

Hindcast of factors contributing to Winter-Run Egg TDM change as forecasted in April compared to as observed in October 2022

Prepared by the Southwest Fisheries Science Center, November 2022

1. Introduction

During the temperature management season of 2022, estimates of mean annual egg temperature-dependent mortality (TDM) for winter-run Chinook salmon changed from a forecasted value of 54% in April 2022 at the time of the final temperature management plan (TMP)¹, to an observed value of 17% in October. To better understand what factors contributed to this decrease in TDM over the course of the temperature management season, the Southwest Fisheries Science Center conducted a hindcast analysis using their water temperature and TDM models^{2,3}.

In the hindcast analysis, individual factors (i.e., model inputs) were run under two conditions: 1) forecasted as of April 27th (time of the final temperature management plan) and 2) observed as of October 31st. A total of five factors were explored for this analysis and are listed in the table below, with additional information for each factor described below in more detail.

Table 1: Factors explored in hindcast analysis with mean annual TDM (dependent on input type, e.g., forecasted or observed).

Factor (model input)	Mean Annual TDM (%)		
	2019 BiOp analog	April 2022 Forecast	Observed
Reservoir outflow operations	92	54	18
TCD operations	NA	54	42
Reservoir inflow (volume and temperature)	NA	54	47
Meteorology	NA	54	52
Redd distribution	NA	54	56

NA = model not simulated under BiOp proxy conditions.

During each model run, only one factor was changed at a time while all others were held at the forecasted values. For example, meteorology was run under forecasted conditions and observed conditions. In both meteorology model runs, all other factors were held at forecasted conditions. With this approach each factor's individual contribution to the change in TDM was assessed by comparing TDM to the baseline case, where the baseline case was TDM as forecasted in April 2022 (i.e. 54% TDM).

Disclaimer: The factors investigated here are not inclusive of all factors contributing to TDM. Additionally, perturbing model inputs one at a time assumes that each input is independent of others. This assumption is known to be incorrect for this system. For example, operations of the Shasta TCD are somewhat dependent on Shasta outflow conditions and only perturbing one of these factors ignores this dependence. Interpretation of this analysis should therefore acknowledge these limitations.

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2. Reservoir outflow operations

Reservoir outflow operations were simulated under three conditions described below.

1. 2021 Operation (BiOp analog): This operation was meant to be an analog for what operations may have been without implementation of the 2022 Interim Operations Plan (IOP) (i.e., using the 2019 BiOp). Specifically, reservoir operations for the year 2021 were used.
2. IOP (April Forecast): This operation was based on the scenario presented in the final 2022 TMP.
3. IOP (Observed Operations): This operation used the observed outflow operations during 2022.

Results from the three scenarios are displayed below. Subplot A to the left shows the release volume time series from Keswick Reservoir for each of the three simulations, while subplot B to the right is the resulting downstream temperature time series at the SAC gauge (the temperature management location for 2022). TDM estimates for each scenario are presented in Table 1.

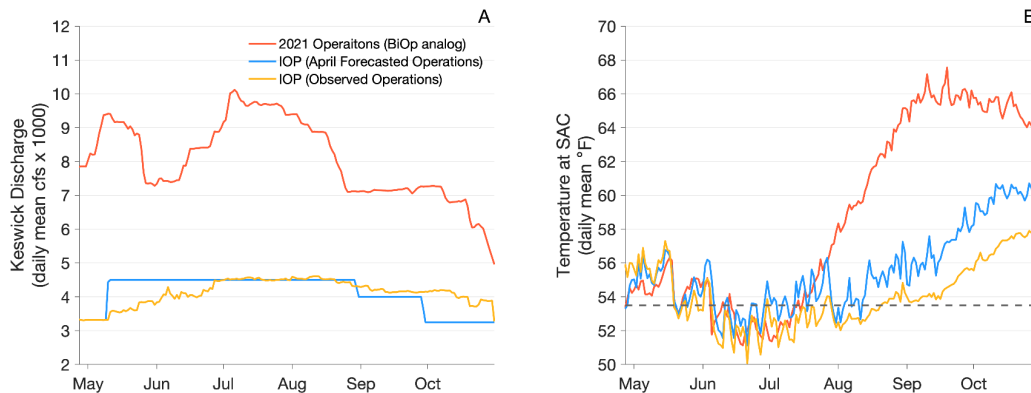


Figure 1: Time series of Keswick release volume (A) and downstream SAC temperature (B) under the 3 scenarios simulated.

