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Water Year 2024 and 2025 Winter-run Chinook Salmon Annual Loss Independent Peer Review

A report to the Delta Science Program

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**Delta
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DELTA STEWARDSHIP COUNCIL

Table of Contents

Water Year 2024 and 2025 Winter-run Chinook Salmon Annual Loss Independent Peer Review	1
Executive summary	3
Key Recommendations	4
Abbreviations used in this report	8
Objective of this review.....	10
Review Documents	11
Supplemental Materials.....	12
Review Questions	13
Background information.....	15
1. California Central Valley.....	15
2. South Delta Water Projects.....	17
3. Winter-run salmon	18
4. Delta entry and residence times for juvenile winter-run	20
5. Timeline of WY 2024 and WY 2025 loss and operations	22
Review Questions	25
Acknowledgements:	68
References.....	69
Appendix Table 1 - SaMT meeting notes from the weekly assessments and ITP risk assessments for WY 2024	75
Appendix Table 2 - WOMT Meeting Timelines for WY 2025	78

Executive summary

The endangered Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*) is characterized by a unique life history, where adults return to freshwater in winter and spring and spawn in early summer. The juveniles emerge in July to October then spread through the system, rearing across diverse freshwater habitats from the upper Sacramento River to the Sacramento-San Joaquin River Delta (hereon, "Delta"). Juvenile winter-run salmon exhibit diverse migratory behaviors and timings, both within and among years, but peak Delta entry generally occurs in January and February and peak outmigration past Chippis Island in March and April. Hatchery and natural origin juvenile winter-run that enter the interior Delta are vulnerable to being entrained into the State Water Project (SWP) and Central Valley Project (CVP) export facilities that pump large volumes of water to millions of agricultural and municipal users. They are particularly vulnerable to the facilities because their outmigration window - in particular, the period when they enter the Delta - is concentrated into the wetter winter/spring period when demand for exports to fill the reservoirs south of the Delta is high. The export facilities can directly entrain (draw in) juvenile salmon and other species, and cause changes in hydrodynamics in the South Delta that delay salmon outmigration and thus increase predation risk. The fish salvaged at the CVP/SWP are used to estimate total mortality of winter-run caused by the facilities, for which the Incidental Take Permit (ITP) has an annual "loss threshold" for hatchery and natural origin winter-run which is implemented as a fraction of the estimated number of juveniles that entered the Delta. The loss thresholds are used to constrain exports with an aim to minimize impacts of water operations on this endangered fish.

In 2024, the 100% annual loss threshold for natural origin winter-run was exceeded on March 20, and in 2025, the 100% annual loss threshold for hatchery-origin winter-run was exceeded on March 21, triggering this review. Here, we review the actions and decisions that contributed to the observed cumulative loss trajectories in both years, explore knowledge gaps, uncertainties and inefficiencies that could be hindering real-time management, and suggest ways to avoid exceeding loss thresholds in the future.

Key Recommendations

Below, we summarize our findings into numbered 'Key Recommendations' that are referenced throughout the review using the # prefix.

1. **Change from reactive to proactive, precautionary management** to avoid loss and contraction of life history diversity, especially during the critical February to March window when risk of exceeding loss thresholds tends to be highest. This will require rapid genetic testing (Recommendation #2) and coded wire tag reads; clearer, more efficient communication and data sharing methods among groups (Recommendation #8); improved forecast modelling and preseason planning (Recommendation #5). Proactive management would likely require reducing exports *before* rather than *after* reaching the 50% annual loss threshold to reduce disproportionate loss of early migrating fish (i.e., maintaining life history diversity) and lessen risk of exceeding the 100% annual loss threshold for hatchery or natural winter-run salmon when the cumulative loss trajectories are steep. These decisions should be informed by paired flow and telemetry experiments (Recommendations #3-4).
2. Shift from length-at-date approaches to **rapid genetic tests to enable real-time decision making and more accurate loss predictions**. Discriminating between early (spring/winter-run) vs. late (fall/late fall run) can be achieved rapidly (<2 hours) at low cost (~\$30) at the facilities using 'Specific High-sensitivity Enzymatic Reporter UnLOCKing' (SHERLOCK) assays. For many samples, a second SHERLOCK test could differentiate spring from winter-run, but some samples will still need to be analyzed by external labs using the more resource-intensive 'Genotyping-in-Thousands by sequencing' (GT-seq) method. This will require increased efficiency along all steps of the pipeline. While results are waiting, we recommend applying the precautionary principle (i.e., assuming length-at-date is correct until proven otherwise). For contemporary samples we recommend using genetic assignment methods to track the progression of winter-run through the season (i.e., at both salvage and monitoring stations). We also recommend completing genetic analysis of historical tissue samples to allow prediction models to be trained using genetic-assigned winter-run only (Recommendation #5).
3. In concert with acoustic tagging (Recommendation #4), we recommend **performing a series of experiments to test how different export levels and**

timings from CVP and SWP - individually and in combination - influence winter-run in terms of (a) behavior and routing in the interior Delta, (b) entrainment into the export facilities, and (c) in-Delta survival. Understanding relationships between in-Delta survival and exports remains a key knowledge gap hindering our ability to perform informed and proactive management. Such experiments do carry risk of increased loss, so should be avoided during years when natural production is particularly low (reduced risk tolerance). We also recommend using tagged fish released over a broader size and time window than previously (see Recommendation #4). Yet even without these experiments, the existing data suggest that managing the two facilities individually and differentially could be best to reduce winter-run loss.

4. Increase **acoustic monitoring in the Delta** (e.g., to understand what fractions of juvenile winter-run move into the Delta via Threemile Slough, how exports are associated with survival and routing in the Delta, and using tagged fish as “sentinels” to monitor the leading edge of the distribution). As part of this, we recommend exploring smaller acoustic tags (e.g., “shad tag” or “Eel-Lamprey Acoustic Tags”) which can be applied to salmon as small as 55 mm fork length, as different sized fish likely exhibit different behaviors and survival, but most of our existing knowledge is based on individuals >95 mm fork length.
5. **Improve and develop new loss prediction models** to improve our ability to perform proactive, real-time actions to reduce loss of natural and hatchery origin winter-run salmon. We separate these recommendations between (a) the existing Winter Run Chinook Machine Learning (WRCML) model developed by CDFW, and new approaches that we suggest developing in the future (b-c).
 - a. We see the significant benefits of the WRCML model developed by CDFW given its ability to predict loss three weeks into the future. However, we believe the utility of the model could be enhanced by either adopting more states or treating loss as a continuous response variable. In addition, the researchers should reconsider how they estimate travel time of fish from monitoring sites to salvage and should publish the model with peer review and add full documentation online.
 - b. We recommend the development of an analogous machine learning model to predict loss of winter-run hatchery fish, trained on coded wire tag (CWT) marked hatchery releases and variables such as release date, location, flow,

temperature, exports. We note that Zeug and Cavallo (2014) developed a Generalized Linear Model based on this type of data (described in more detail under Question 8). We also recommend active communication between hatchery staff and water operators to reduce likelihood of rapid loss exceedance events such as WY 2025.

c. Finally, we recommend earlier season planning. This could be achieved by developing an early season modeling mode based on Red Bluff Diversion Dam counts and using alternative flow regimes based on water years ranging from low to high flow conditions. This would allow managers to begin discussions earlier about export plans for the season, which could have the benefit of protecting the entire run and avoiding ‘surprises’.

6. Test the **demographic impacts of different loss scenarios** using life cycle models (e.g., via forecasting population size into the future using the Hendrix et al. (2022) model under differing JPE and loss scenarios).
7. Use existing hydrodynamic models and South Delta (south of the San Joaquin River) hydrodynamic monitoring stations to better **understand how pumping influences circulation patterns and water residence times** in the South Delta and assess whether it improves accuracy of predictions from Recommendation #3.
8. Create a **simple system for reporting and sharing key information** between agencies in real time. The Salmonid Monitoring Team’s (SaMT) weekly assessments and Incidental Take Permit (ITP) risk assessment reports are valuable, but long and complicated, and often include repetitive boilerplate language that increases risk of missing information or trends. SacPAS (<https://www.cbr.washington.edu/sacramento/>) also has lots of useful information, but it is spread across multiple webpages, and it does not yet include a prediction application for the CDFW machine learning model. It is also unclear how quickly genetic data are added into SacPAS. SaMT and Water Operations Management Team (WOMT) should agree on the key metrics that support decision making and generate a dynamic, online table or suite of figures on a single webpage that are updated in real time to support transparent, rapid management responses.

