Environmental factors associated with the upstream migration of fall-run Chinook Salmon and Steelhead on the Stanislaus River

Matthew L. Peterson | Andrea Fuller | Doug Demko

Introduction

The migratory patterns of adult Chinook salmon in the Stanislaus River from 2003 to 2014 were recently summarized and their relation to management actions and environmental conditions in Peterson et al. (2017). Similar analyses have not yet to date been conducted to examine migratory patterns of steelhead in the Stanislaus River. Management of the flow regime during the fall has focused for nearly 25 years on providing a fall pulse flow to improve migratory conditions for anadromous salmonids, however, the efficacy of that action had previously not been evaluated.

Objectives

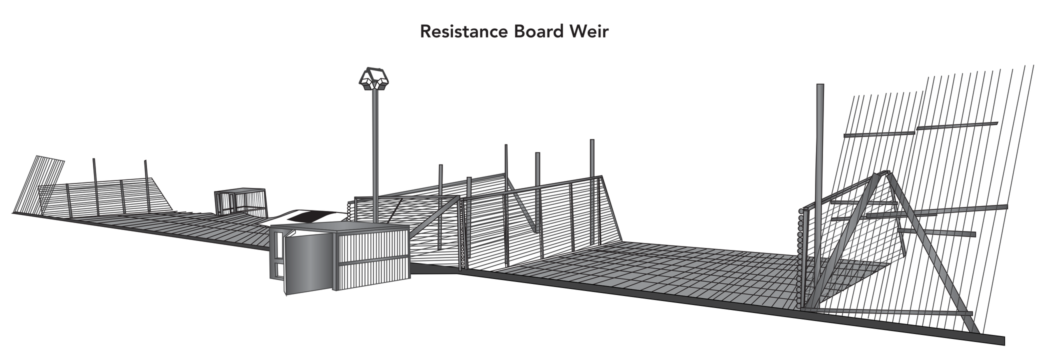
(1) Evaluate the relative importance of environmental factors and management actions on the migratory patterns of adult fall-run Chinook salmon with two additional years of data.

(2) Conduct exploratory analyses on migratory patterns of adult steelhead observed at the weir using a similar framework.

Methods

Field Methods

- Operated portable resistance board weir and Vaki Riverwatcher every fall from 2003 to 2016 at river kilometer 52.6.
    - o Median start date was 9 September (2003 – 2010, 2012 – 2016).
    - o Exception was during 2011 (installed on 8 November) when high flows prevented typical installation.
- Infrared images, as well as still and video imagery, are used to identify, measure, and assess condition of each individual fish and other fauna.



Data Analyses

- Explored variables at a daily level, which included: absolute discharge at Ripon and Vernalis, coefficient of variation (CV = SD/Mean) of discharge at Ripon, water temperature at Ripon, coefficient of variation of temperature at Ripon, dissolved oxygen at Rough and Ready Island, moon illumination, precipitation, the installation of the HORB and whether managed pulse flows were in effect or not.
- Because the weir is a single monitoring station (i.e., a fixed location), we explored a variety of daily lags on the data, which were: 0, 1, 2, 3, 5, and 7-day lags.
    - o Lags that explained the most variation for each variable were used in the final set of candidate models.
- For Chinook salmon, we used negative-binomial generalized linear models (GLMs; Zuur et al. 2009) and mixed-effects generalized additive models (GAMs; Wood 2006).
    - o A variety of candidate models were evaluated using Akaike Information Criterion corrected for small sample sizes (AICc) and multimodel inference (Burnham and Anderson 2002).
- For steelhead (defined as O. mykiss > 42 cm), data was very sparse and contained a high amount of zeroes.
    - o Exploratory analyses using counts were conducted with zero-inflated GLMs, hurdle-type GLMs, and GAMs (Zuur et al. 2009).
    - o Limited data from 1 October through 31 December to remove some excess zeroes.