Interpretation: The BiOp analog resulted in the highest TDM (92%). Comparing the forecasted to observed IOP conditions indicated that the lower than forecasted outflow from May to July and the higher than forecasted outflow in October reduced TDM by 36% (i.e., 54%-18%). Most of this reduction in TDM was attributed to the reduced outflow in May and June rather than the increased outflow in October. More specifically, the reduced outflows in May-June likely conserved additional cold-pool volume that benefited downstream temperature management later in the season.

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3. TCD operations

Shasta Dam temperature control device (TCD) operations were simulated under two conditions described below.

1. IOP (April Forecast): This operation was based on the scenario presented in the final TMP.
2. IOP (Observed Operations): This operation used the observed TCD gate operations during 2022.

Results from the scenarios are presented below, with the plot on the left (subplot A) showing the temporal sequence of TCD operations for both scenarios. These plots show TCD operations overlaid on top of the vertical temperature distribution (represented by color) in Shasta Reservoir nearest the dam. Specifically, when a TCD gate elevation is in use, that elevation is indicated by the horizontal line that is color coded to the scenario. Note that the horizontal line indicates when any gate is open for a given TCD elevation, but does not show the number of gates open. Also note that the location of TCD gates on the Y-axis do not reflect precise elevations, but rather are meant to assist with visual interpretation. In addition to TCD operations, the plot on the right (subplot B) displays the resulting downstream temperature time series at the SAC gauge (the temperature management location for 2022) for each scenario. TDM estimates for each scenario are presented in Table 1.

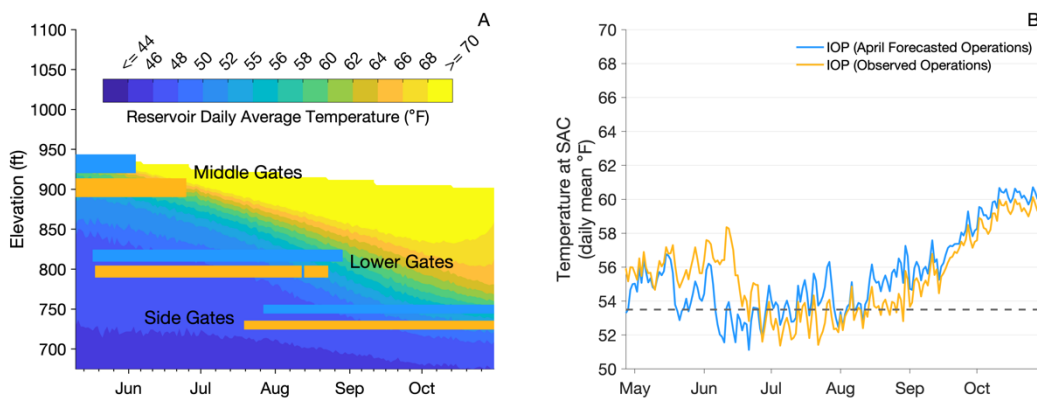


Figure 2: Shasta TCD operations time series (colored horizontal lines) overlaid on Shasta's vertical temperature distribution near the dam (A) and downstream SAC temperature (B) under the 2 scenarios simulated. Note, location of TCD gates on the Y-axis do not reflect precise elevations, but rather are meant to assist with visual interpretation.

Interpretation: Observed gate operations extended the use of the middle TCD gate out from the start of June to near the end of June with the first use of the side gates being earlier than forecasted. These and other changes between gate operations resulted in TDM to drop by 12% from the forecasted to the observed (i.e., 54%-42%) conditions. Specifically, observed temperature was higher than forecasted up until July and then became cooler than forecasted. From this, it appears the cooler observed conditions after July had a larger impact on TDM compared to the warmer observed conditions prior to July as the net TDM change from forecasted to observed was lower.

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4. Reservoir inflow (volume and temperature)

Shasta Reservoir inflow volume and temperature were simulated under two conditions described below.