9. We recommend **re-estimating the Juvenile Production Estimate (JPE) each year in early February based on year-specific survival estimates** informed by flow and temperature forecasts and any available tagging data (“sentinels”). Currently, the JPE is an early season forecast based on historic survival estimates and is heavily reliant on hatchery fish that may be poor surrogates for wild fish. JPE typically has broad prediction intervals but is used as a point estimate, and this could result in inaction that is counter to winter-run recovery. For example, if the true number of juveniles reaching the Delta is greater than the JPE as a result of good river conditions (e.g., high flows leading to high smolt survival), triggers are more likely to be met and exports reduced. More worrying is that when conditions are poor and survival lower than average - i.e., when the cohort is in greatest need of protection - the numbers of winter-run reaching the Delta and salvage will be lower than expected, resulting in lower probabilities of loss thresholds being exceeded and exports being reduced.
10. Ultimately, juvenile winter-run are most vulnerable to loss at the export facilities if they cannot find territory upstream to feed, rest, and seek refuge from predators, so **taking a holistic view to support winter-run recovery and reduce loss is highly recommended**. We know that survival of fish through the interior Delta is relatively poor relative to fish that remain in the mainstem Sacramento River, so keeping fish out of and/or improving conditions in the Delta is paramount. Three of the longer-term actions we recommend include (a) performing restoration upstream of the Delta to improve growing conditions and habitat carrying capacity, thus reducing the numbers of winter-run attempting to rear in the Delta, (b) reducing movement of winter-run into the interior Delta. Barriers such as the Delta Cross Channel (DCC) and Bioacoustic Fish Fence (BAFF) appear to work well, but unmonitored entry points such as Threemile Slough are potentially problematic and where installation of a BAFF fence could be valuable, and (c) restoring habitats within the interior Delta to improve in-Delta winter-run survival and growth, and potentially also reducing entrainment rates into the facilities. Any such efforts would need to be monitored (e.g., through acoustic tag monitoring within the Delta and long-term monitoring of population growth) and fed into life cycle models (Recommendation #6) so that loss thresholds and management plans can be adapted as a function of population size and stability.

Abbreviations used in this report

Abbreviation	Description
BAFF	Bioacoustic Fish Fence on Georgiana Slough
BOR	Bureau of Reclamation
BY	Brood Year
CALSIM	Watershed hydrology planning model for the State Water Project and Central Valley Project
CCF	Clifton Court Forebay
CCV	California Central Valley
CDFW	California Department of Fish and Wildlife
CVP	Central Valley Project
CWT	Coded Wire Tag
DCC	Delta Cross Channel
Delta	Sacramento-San Joaquin River Delta
DSM2	Delta Simulation Model II: A one-dimensional hydrodynamic model of the Delta used by the California Department of Water Resources
DWR	California Department of Water Resources
ELAT	Eel-Lamprey Acoustic Tag
FL	Fork length
GLM	Generalized Linear Model
GT-seq	Genotyping-in-Thousands by sequencing
Interior Delta	Delta region interior to the Sacramento and San Joaquin Rivers including Georgiana Slough, Mokelumne, Old River, Middle River, Frank's Tract and Mildred Island
ITP	Incidental Take Permit
JPE	Juvenile Production Estimate
LAD	Length-at-date criteria to estimate run type
LSNFH	Livingston Stone National Fish Hatchery
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OMR	Estimate of tidally averaged flow on Old and Middle Rivers in the South Delta
OMRI	Old and Middle River Index: Regression equation estimate of OMR

Abbreviation	Description
PIT tag	Passive Integrated Transponder tags
Reclamation	U.S. Bureau of Reclamation
RBDD	Red Bluff Diversion Dam
RST	Rotary Screw Trap
SaMT	Salmonid Monitoring Team
SHERLOCK assay	Specific High-sensitivity Enzymatic Reporter UnLOCKing assay
South Delta	Delta Region south of the San Joaquin River
SST	Salmon Scoping Team
STARS	Survival, Travel time, And Routing Simulation model based on Perry et al. (2018) and Hance et al. (2022)
SWP	State Water Project
TFCF	Tracy Fish Collection Facility
Tillotson Model	Machine Learning Model to predict entrainment outlined in Tillotson et al. (2022)
TPP	Tracy Pumping Plant
USFWS	U.S. Fish and Wildlife Service
WOMT	Water Operations Management Team
WRCML	Winter Run Chinook Machine Learning Model made by CDFW
WY	Water Year

Objective of this review

The intent of the review is to constructively inform the U.S. Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR) with recommendations to stay within the annual loss threshold for natural and hatchery winter-run Chinook salmon for the State Water Project (SWP) and Central Valley Project (CVP). Reclamation signed a Record of Decision on December 20, 2024, for the Long-Term Operation of the Central Valley Project (CVP) and State Water Project (SWP). The Decision includes a commitment to convene an independent peer review if salvage loss of hatchery winter-run Chinook salmon exceeds 0.12% of the juvenile production estimate (JPE) entering the Delta or if wild winter-run Chinook exceeds 0.5% of JPE. In water year (WY) 2025, measured loss of hatchery winter-run was 242 (0.18% of the JPE). The 2024 Incidental Take Permit for the SWP contains a similar commitment requirement for an independent peer review of actions and conditions related to winter-run Chinook salmon loss for both water years 2024 and 2025.

In 2024, 50% of annual loss threshold for natural-origin winter-run Chinook salmon was exceeded on February 25, 2024, 75% of the annual loss threshold was exceeded on March 7, 2024, and the annual loss threshold was exceeded on March 20, 2024.

In 2025, 50% of the annual loss threshold for hatchery-origin winter-run Chinook salmon was exceeded on March 18, 2025, 75% of the threshold was exceeded on March 19, 2025, and the annual loss threshold was exceeded on March 21, 2025.

This peer review aimed to review the actions and decisions contributing to the loss trajectory that led to an exceedance of the annual loss threshold, and make recommendations on modifications to SWP and CVP operations, or additional actions to be conducted to stay within the threshold in subsequent years including the use of indicators from in-season monitoring (e.g., existing/new monitoring data) and tools (e.g., modeling tools).

Review Documents

1. Weekly Assessment of CVP and SWP Delta Operations on ESA-listed Species
 - a. February 6, 2024
 - b. February 13, 2024
 - c. February 20, 2024
 - d. February 27, 2024
 - e. March 5, 2024
 - f. March 12, 2024
 - g. March 19, 2024
 - h. March 26, 2024
 - i. March 20, 2025
2. Final State Water Project Incidental Take Permit Risk Assessments for Winter-run and Spring-run Chinook Salmon
 - a. February 20, 2024
 - b. February 27, 2024
 - c. March 5, 2024
 - d. March 12, 2024
 - e. March 19, 2024
 - f. March 26, 2024
 - g. April 2, 2024
 - h. April 9, 2024
 - i. April 16, 2024
3. Long-Term Operation – Biological Assessment. Appendix AB, Chapter 3 – Proposed Action. - 3.7 Delta, pages 3-49 to 3-67
4. 2019 Biological Opinions, Consultation on the Coordinated Long-Term Operation of the Central Valley Project and State Water Project. Chapter 4: Proposed Action. 4.10.5 Delta, 4-54; 4.10.5.1 Seasonal Operations, 4-55; 4.10.5.10 OMR Management, 4-66 to 4-80
5. Biological Opinion for the Reinitiation of Consultation on the Long-Term Operation of the Central Valley Project and State Water Project (2019) - Section 8.6.9.2.1 Sacramento River Winter-run Chinook salmon exposure pgs. 486-489; Section 8.6.9.2.2 Juvenile Salvage Estimates using the Salvage-Density Model 489-497; Sections 8.6.9.2.9 - 8.6.9.2.24 pgs. 519-549

6. Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta Report, Volume 1 (2017) - Section 3.13 Migration and Survival as a Function of Old and Middle River Flows pages 72-73; Section 3.18 Discussion and Summary of Key Findings pages 80-95
7. Effects Analysis, State Water Project Effects on Winter-run and Spring-run Chinook Salmon (March 2020) – Section 8.14, pages 119-145
8. Effects Analysis, State Water Project Effects on Winter-run and Spring-run Chinook Salmon, Attachment 6 (November 2024) – pages 217-227
9. Winter-run Chinook Salmon Machine Learning Model
 - a. Using Monitoring Data as an Early Warning Indicator of Salvage
 - b. Winter-run Chinook Salmon Machine Learning Model Old and Middle River Scenarios
10. Winter-run Chinook Salmon Juvenile Production Estimates, Appendix F
11. Water Operations Management Team Notes
 - a. March 25, 2024 (ad hoc)
 - b. March 27, 2024
 - c. March 19, 2025
 - d. March 25, 2025 (ad hoc)
 - e. March 26, 2025
 - f. April 1, 2025
 - g. April 9, 2025
12. Incidental Take Permit: Long-term Operations of the State Water Project in the Sacramento-San Joaquin Delta (2020) - pages 66-75; 87- 89
13. Incidental Take Permit: Long-term Operations of the State Water Project in the Sacramento-San Joaquin Delta (2024) - pages 62-66; 73-75

Supplemental Materials

1. Salmon Monitoring Team notes
 - a. Items for WOMT Discussion and Direction, April 1, 2025
 - b. Weekly Meeting notes, March 25, 2025
 - c. Weekly Meeting notes, April 1, 2025
2. Water Year 2024 Seasonal Report for Old and Middle River Flow Management
3. Appendix H. Winter-Run Chinook Salmon Cohort Report (Brood Year 2023)