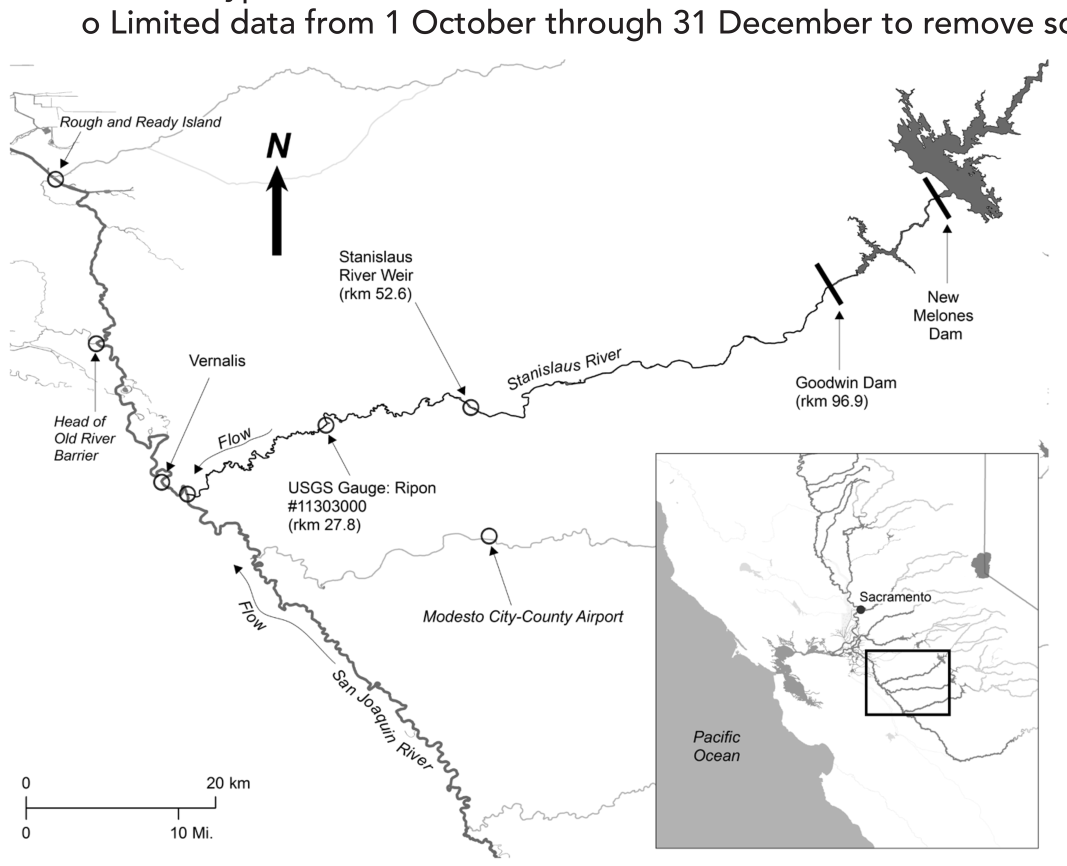


Figure 1. Map of the Stanislaus River with locations of the Stanislaus River weir, Goodwin Dam, and water quality monitoring stations.

Results

Weir Performance

- Excluding 2011, the weir operated >95 percent of the time between 2003 and 2016 in flows of up to 50.9 cubic meters per second (m^3/s; or 1,800 cubic feet per second [cfs]).
- On 106 of the total 1,497 days (7.1 percent) when the weir was operational, the weir either had some spill (or high debris) or a problem was detected with the Riverwatcher.

General Observations

- Over the entire monitoring period:
    - o 65,193 fall-run Chinook salmon (upstream passages) observed.
    - o Steelhead observed in only 9 of 14 monitoring seasons (fall monitoring defined as Sept. 1 – Dec. 31).
    - o Only 56 upstream passages total of steelhead.

