. 2017). For the Final project, we expect to have redd survey location data, enabling us to sample from a spatial distribution based on actual data.

Juveniles, especially fry, appear to have suitable habitat along the entirety of the accessible sections of the Stanislaus River, from Goodwin Dam downstream to the San Joaquin River; the direct amount of available habitat appears limited by discharge (Bowen et al. 2012). We therefore sampled rearing habitat from a uniform distribution along the entire river.

Tuolumne River

Most spawning occurs upstream of river km 46, so for this Draft, we sampled from a uniform distribution from river km 46 to the LaGrange Dam (river km 86) (FISHBIO 2013). For the Final project, we will fit a distribution based on redd survey data. For this Draft, we also assumed that rearing could occur uniformly along the entirety of the Tuolumne River.