4. Water Year 2025 Seasonal Report for Old and Middle River Flow Management
 - a. Appendix A. Water Year 2025 Old and Middle River Entrainment Seasonal Report Data
 - b. Appendix C. Winter-Run Chinook Salmon Cohort Report (Brood Year 2024)
 - c. Appendix D. Genetic Analysis
5. Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta Report (2017)
6. Enhanced Acoustic Tagging, Analysis, and Real-Time Monitoring of Wild and Hatchery Salmonids in the Sacramento San Joaquin Rivers and Delta 2021-2024 Final Report
7. 2024 Salmon Scoping Team Report
8. Brood Year 2024 Juvenile Production Estimate Letter (January 17, 2025)
9. Brood Year 2023 Juvenile Production Estimate Letter (January 12, 2024)

Review Questions

1. Were there indicators in the current monitoring data or tools that could have been used proactively to predict an exceedance of the annual loss threshold? If so, how can that information or tool be used to change the loss trajectory to not exceed thresholds in the future?
2. What indicators could have been incorporated from WY 2024 and 2025 monitoring data or assessments that could have improved the prediction of winter-run detection trajectories at Central Valley Project (CVP) and State Water Project (SWP) export facilities?
3. Recognizing the different loss trajectories in 2024 and 2025, were there any actions that could have been implemented once the 50% threshold exceedance occurred to have prevented the annual loss threshold being exceeded?
4. Does evidence suggest changes to OMRI or other operations would have resulted in changes to the observed loss trajectories in WY 2024 or WY 2025?
5. What information could have been incorporated into WY 2024 and 2025 monitoring data or assessments that could have informed routing, through-Delta survival, salvage loss, and other effects to the winter-run population from different export levels?

6. Were the conclusions of the assessments regarding export operations supported by the information available at the time the assessment was prepared?
7. What monitoring data and assumptions could have been incorporated into the Water Year (WY) 2024 and 2025 Juvenile Production Estimate (JPE) to improve the establishment of the winter-run threshold?
8. What is the best framework for incorporating relevant sources of information and data into real-time management decisions for the SWP to estimate and manage population impacts to the winter-run population, including but not limited to informing operational decisions to change the loss trajectory and avoid exceeding the annual loss threshold? Specifically, how can prediction tools such as the Winter-run Chinook Salmon Machine Learning (WRCML) Model be modified, adjusted, or used complimentary with relevant real-time data, including but not limited to, the juvenile production estimate (JPE), reach-specific survival, real-time acoustic data, non-physical barrier operations, river inflows, physical conditions, and other relevant information?
9. Are there new or alternate approaches to incorporate into assessments to inform real-time estimates on effects to fish from CVP and SWP export operations?

Background information

1. California Central Valley

California's Central Valley (CCV) is one of the most important and intensively managed regions in the United States, balancing a large human population, globally significant agriculture, and a heavy reliance on engineered water systems. The CCV is home to about 7 million people and is one of the most productive agricultural regions in the world, supplying large quantities of fruits, vegetables, nuts, and dairy products. This has been made possible by millions of irrigated acres and an extensive water conveyance infrastructure network, particularly the Central Valley Project (CVP) and State Water Project (SWP). The CVP/SWP stores runoff and snowmelt in several large reservoirs, transporting water to areas around the Sacramento-San Joaquin River Delta (hereon 'Delta') and to millions of people in southern California via large pumps in the South Delta (Fig. 1).

California has a Mediterranean climate, characterized by hot, dry summers and - in non-drought years - cool, wet winters with most precipitation falling in November to March. Precipitation is delivered by Pacific storm systems and atmospheric rivers, which can result in extreme flood events. Conversely, the summer months are typically rainless, creating a strong reliance on winter snowpack and reservoirs to store water for year-round (and among-year) water supply (Null et al., 2024). This climate and reservoir system supports highly productive ecosystems and (in combination with extensive water conveyance and irrigation systems) agriculture, but it also creates inherent water scarcity, making California particularly vulnerable to drought, wildfire, and climate-driven shifts in precipitation timing and intensity. Indeed, water demand consistently exceeds local supply (Grantham and Viers, 2014), creating competition among agricultural, urban, and environmental uses. This pressure is being heightened by climate change, with multi-year droughts predicted to increase in frequency and severity, and extreme flood events (so called 'whiplash weather'; Swain et al., 2025) and reduced snowpack, making it more difficult to ensure water supply reliability and ecosystem health (Cloern et al., 2011).

Overall, the Delta has been transformed from a rich, tidal wetland of dendritic channels to a simplified series of channels (Robinson et al., 2014), with "islands" drained and protected by levees as early as the 1860s as part of the Swamp and Overflow Land Act to promote agriculture in the Delta region. When combined with high levels of introduced predators, rapid warming and reduced prey, this results in

very poor survival and growth opportunities for early migrating salmon. Indeed, tagging studies show that survival in the South Delta has been low along all routes since 2008 (Buchanan et al., 2018; SST, 2017).

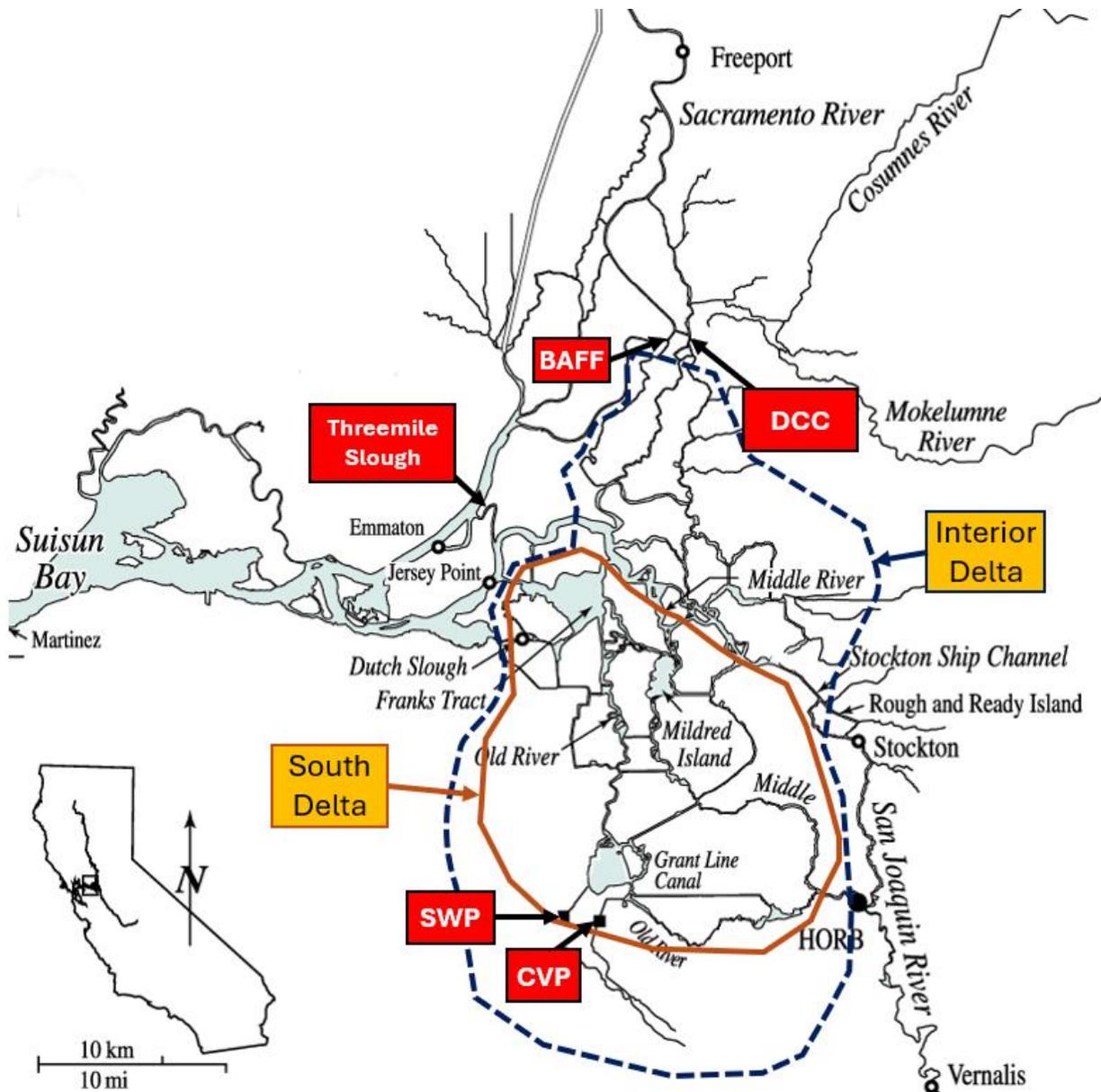


Fig. 1 Map of the Delta, labelled with the State Water Project (SWP), Central Valley Project (CVP), Delta Cross Channel (DCC), bioacoustic fish fence (BAFF) at the confluence of Georgiana Slough and the Sacramento River, and Threemile Slough. Orange line demarcates the area we refer to as the South Delta and the dashed line shows the area we refer to as the interior Delta. Adapted from Monsen et al. (2007).