Seasonal Run Timing

- Median dates of 5, 50, and 95 percent of cumulative passage of Chinook salmon occurred on 3 October, 31 October, and 7 December, respectively.
- Generally run timing of Chinook salmon later during highest water temperature years (e.g., 2014 - 2016) and earlier when warmer seasonal temperatures were present (2003 – 2013).
- Run timing could not be assessed for steelhead, but:
    - o Earliest observation(s) was 8 October (2013 and 2016).
    - o Median date of observation across all years was 13 November.

Modeling Results

Chinook salmon

- Multimodel inferential approaches and relative importance values indicated that there was high variation in which variables were most important year to year (Figure 2).
- Variables that appeared most frequently in the top models were:
    - o Average daily temperature at Ripon
    - o Installation of HORB
    - o Coefficient of variation of daily temperature at Ripon
- Managed pulse flows were included in the top candidate model in 3 of 13 years (including 2006).
- Predicted responses of daily proportions (to adjust for seasonal abundance) were maximized around discharges of about 20 m^3/s (Figure 3).

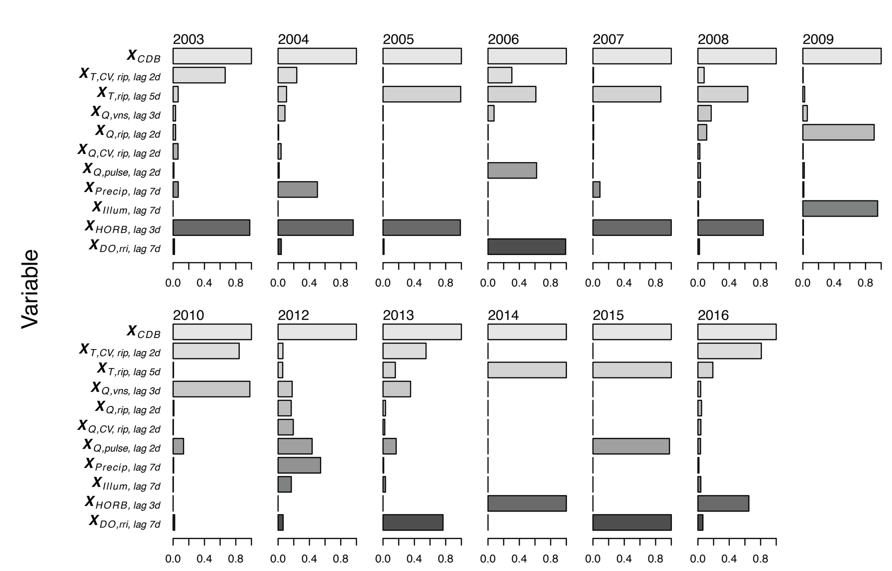


Figure 2. Relative importance values (on a scale from 0 to 1; 1 = very important) for each variable from model averaging to explain daily counts of Chinook Salmon at the Stanislaus River Weir.

