**Measuring Effectiveness of Pulse Flow at Increasing Salmonid Survival using Telemetry**

The target populations for this study are ESA-listed wild spring-run Chinook salmon and both wild and hatchery fall-run Chinook salmon. We propose to acoustic-tag outmigrating smolts from these populations to measure survival under normal and pulse-flow river conditions. Because capture of taggable sized wild spring-run smolts is unpredictable and cannot solely be relied on to provide sufficient sample sizes for appropriate statistical power we are proposing to use Coleman National Fish Hatchery (CNFH) fall-run Chinook salmon smolts as surrogates for this study. Hatchery fall-run Chinook salmon smolts are similar in size to the wild smolts that out-migrate from Mill and Deer Creek in the spring, have overlapping outmigration timing, and migrate through the same migration corridor. The advantage of using hatchery fish is they are readily available in large numbers allowing for statistically appropriate release group sizes.

To assess survival of wild Chinook salmon smolts in addition to CNFH smolts, the Red Bluff Diversion Dam (RBDD) facility can be used to capture and tag relatively large groups of wild spring-run Chinook salmon and fall-run Chinook salmon smolts. There are 3-4 rotary screw traps (RSTs) checked daily at RBDD and out-migrating smolts could be caught and held for 1-2 days prior to tagging in order to obtain a larger sample size.

To estimate a statistically appropriate release group size, a power analysis was performed. Capture-recapture data was simulated given different levels of survival gains from the pulse flow and given different sample sizes: a 50% increase in survival, a 75% increase in survival, a 100% increase in survival, and the 250% increase as predicted by the threshold analysis. These simulated capture-recapture datasets were then analyzed in a CJS-model framework using the Rmark package in R. The above and below threshold survival estimates for the study region were then compared for each model run to determine statistical difference (defined as non-overlapping 95% confidence intervals). Overall, 300 simulated datasets were generated for each survival gain percentage and for various sample sizes. To obtain a 95% or higher chance of accurately detecting a survival gain from the pulse flow, a minimum of 600 tagged fish per release group are needed for the 50% survival improvement scenario (Table 1). At the 75% survival improvement scenario, a minimum of 300 tagged fish per release group are needed to have a higher than 95% chance of accurately detecting a survival gain. Finally, for the 100% and 250% survival improvement scenarios, a release group size of 200 tagged fish is sufficient.

*Table 1. Percent of models detecting significant differences between the above and below threshold release groups (out of 300 model runs per sample size/survival improvement scenario). A detection probability of 95% was applied to all receiver locations for the simulated data. Numbers in red represent scenarios in which less than 95% of models showed significant differences. * A 250% improvement is similar to what is predicted by the threshold analysis.*

| Sample size (per release group) | 50% improvement in survival | 75% improvement | 100% improvement | 250% improvement * |
|---|---|---|---|---|
| 200 | 34.0 | 79.3 | 95.7 | 100.0 |
| 300 | 60.3 | 95.0 | 100.0 | 100.0 |
| 400 | 74.7 | 99.7 | 100.0 | 100.0 |
| 500 | 83.7 | 100.0 | 100.0 | 100.0 |
| 600 | 94.3 | 100.0 | 100.0 | 100.0 |

Ideally, a release group size of 600 would allow the detection of even modest survival gains (such as a 50% increase). However, the return on investment is much better for a release group size of 300, allowing for the detection 75%, 100% and 250% increases in survival. We therefore propose tagging 300 fish per release group, for a total of **900 hatchery fall-run smolts** (300 * 3 releases of 300 fish each = 900 fish) with JSATS tags. An additional 50 fish should be held at the hatchery and tagged for a tag retention study. As a minimum release group size of 200 fish is required to at least detect a 100% increase in survival, release group sizes should not be any lower than this minimum.

The fish release schedule is described below:

- Tag and release three groups of 300 fish:
  - Group 1 the week before, but no later than 4 days before, the pulse flow
  - Group 2 during the pulse flow (ideally the first day of the pulse)
  - Group 3 once flows have dropped back to pre-pulse flows (ideally 1-2 weeks after the pulse)
- Fish will be released at Red Bluff Diversion Dam and tracked during their migration through the Sacramento River.

Fish will be tracked using a combination of existing array of JSATS receivers and additional receivers deployed at locations of interest and transitional reaches (e.g., release site, Butte City, Knights Landing, Feather River confluence, City of Sacramento, Benicia Bridge). Use of additional receiver sites established as part of agency collaborations may increase spatial resolution of survival data.