2. South Delta Water Projects

Features of the SWP relevant to this review include the Clifton Court Forebay (CCF) located near Byron in the South Delta, the John E. Skinner Delta Fish Protective Facility which salvages fish entrained in the intake, and the Harvey O. Banks Pumping Plant, which consists of 11 pumps that provide the initial lift of water from the CCF into the California Aqueduct. Entrainment refers to fish being drawn into a flow, while 'facility entrainment' or 'entrainment into the CVP or SWP' refers to fish being drawn into the water export facilities. A set of five radial gates at the CCF inlet are operated so that they can be closed during critical periods of the ebb/flood tidal cycle to maintain appropriate water levels in the South Delta. The federally operated CVP comprises the Tracy Pumping Plant (TPP) that draws water off the Old River channel into the inlet to the Delta Mendota Canal via a large fish diversion and salvage facility known as the Tracy Fish Collection Facility (TFCF). The Skinner and Tracy Fish Facilities use a series of screens and louvers to try to prevent fish from entering the pumps by actively redirecting them away from the intake into holding tanks, where a subsample is counted and documented as "salvage". After processing (including length and fin clip for length-at-date [LAD] and genetic run assignment), the salvaged fish are transported in oxygenated tank trucks for release back into the Delta at SWP/CVP release sites near the confluence of the Sacramento and San Joaquin rivers around Sherman Island or Antioch.

Fish loss is estimated as an index (rather than a direct count of total mortality), because only a fraction of fish affected by project operations are actually handled. The theory is that the number of fish salvaged represents a detectable fraction of the population that would otherwise be entrained or harmed by CVP and SWP operations, and this information is expanded using statistical methods to estimate overall loss.

In practice, salvage counts are combined with estimates of salvage efficiency (the probability that a fish entering the facility is successfully captured), pre-screen loss (fish killed or injured before reaching salvage), and post-salvage mortality (delayed mortality after handling and transport). These factors are incorporated into models that expand observed salvage numbers into total estimated loss. The resulting loss estimates are then evaluated in the context of a proxy of population size (for winter-run specifically being the Juvenile Production Estimate [JPE], which is the number of juveniles predicted to reach the Delta in a given year), and used by managers and

regulators to assess project impacts and trigger operational constraints, forming the basis of this report.

3. Winter-run salmon

The Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*) (hereon 'winter-run') is an anadromous population listed as Endangered under the U.S. Endangered Species Act after large declines that have been linked to the construction of Shasta and Keswick Dams that blocked passage to historical spawning habitats in the McCloud and Pit Rivers, and severe loss and degradation of habitats along the migratory corridor (Yoshiyama et al., 1998). Chinook salmon are highly valued by both Pacific Coast commercial fisherman and Delta recreational fisherman, however the low numbers of winter-run within the mixed stock Ocean fishery can constrain access to other, more abundant stocks (see PCFFA public comment). Winter-run exhibit highly diverse freshwater rearing strategies (Phillis et al., 2018), with their movement timing and rearing patterns linked to their life stage, age and size, environmental triggers (e.g., temperature, flow and turbidity), the availability of rearing habitat, and the densities of conspecifics in their immediate environment (i.e., density dependent migration; Greene and Beechie, 2004).

Winter-run are characterized by unique life histories, where adults return to freshwater in winter and spring (December to May, peaking in March) and spawn in early summer (May to August, peaking May to June) (Yoshiyama, 1998). The eggs incubate in the gravel during the warm summer months, and the fry then emerge in July to October, but mostly in August and September (Dusek Jennings and Hendrix, 2020). During this critical summer window, winter-run are heavily dependent on managed cold-water releases for successful reproduction and survival. While there is always variation, winter-run juveniles generally leave the spawning areas and migrate through the upper Sacramento River in October, sampled as they pass the Red Bluff Diversion Dam (RBDD) Rotary Screw Trap (RST). They then tend to pass the lower Sacramento River and Knights Landing RST in November to March and enter the Delta in December to March, with average peak Delta entry occurring in January and February. Importantly, the timing of all these movements and key habitat transitions are shaped by environmental triggers such as high flow and turbidity events (del Rosario et al., 2013). Winter-run tend to outmigrate to the Pacific Ocean past Chipps Island in February to May, peaking in March (del Rosario et al., 2013; NMFS, 2024).

Juvenile winter-run are particularly vulnerable to the SWP and CVP export facilities because their outmigration window and - in particular, the period when they enter the Delta - is concentrated during the wetter winter/spring period when demand for exports to fill the reservoirs south of the Delta is high. The export facilities can directly entrain juvenile salmon and other species at the pumps, while altered flow patterns linked to exports can delay salmon outmigration, increase predation risk, and reduce access to rearing habitat. While not the focus of this review, CVP and SWP reservoir operations also affect the availability of cold-water pools at the spawning grounds needed for egg incubation, especially during dry and critically dry years, when competing demands for water can elevate temperatures to lethal levels, which resulted in high egg mortality and near cohort failure in 2014, 2015 and 2021 (BOR, 2024). Brood year (BY) 2022 also had very poor egg-to-fry survival, but this was attributed to the effects of thiamine deficiency rather than temperature (BOR, 2024). With projections of reduced snowpack and increased summer temperatures in the climate future (Cloern et al., 2011), the future of winter-run is tightly linked to water operations, making it one of the most management-sensitive and extinction-prone salmon populations in the world.

The Livingston Stone National Fish Hatchery (LSNFH) is operated by the U.S. Fish and Wildlife Service (USFWS) on the upper Sacramento River. It is often referred to as a conservation hatchery, as its primary purpose is the conservation and recovery of winter-run, rather than large-scale production for harvest. The hatchery collects a limited number of natural-origin winter-run adults, spawns them using genetic management protocols to preserve population diversity, and rears juveniles under controlled conditions before releasing them into the Sacramento River to supplement the natural population. LSNFH plays a critical role as a genetic refuge and population safeguard, especially during years when river conditions or water operations threaten egg and juvenile survival in the wild.

Naturally produced juvenile winter-run exhibit a wide variety of migratory strategies, with some fry dispersing downstream from the spawning reaches soon after emergence, some rearing in natal habitats in the upper Sacramento River for multiple months, and some rearing into adjacent non-natal rivers and creeks (Phillis et al., 2018; Maslin, 1998). Diverse habitat options along the migration corridor (e.g., off-channel flooded areas, floodplains, adjacent rivers and creeks) can boost juvenile winter-run growth and survival by reducing crowding and density-dependent effects, and providing improved prey and temperature options than

the mainstem river (Maslin et al., 1998; Limm and Marchetti, 2009). Variation in habitat options and fish behavior (e.g., habitat use and migration timing) also spreads risk in time and space, buffering the cohort against disturbances.

It is generally deemed unlikely that hatchery-produced juveniles act as an appropriate 'surrogate' for wild fish in terms of exhibiting the variety of migration and rearing behaviors demonstrated by wild fish. This is primarily because they spend their first months of life in a hatchery, being fed pellets at regular intervals and not needing to perform behaviors (predator avoidance, foraging, refuge seeking) that are imperative to survival in the wild. Furthermore, they are usually released from the hatchery at a larger, more 'sea-ready' size to increase survival rates and reduce competition with in-river fish, with a recent study by Chen et al. (2025) showing shorter duration of hatchery fish in freshwater (post-release) (mean = 11 vs. 129 days in wild fish) and less spatially diverse (i.e., less 'wandering' into non-natal habitats) rearing patterns than their natural origin counterparts. In Chen et al. (2025), hatchery and natural origin winter-run did enter the Ocean at a similar size, suggesting similar outmigration timings, however, these were outmigration reconstructions derived from the otoliths of returning adults, so there is potential for marine mortality to have shaped and truncated this metric in both groups.

4. Delta entry and residence times for juvenile winter-run

Natural origin winter-run generally enter the Delta in December to March, with the average earliest date when length-at-date (LAD) winter-run appear at the Sherwood Harbour Sacramento Trawl being December 9 (BY 1999-2023) and the average date for 50% passage past that point being January 27 (BY 1999-2023; median date = February 11) (NMFS, 2024). However, salmonids are renowned for their diverse life histories, and their movement timing is tightly linked to hydrology, which is inherently variable within and among years in this system. As such, it can be misleading to focus on averages, as there are always exceptions, for example, with the earliest appearance of LAD winter-run in the Sherwood Harbor Trawl being as early as September 10 in 2001 vs. as late as March 3 in 2017 (BY 2016). This emphasizes why the sequential monitoring stations dotted along their migratory corridor (Fig. 2), particularly the trawl and beach seine sites at Sherwood Harbor, are so important for tracking their downstream migration and predicting risk of entrainment at the CVP and SWP in any given year, e.g., using the CDFW machine learning model (see Question 8).