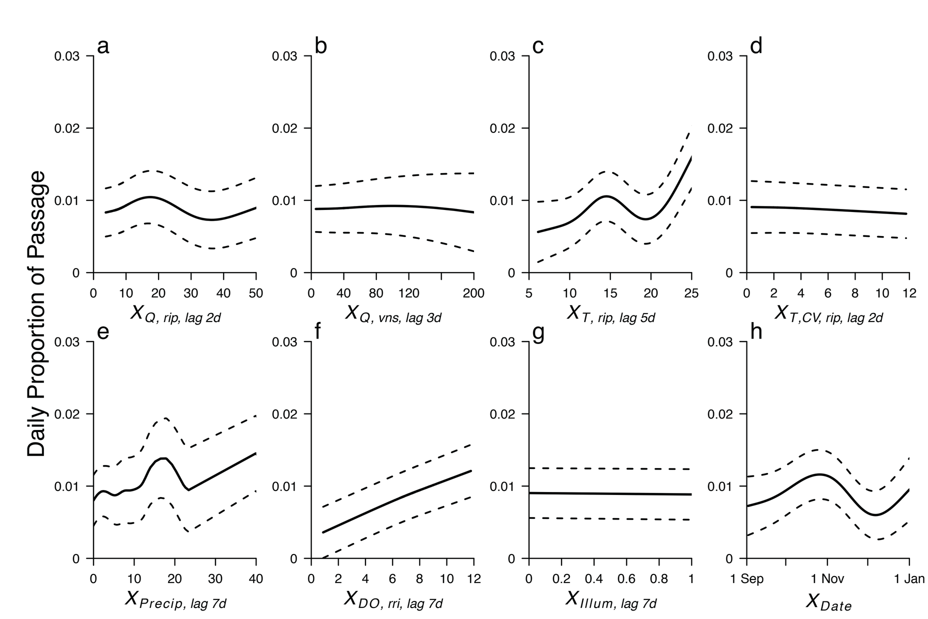


Figure 3. Predicted response (and standard errors) of daily proportions of Chinook Salmon passage in relation to the ten explanatory variables from generalized additive model analyses (family = Gaussian). Response surfaces of the pulse flow and HORB (both treated as factors) plotted together as 2-dimensional step functions.

Steelhead

- Examined the full model for each modeling approach (e.g., binomial, Poisson, etc.)
- The odds of observing versus not observing an adult steelhead:
    - o increased by about 1.08 times the baseline with one unit increase in discharge at Ripon (across all modeling approaches; Table 1).
    - o decreased by about 0.96 times with one unit increase in discharge at Vernalis (across all modeling approaches; Table 1).
    - o increased by about 1.71 times with one unit increase in dissolved oxygen at Rough and Ready Island (Table 1).
- Other than water temperature at Ripon (count portion of hurdle model), no other variables were found to be significant to explain either presence or counts.
- Results from GAMs (mixed-effects and with binomial distribution) indicated that some variables examined had little effect on the probability of observing an adult steelhead (i.e., discharge at Vernalis, temperature at Ripon, moon illumination, and date) (Figure 4).
- Dissolved oxygen had a strong positive effect with an increased probability of observation with increased DO content and Rough and Ready Island.
- Similar to the response of Chinook salmon (counts and proportions), discharge at Ripon appeared to have a non-linear relationship with probability of observation with an adult steelhead.

Table 1. Estimated odds for variables to explain the presence or absence or count of observing an adult steelhead at the Stanislaus River weir (2003 -- 2016; Oct 1 -- Dec 31). Various models were used to explain presence (binomial and zero--portion of the hurdle model) or count (Poisson, negative binomial, and count portion of hurdle model). Cells shaded blue indicate an increase in odds of observing an adult steelhead or an increase in counts. Bolded and italicized text indicates a coefficient that was statistically significant at alpha = 0.05.

				Hurdle Model	
Variable	Binomial	Poisson	Negative Binomial	Count	Zero Hurdle
(Intercept)	***0.0012***	***0.0002***	***0.0003***	***0.0000***	***0.0004***
xTrip_lag5	1.0302	1.0794	1.0710	***1.4029***	1.0605
xTripCV_lag2	0.9807	0.9628	0.9883	0.9589	0.9936
xPrecip_lag7	0.9821	0.9906	0.9878	1.0895	0.9851
xQripavg_lag2	***1.0845***	***1.0880***	***1.0898***	1.0485	***1.0851***
xQcv_lag2	0.9304	0.9551	0.9399	0.9637	0.9306
xQvnsavg_lag3	***0.9669***	***0.9614***	***0.9628***	0.8627	***0.9684***
xPulse_lag2	1.1201	1.2786	1.2040	0.4415	1.1539
xDOrri_lag7	***1.5741***	***1.8100***	***1.7564***	***4.3599***	***1.7150***
xIllum_lag7	1.3000	1.2953	1.2522	5.6833	1.2076
xHORB_lag3	0.8709	0.7271	0.6944	0.1201	0.7672