1. IOP (April Forecast): This operation was based on information from the California Nevada River Forecast Center 90% exceedance⁴ for inflow volume and used a warm inflow temperature time series (90% percentile) from the historical record (1990-2020).
2. IOP (Observed Operations): This operation used the observed inflow volume and temperature during 2022 from CDEC⁵.

Results from the scenarios are presented below, with the plot on the left (subplot A) showing forecasted and observed inflow volume into Shasta Reservoir (smoothed over a 30 day average window for visual purposes), while the middle plot (subplot B) shows the forecasted and observed inflow temperature weighted by inflow volume. The plot on the right (subplot C) displays the resulting downstream temperature time series at the SAC gauge (the temperature management location for 2022) for each scenario. TDM estimates for each scenario are presented in Table 1.

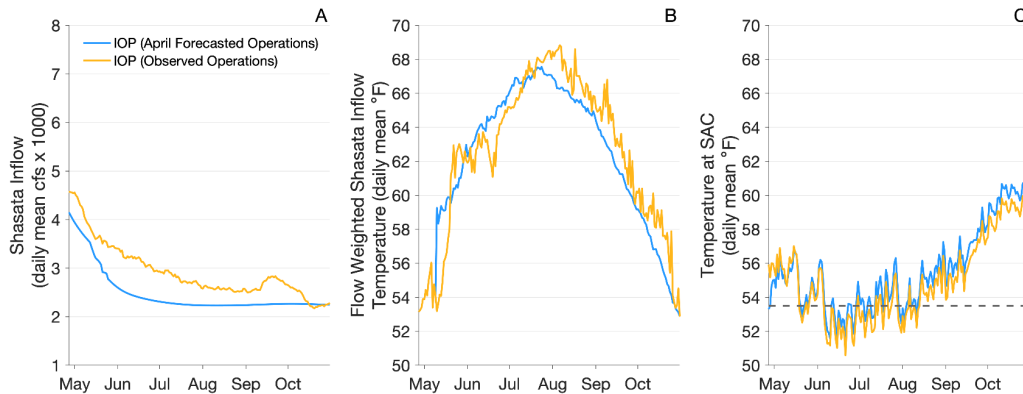


Figure 3: Time series of Shasta inflow volume (A) with daily data smoothed over a 30 day moving average window, Shasta inflow temperature (B), and downstream SAC temperature (C) under the 2 scenarios simulated.

Interpretation: Observed inflow volume tended to be greater than forecasted inflow volume, while observed inflow temperature tended to be cooler in the early season (i.e., before August) and warmer in the later season. These changes resulted in cooler SAC temperatures and a drop in TDM by 7% from the forecasted to the observed (i.e., 54%-42%) conditions.

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5. Meteorology

Meteorology forcings for the water temperature models were simulated under two conditions described below.

1. IOP (April Forecast): This operation was based on an assumed meteorology of 2015 as assessed by the NARR⁶ weather product.
2. IOP (Observed Operations): This operation used the observed meteorology for 2022 as estimated with the GFS⁶ and GEFS⁶ weather products.

Results from the scenarios are presented below, with the plot on the left (subplot A) showing forecasted and observed air temperature (smoothed over a 30 day average window for visual purposes), while the middle plot (subplot B) shows the forecasted and observed downward solar radiation (smoothed over a 30 day average window for visual purposes). Note, that in total, air temperature, downward solar radiation, dew point, wind speed and wind direction were used as inputs into the temperature models. For display purposes, only air temperature and solar radiation, two forcings known to be primary drivers of temperature dynamics are plotted. The plot on the right (subplot C) displays the resulting downstream temperature time series at the SAC gauge (the temperature management location for 2022) for each scenario. TDM estimates for each scenario are presented in Table 1.