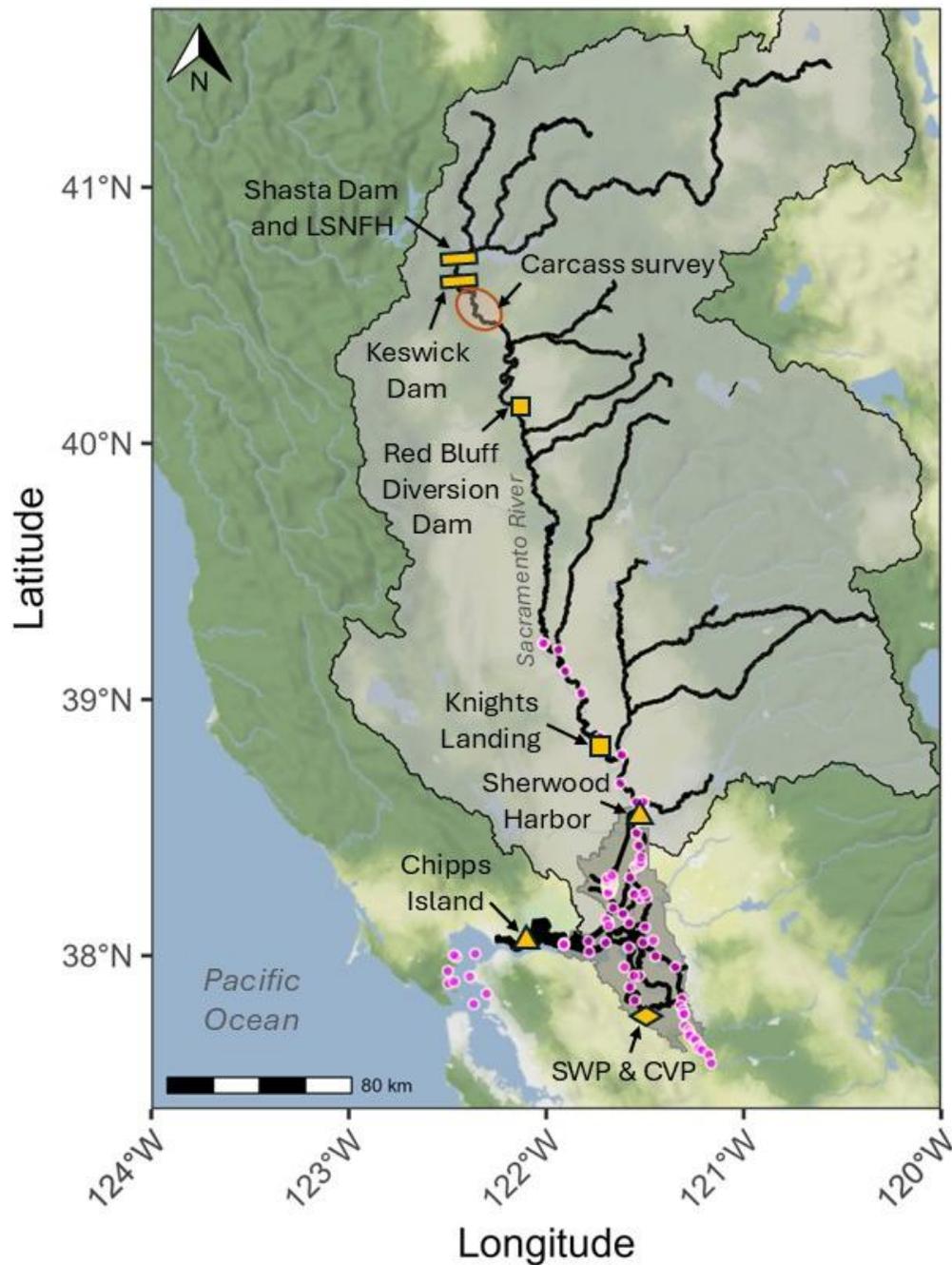


Fig. 2 Map of the Sacramento River Basin (pale grey area) showing key winter-run monitoring locations. The different gear types used to sample them are indicated by different symbols: beach seines (purple circles), rotary screw traps (orange squares), and trawls (orange triangles). The CVP/SWP export facilities are indicated by a diamond. The Sacramento-San Joaquin River Delta is indicated by a dark grey area and the winter-run spawning area just below Keswick Dam is shown by an orange oval. LSNFH = Livingstone Stone National Fish Hatchery.

Juvenile natural and hatchery winter-run do spend extended periods rearing in the Delta, and some of these survive to reproduce, as indicated by otolith chemistry data from post-spawned adults (Phillis et al., 2018; Chen et al., 2025). According to del Rosario et al. (2013) in regard to Delta residence times of natural winter-run: *“Differences in timing of cumulative catch at Knights Landing and Chipps Island indicate that apparent residence time in the Delta ranges from 41 to 117 days, with longer apparent residence times for juveniles arriving earlier at Knights Landing.”*

Peak outmigration of winter-run - migrating past Chipps Island to the Pacific Ocean - occurs in March to mid- to late-April based on LAD and genetic identification methods (del Rosario et al., 2013), with *“no detection of genetic winter-run in the Delta past May 1st”* (SaMT 2024h weekly assessment March 26, 2024).

Thus, the critical window for when most winter-run are in the Delta and most susceptible to loss at the export facilities is January to April, but particularly February to March. Indeed, the 100% annual loss exceedances in WY 2024 and WY 2025 occurred on almost exactly the same date: March 20 and March 21, respectively.

5. Timeline of WY 2024 and WY 2025 loss and operations

WY 2024 and WY 2025 had very different observed loss trajectories and were also based on different Incidental Take Permits (ITP) with different loss thresholds and changes in winter-run identification at salvage, outlined below.

The 2020 ITP permit single year loss thresholds applied in WY 2024:

Natural winter-run: 1.17% of JPE based on unclipped LAD winter-run
Hatchery winter-run: 0.12% of JPE

The 2024 ITP permit single year loss thresholds applied in WY 2025:

Natural winter-run: 0.5% of JPE based on genetically assigned winter-run
Hatchery winter-run: 0.12% of JPE

In WY 2024, loss of natural LAD winter-run exceeded the 50% then 100% threshold for natural LAD over the course of several weeks (50% on February 25 and 100% on March 20; Fig. 3A), and the pumps continued to entrain natural LAD winter-run until May 7, 2024. In the end, 616 LAD winter-run were salvaged in WY 2024, representing a loss of natural LAD winter-run of 4,209, equivalent to 1.79% of the JPE. Loss of genetically confirmed winter-run was 127.4, equivalent to 0.054% of the JPE. The Panel prepared summary tables detailing the WY 2024 loss trajectories (Table 1) and notes (Appendix Table 1) obtained from the SaMT weekly assessments and ITP risk assessments provided for this review.

In WY 2025, it was hatchery origin winter-run that triggered changes to CVP/SWP operations, exceeding 50% through 100% thresholds over just three days (March 18 to March 21; Fig. 3B). In the end, 42 hatchery winter-run were salvaged in WY 2025, representing a loss of 216.58 (0.16% JPE). In WY 2025, 11 genetically confirmed natural winter-run were salvaged, representing a total loss of 28.82, with no more salvaged after March 24, 2025.

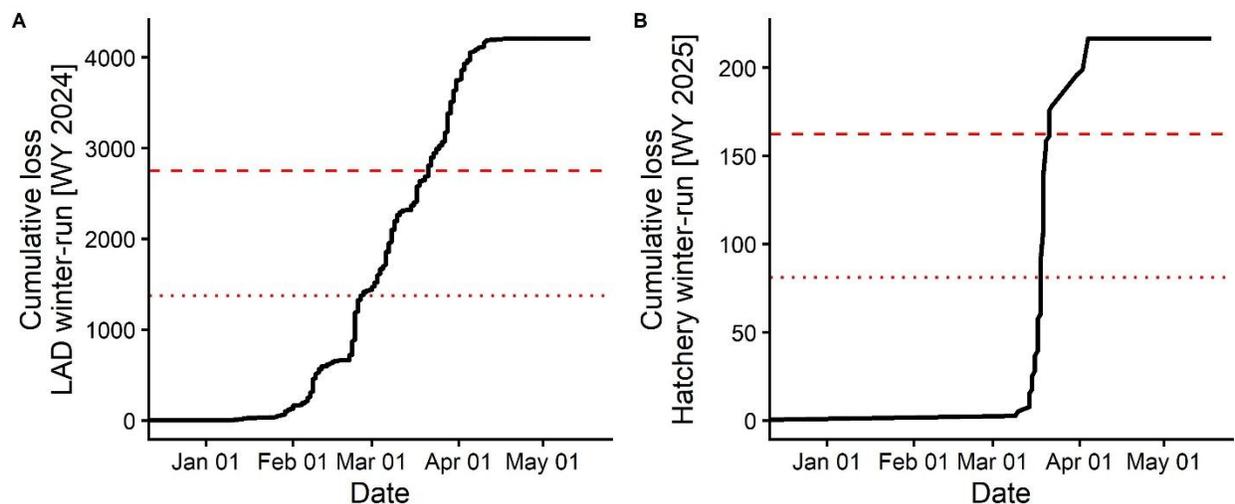


Fig. 3 (A) WY 2024 loss trajectory of LAD natural origin winter-run and (B) WY 2025 loss trajectory of hatchery origin winter-run. The 50% annual loss threshold is indicated by a dotted line, the 100% threshold by a dashed line.