Standard surgical approaches, trained taggers, tag code coordination, and open data accessibility will be facilitated through the Interagency Telemetry Advisory Group (ITAG). At least one tag battery study will occur annually to support these releases and estimating battery life effects on survival estimates.

**Proposed Analysis of Telemetry Data**

Initially, survival estimated per release group will be compared to evaluate if the pulse flow release group has higher survival than other release groups. To further evaluate the effectiveness of the pulse flow in improving outmigration survival, a similar survival modeling effort as described in Henderson et al. (2019) will be used. Specifically, numerous spatial and/or temporal environmental covariates, as well as fish-specific covariates, will be collected to determine covariate influence on observed survival data. This will increase ability to evaluate the direct and indirect mechanisms increasing survival, which are related to flow, and mechanisms behind the flow-survival relationship. For example, increased turbidity and increased water velocities during the storm events have been found to increase smolt survival, but most studies are not able to decouple the effects of these variables. It is presumed that a managed pulse flow will likely increase water velocities to mimic conditions during storm events, but likely with a more muted response in turbidity than as seen during storm events (Figure 1). That is because in the Sacramento River, much of the storm-generated turbidity occurs due to increased inputs from tributaries, while during a managed pulse flow, these tributaries would remain unchanged. To this end, turbidity sensors should be deployed at key locations in the study region to supplement the scarce gauges that collect turbidity data

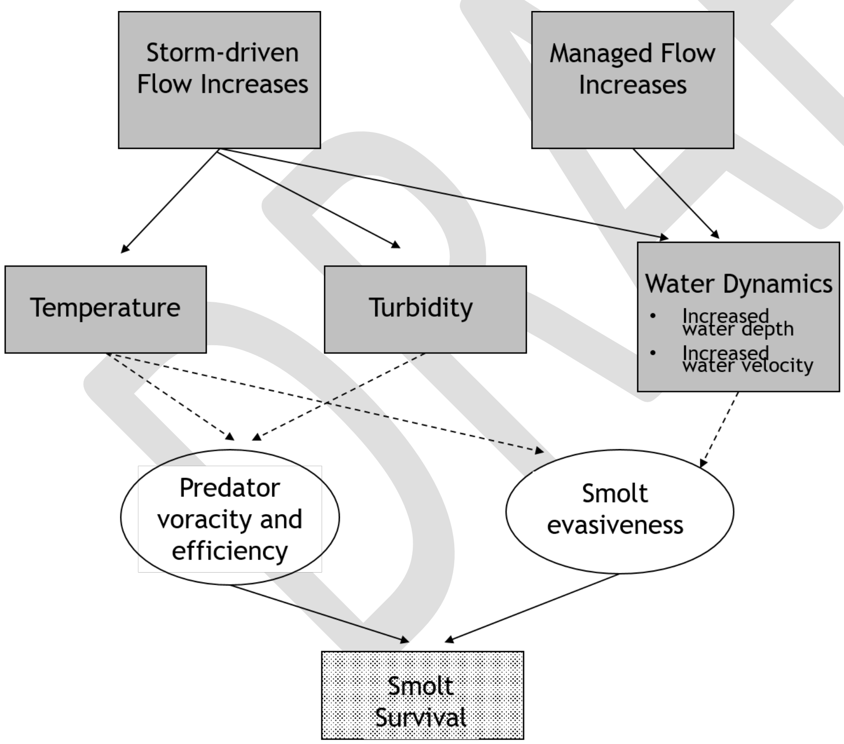


*Figure 1. Hypothesized conceptual model for how increases in flow lead to increases in survival. Solid lines represent known relationships, while dashed lines represent hypothesized mechanisms.*

Real-time data analytics and download data will be accessible via the Enhanced Acoustic Telemetry for Salmon Monitoring site for each group (https://calfishtrack.github.io/real-time/index.html), giving researchers the ability to have a preliminary assessment of the pulse flow's success in real-time. Final analyses will be conducted through collaborations with funded synthesis and analysis tasks as part of an existing USBR-UCSC/SWFSC Agreements.

**References**

Henderson, M. J., I. S. Iglesias, C. J. Michel, A. J. Ammann, and D. D. Huff. 2019. Estimating spatial–temporal differences in Chinook salmon outmigration survival with habitat- and predation-related covariates. Canadian Journal of Fisheries and Aquatic Sciences 76:1549-1561.