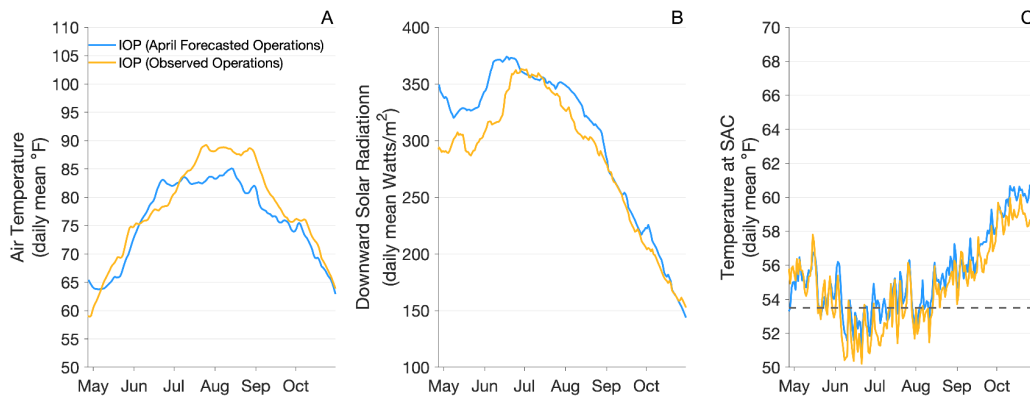


Figure 4: Time series of air temperature (A) with daily data smoothed over a 30 day moving average window, downward solar radiation (B) with daily data smoothed over a 30 day moving average window, and downstream SAC temperature (C) under the 2 scenarios simulated.

Interpretation: Observed air temperature and solar radiation tended to be similar with daily variation resulting in observed conditions being higher and/or lower than forecasted conditions depending on the given day. Overall, the differences in forecasted and observed conditions resulted in generally cooler SAC temperatures and a drop in TDM by 2% (i.e., 54%-52%).

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6. Redd distribution

Redd year distribution for the TDM model were simulated under two conditions described below.

1. IOP (April Forecast): This operation was based on an assumed redd distribution equal to the observed distribution in year 2021 obtained from CDFW⁷.
2. IOP (Observed Operations): This operation used the observed redd distribution of the year 2022⁷.

Results from the scenarios are presented below, where redds for the April forecast and observed conditions are plotted on top of the TDM landscape of the baseline condition (i.e., all forecasted inputs). TDM estimates for each scenario are presented in Table 1.

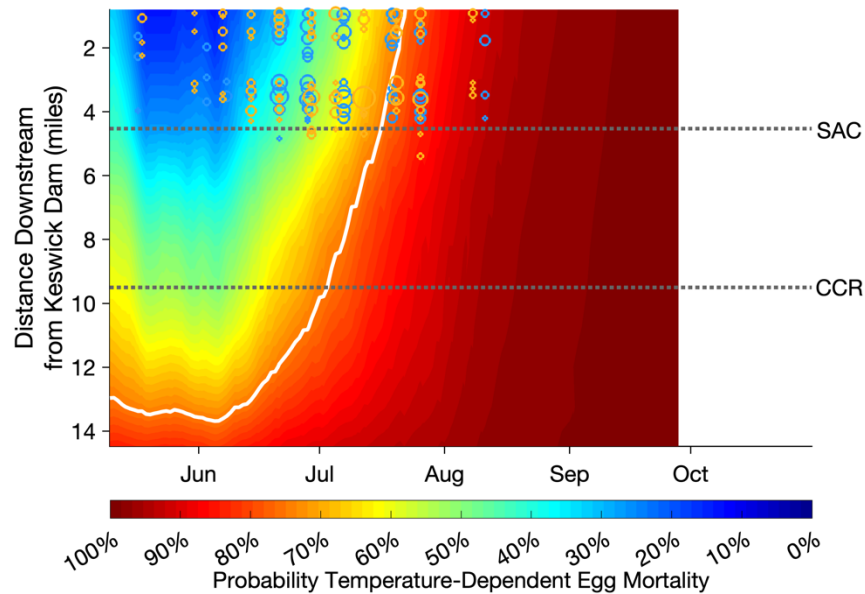


Figure 5: Spatial and temporal redd distributions for 2021 and 2022 overlaid on top of the temperature-dependent egg mortality landscape for the baseline scenario (i.e., all forecasted inputs).

Interpretation: Observed redd distribution of 2022 was similar to the redd distribution of 2021. Overall, the redd distribution in 2022 resulted in an increase in TDM by 2% (i.e., 54%-56%). This indicated that redds on average were either distributed slightly lower in the system or later in the season, or both, compared to in 2021.