Table 1. Key data from WY 2024 from SaMT weekly assessments and ITP risk assessments reporting for previous week. Values in parentheses were obtained from SacPAS on February 8, 2026. Bold font indicates weeks where annual loss thresholds for natural LAD winter-run were exceeded based on a threshold of 1.17% of the JPE (CDFW, 2020b). Natural winter-run JPE for WY 2024 was 234,896, thus the 100% loss threshold was 2,748.

SaMT Week	Cumulative loss LAD natural winter-run (N / % JPE)	Cumulative loss genetic natural winter-run (N / % JPE)	Percent of winter-run in Delta	5-day USGS OMR (cfs)	5-day OMRI (cfs)	Entrainment risk in the central Delta next week based on OMRI
2024-02-06	191.4 / 0.081%	(4.33) / (0.002%)	60-70%	N/A	N/A	N/A
2024-02-13	594.1 / 0.253%	(6.66) / (0.003%)	65-80%	N/A	N/A	N/A
2024-02-20	650.4 / 0.277%	6.66 / 0.003%	70-85%	-3,500	-3,200	-2,600 cfs low -3,500 cfs med
2024-02-27 [50%]	1,443.5 / 0.615%	23.99 (15.32) / 0.010% (0.007%)	75-94%	-2,500	-2,500	-2,300 cfs low -2,500 cfs med
2024-03-05	1,720.8 / 0.733%	27.55 (52.09) / 0.012% (0.022%)	75-89%	-3,400	-2,400	-2,000 cfs low -2,500 cfs med
2024-03-12 [75%]	2,294.2 / 0.977%	104.1 (110.9) / 0.044% (0.047%)	70-84%	-2,700	-2,500	-400 to -600 cfs low
2024-03-19	2,633.7 / 1.121%	118.79 / 0.051%	65-79%	-700	-500	-400 cfs low -1,600 cfs med
2024-03-26 [100%]	3,030.4 / 1.29%	118.79 (127.4) / 0.051% (0.054%)	55-69%	NA	-450	-500 cfs low -2,500 cfs high
2024-04-02	4,083 / 1.74%	(127.4) / (0.054%)	N/A	-3,900	-1,400	+300 cfs low -2,600 cfs high
2024-04-09	4,192 / 1.78%	(127.43) / (0.054%)	N/A	-2,300	-1,800	+900 cfs low -1,000 cfs med -2,500 cfs high
2024-04-16	4,201 (4,209) / 1.79%	(127.43) / (0.054%)	N/A	-1,100	+100	> +400 cfs low

Review Questions

Question 1. Were there indicators in the current monitoring data or tools that could have been used proactively to predict an exceedance of the annual loss threshold? If so, how can that information or tool be used to change the loss trajectory to not exceed thresholds in the future?

We believe researchers should develop a pre-season forecasting tool for wild winter-run Chinook based on the current WRCML. The inputs to the model would be calibrated to predictor variables available in early January, including Red Bluff Diversion Dam counts, day of year, and river flows and temperatures. These represent most of the important features of the model (Gaeta, pers comm.) but would exclude beach seine counts and secchi depth readings. To run the model early in the season in forecast mode, the environmental information (i.e., water flows and temperatures) could be based on previous years' flows and temperatures, representing a range of conditions from very dry to very wet (each historical year run separately). Presumably, JPE would be available at this point in time also. For each of these scenarios (i.e., a particular historical water year), the modeling team would run the model to predict loss for the entire season. This would require developing the model to forecast continuous loss values. The management team could then develop a strategy of scheduling exports to avoid crossing the JPE threshold in a way that preserves life-history diversity using optimization routines with constraints. This could be performed early in the season before fish arrive at the export facilities. As the season progresses, the managers could focus on which of the trajectories are more likely (based on current river conditions and updated JPE - see Question 7) and adjust their management plan (agreed upon preseason) accordingly. This would allow the managers to be much more proactive than reactive by eliminating "surprises".

WY 2024

In terms of current monitoring tools that were used to predict natural winter-run loss trajectories in WY 2024, the SaMT reports show that the Tillotson et al. (2022) model (available at <https://www.cbr.washington.edu/sacramento/lossandsalvage/>) predicted the following week's loss of LAD winter-run relatively accurately through the season (typically within predicted 75th quantiles, and for many weeks close to the median). So it seems that the tools were already in hand to predict 50%, 75%

and 100% exceedance at least one week prior. Indeed, the SaMT actually correctly predicted on February 20 that the 100% loss threshold for LAD winter-run might be exceeded that season (i.e., 1 month before it happened). Ideally SaMT would have the tools that allow them to predict *when* thresholds are likely to be exceeded, and doing this early enough to enable actions that reduce population impacts. The CDFW WRMLM, which predicts loss 3 weeks into the future, could be valuable to provide an earlier warning system (see Question 8). An even greater challenge is acting on that information in order to alter the loss trajectory (discussed below).

Based on our recommendation to explore pre-season forecasting and to better plan for/avoid sudden increases in loss, we wondered if high risk of exceedance in WY 2024 could have been predicted earlier with the data available to SaMT at the start of January. In terms of what we know about the factors that cue Chinook salmon to migrate downstream, two key triggers are (1) density dependence, with “crowding” in a given location resulting in higher numbers of juveniles being unable to secure territory and thus increased downstream movement (Greene and Beechie, 2004), and (2) high river flows (del Rosario et al., 2013), which act as a cue and an aid, supporting downstream movement of juveniles not able to secure territory upstream or that were inhabiting suboptimal habitats. Indeed, del Rosario et al. (2013) showed that downstream migration of winter-run out of the upper Sacramento past Knights Landing was tightly linked to the timing of the first high flows within the migratory season ($>400 \text{ m}^3/\text{s}$ or $>14,126 \text{ cfs}$ at the Sacramento River below Wilkin’s Slough). Poytress et al. (2014) also describes the importance of the first storm event of the season, linking increased passage to both flows and turbidity. Temperature likely also plays an important role in the redistribution and survival of juvenile winter-run, with early life stages likely to actively seek lower velocity, warmer habitats in non-natal habitats when winter flows on the mainstem are particularly cold and fast moving (Maslin, 1998; Phillis et al., 2018). Conversely, elevated spring temperatures – particularly in the Delta - can increase physiological stress and predation rates (Nobriga et al., 2021).

Ecological forecasting is inherently challenging, but we believe that using metrics such as the JPE, river conditions, meteorological forecasts, and acoustic tag detections (see Question 5), the SaMT could identify *more likely* loss trajectories during early season discussions in early January. While it would be prudent for SaMT to still consider the full range of loss trajectories observed previously, like

they did in Figure 4 below, **we suggest they focus more on trajectories from years exhibiting similar (1) JPE estimates (available in January) and (2) river conditions (current and coarse forecasts). Once these have been identified and possibly even ranked, we would recommend a precautionary approach - i.e., assume the worst-case scenario will occur (as was the case in WY 2024).** Obviously - as the season progresses - nearer term forecasts and real-time monitoring data showing the movement of winter-run downstream will always be most accurate and should be used to guide management advice and hone in on the most likely loss trajectory. For this, we suggest updating the JPE in early February using year-specific survival estimates (see Question 7) and considering new hydrodynamic modelling methods to improve prediction power (see Question 9).