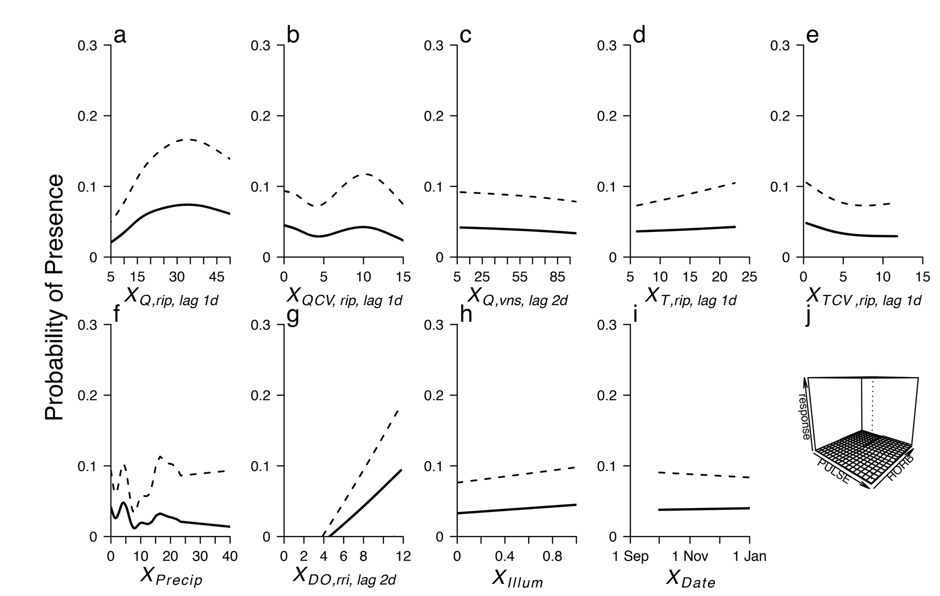


Figure 4. Predicted response (and standard errors) of daily observation probabilities of adult steelhead passage in relation to the ten explanatory variables from generalized additive model analyses (family = binomial).

Summary and Implications

- Detailed information on the migration patterns of anadromous salmonids has been relatively sparse in the Central Valley and to our knowledge; this particular dataset is one of the longest continuous programs collecting this type of information.
- The analysis framework allowed for an objective assessment of migration patterns of both Chinook salmon and steelhead and to assess the relative importance of environmental conditions and management actions.
- Due to the often-complicated nonlinear responses, the use of GAMs was very beneficial in identifying optima and thresholds in migratory responses.
- Key results include that the migratory response (daily proportion) of Chinook salmon is maximized around 20 m^3/s and the probability of observing an adult steelhead is maximized around 30 m^3/s.
- Adjusting the magnitude, duration, and seasonal timing of managed pulse flows should be considered especially during periods of drought, as it may balance the migratory requirements of anadromous salmonids and societal needs.
- If implemented, the conservation of water during the fall could be used for fisheries needs in the form of increased carryover storage to maintain cooler water temperatures in the upstream reservoir and/or released as larger or longer duration pulse flows during the spring outmigration period.

Acknowledgements

We thank the Oakdale and South San Joaquin Irrigation Districts (Tri-Dam Project) for long-term funding for the monitoring. The United States Fish and Wildlife Service provided funds for the initial purchase and long-term loan of the Vaki Riverwatcher and weir components. Many people have contributed to this project, including many FISHBIO staff that constructed, operated, and maintained the weir through a variety of inclement conditions over the past 14 monitoring seasons. Dee Thao assisted with poster creation and layout.

References

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer, New York, New York.
Peterson, M. L., A. N. Fuller, and D. Demko. 2017. Environmental factors associated with the upstream migration of fall-run Chinook salmon in a regulated river. North American Journal of Fisheries Management 37: 78-93.
R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
Wood, S. N. 2006. Generalized Additive Models: An Introduction with R. Chapmam and Hall/CRC, Boca Raton, Florida.
Zuur, A., E. N. Ieno, N. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer Science & Business Media.

Contact: Matt Peterson, FISHBIO, 180 E. Fourth Street, Suite 160, Chico, CA 95928, USA. | E-mail: mattpeterson@fishbio.com. | Phone: (530) 892-9686

www.FISHBIO.com