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7. Summary

When looking at the individual factor level contribution to the change in TDM observed between forecasted and observed conditions (Figure 6), we can see that all but one factor (redd distribution) resulted in the observed TDM estimate to be lower than forecasted in April. Of these factors, changes in reservoir outflow operations had the largest effect on TDM, with TDM dropping by 36% in this case.

This analysis suggests that several factors contributed to the TDM estimate in April dropping over the season. Some of these factors are more directly related to management actions (e.g., reduced releases in May and June), while others are more related to uncertainty around expected conditions of the system (e.g., greater Shasta inflow observed than forecasted).

As stated in the final Temperature Management Plan of 2022¹, “Because this forecast (using conservative estimates in April to estimate what might happen at the end of October) can never exactly predict the actual hydrology, operations, and meteorology, the model results are not expected to precisely match actual water temperatures”. This analysis aligns with this statement and highlights that using conservative inputs into a scenario in April will often result in TDM to drop over the season as less-conservative conditions are observed and manifest in system operations. This dynamic should be considered when referencing early season temperature management plans forced with conservative inputs.

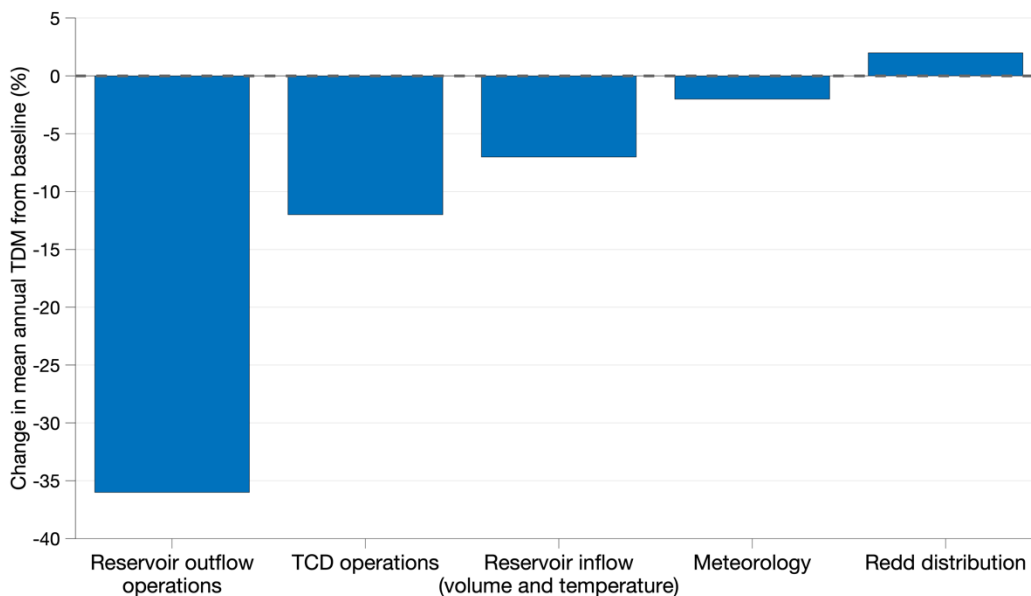


Figure 6: The estimated change in TDM when using observed inputs compared to the baseline scenario (i.e., all inputs as forecasted in April) for each factor examined.

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References

¹https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/sacramento_river/docs/2022-sac-tmp-final.pdf

²Daniels, Miles E., Vamsi K. Sridharan, Sara N. John, and Eric M. Danner. 2018. Calibration and validation of linked water temperature models for the Shasta Reservoir and the Sacramento River from 2000 to 2015. NOAA Technical Memorandum NMFS-SWFSC-597. 60 p

³Martin, B. T., Pike, A., John, S. N., Hamda, N., Roberts, J., Lindley, S. T. and Danner, E. M. (2017), Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters 20: 50–59. doi:10.1111/ele.12705

⁴<https://www.cnrfc.noaa.gov/ahps.php>

⁵<http://http://cdec.water.ca.gov/>

⁶<https://nomads.ncep.noaa.gov/>

⁷<https://www.calfish.org/ProgramsData/ConservationandManagement/CentralValleyMonitoring/CDFWUpperSacRiverBasinSalmonidMonitoring.aspx>