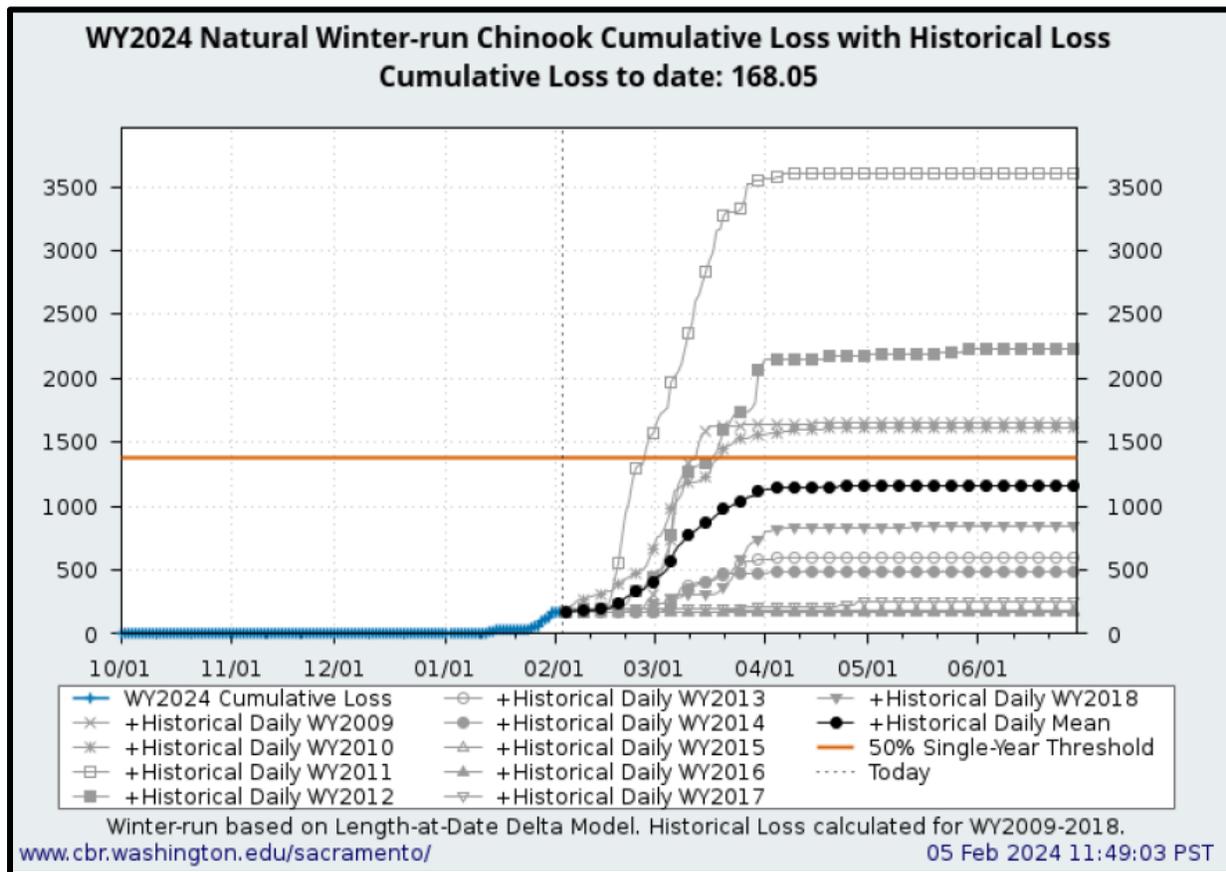


Fig. 4 Cumulative natural LAD winter-run loss for focus year WY 2024 (blue) and 2009-2018 historic cumulative loss. Of the historic trajectories shown, WY 2011 (open squares) was the closest to the observed cumulative loss in WY 2024. Figure copied from SaMT (2024a)

We performed a cursory exploration of this 'pre' season forecasting for WY 2024 imagining we were performing it in January 2024. First, we compared the JPE for WY 2024 (BY 2023) with previous years. The brood years within the last two decades exhibiting the most similar JPEs were 2010, 2017, 2018 and 2020 (Fig. 5). Second, we examined the flows in the Sacramento River at Keswick (upper reaches) and below Wilkin's Slough (mid reaches) (Fig. 6). This suggested that - of the four years identified based on JPE (WYs 2011, 2018, 2019, 2021) - WY 2011 and 2019 were most similar to WY 2024 in terms of river flows. Interestingly, the loss trajectory for WY 2011 was very similar to WY 2024, but the loss trajectory for WY 2019 was much lower than either other year (Fig. 7), despite similar JPEs (Fig. 5), similar river flows (Fig. 6), and similar OMR values (at least earlier in the season) (Fig. 7).

Given that the RBDD RST is the most downstream location with calibrated abundances, it is impossible to assess the mechanism(s) underpinning these differences, but without this information, it shows how difficult it is to perform long range forecasting. But this does not mean that preseason planning is not valuable, it just highlights the complexity of the issue and the importance of performing recalibration as new information comes in. Possible explanations for the lower losses in WY 2019 than WY 2024 and WY 2011 include inaccuracies in the JPE (e.g., overestimated in WY 2019), among-year differences in true survival downstream of RBDD (e.g., lower in WY 2019), different fractions of each cohort entering the interior Delta (e.g., lower in WY 2019), and/or among-year variation in juvenile production for other runs that were then misclassified as winter-run based on LAD. Shifting towards real-time genetic-based run assignment, as well as analyzing the genetics of LAD winter-run from previous years, will be valuable to better assess within-season loss trajectories and learn from genetic-based loss trajectories from previous years. However, it is worth noting that the loss trajectory of LAD winter-run in WY 2024 was highly similar to WY 2011, and both years exhibited similar JPE values and large, early season storms.

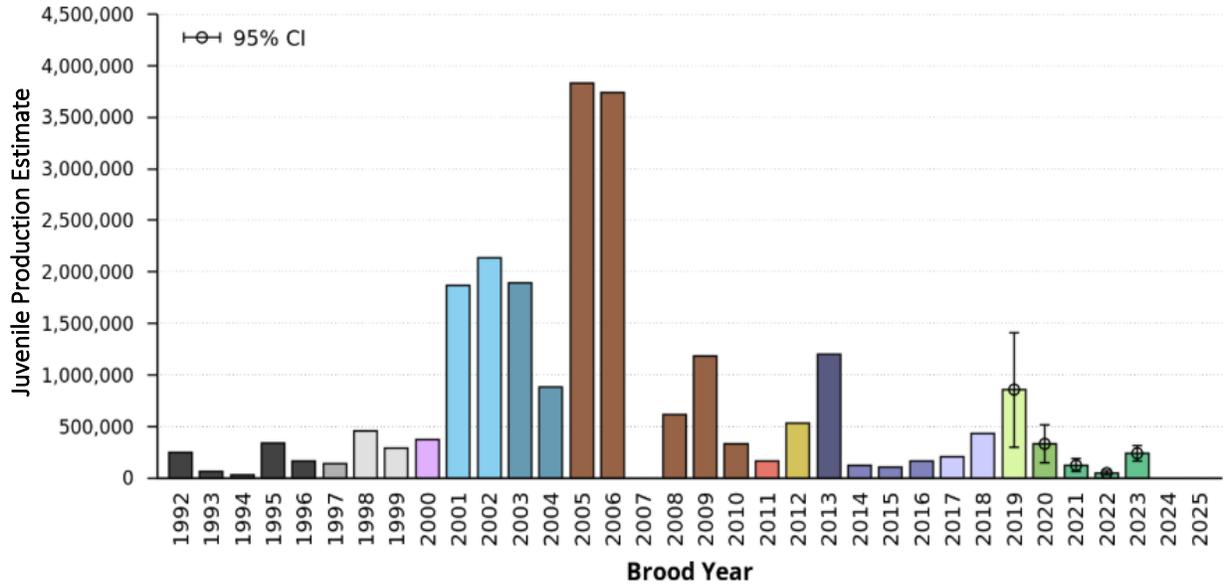


Fig. 5 Natural origin winter-run Juvenile Production Estimates (JPE) since 1992. This suggests that the JPE for our focus year (BY 2023) was closest to BYs 2010, 2017, 2018 and 2020 in the last two decades. Plot copied from SacPAS, which describes the methodologies depicted by the color coding (accessed February 8, 2026: www.cbr.washington.edu/sacramento/data/metadata/method_jpe_letter.html).

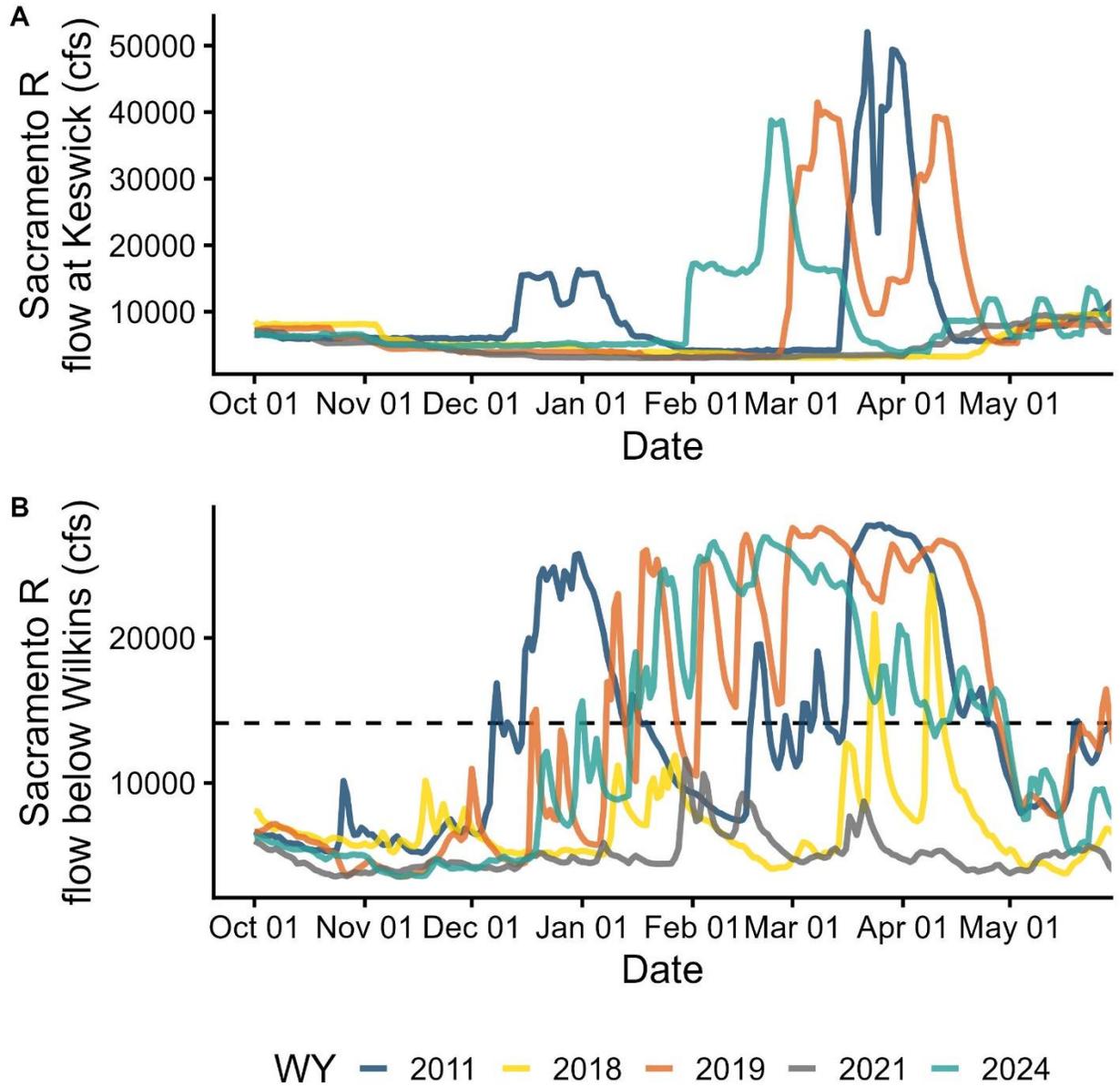


Fig. 6 Sacramento River flows in (A) the upper reaches at Keswick (USGS gauge 11370500) and (B) the middle reaches below Wilkins Slough (i.e., below Sutter Bypass; USGS gauge 11390500) for the four water years (WY) exhibiting a similar JPE values to focus WY 2024.

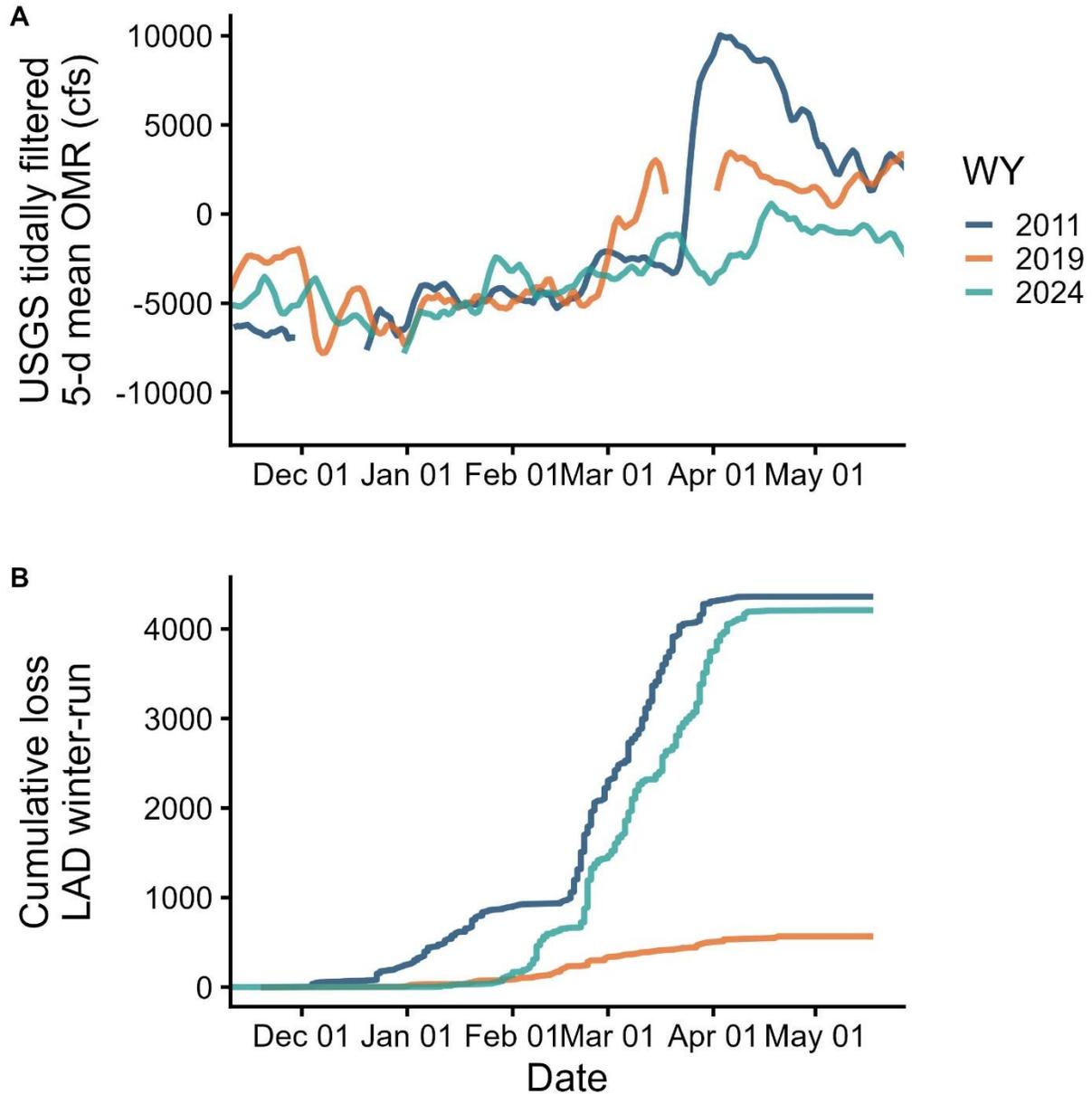


Fig. 7 (A) Shows the USGS Tidally Filtered 5-day mean OMR and (B) shows the cumulative loss trajectories for natural LAD winter-run in WY 2011, WY 2019 and WY 2024. Data downloaded from SacPAS on February 8, 2026 (https://www.cbr.washington.edu/sacramento/data/delta_loss.html).

WY 2025

In 2025, the annual loss threshold was only exceeded for hatchery origin winter - run, and the time between 50% and 100% exceedance was just 3 days (50% exceeded at 11am on March 18 and 100% exceeded at 4am on March 21). With no hatchery specific predictive model (see Question 5), it is unclear what “indicators in the current monitoring data or tools could have been used proactively to predict an exceedance of the annual loss threshold”. The WOMT (2025) met March 19 and wrote *“Reclamation noted that the 100% annual threshold for hatchery winter-run salvage (CWT) fish for 2025 is 162 fish, with the corresponding 50% annual threshold salvage at about 80 fish. The current salvage count is about 73 fish, so 1-4 more hatchery winter-run salvage at export facilities could trigger an exceedance of the 50% threshold, and an operational export restriction for seven days of an OMRI no more negative than -3,500 cfs.”*

The next day (March 20) SaMT report *“A total of 27 hatchery winter-run Chinook salmon have been salvaged this year, with 25 of these fish being salvaged in the past 7 days. This has produced a cumulative loss of 89.82 fish, which is **55.3%** of the 100% cumulative loss threshold”*. However actions were not taken to reduce exports as per the 2024 ITP: ***“If cumulative loss of either natural or hatchery-origin CHNWR in a brood year exceeds 50% of the annual loss thresholds, then Permittee shall, in coordination with Reclamation, adjust south Delta exports to achieve a 7-day average of the OMR index no more negative than -3,500 cfs for seven consecutive days. If a CHNWR is salvaged during the 7-day action, the action will be extended for another seven days.”*** (CDFW, 2024).

It seems that the reason SaMT gave for delaying action was: *“Seasonal behavior and timing rather than OMRI are likely driving observed loss at facilities, therefore modifications more positive than -5,000 are unlikely to reduce loss or change the population level effect of exports on winter-run Chinook salmon.”* (SaMT 2025). Yet SaMT also state in the same report *“Predicted loss is expected to continue at a higher rate in the -5000 OMRI scenario than the -3500 OMRI scenario”* (SaMT 2025).

In fact, by 8am on Thursday, March 20, 34 marked winter-run hatchery fish had been salvaged, representing a loss of 158.5 and **98% of the annual loss threshold**. The 100% threshold (162) for hatchery winter-run was exceeded the following morning (4am on Friday, March 21, so still on a week day). Yet the next

conversation about these events was not until Tuesday, March 25, at an ad-hoc WOMT meeting (outlined in Appendix Table 2). At this meeting and the next on April 1, consensus about next steps was not reached resulting in the *“Directors to meet and decide appropriate OMRI level for WR and DS protection.”* (WOMT 2025).

This timeline highlights two important things: a lack of clarity and coherence about how water operations should be modified following loss exceedance events, and how delays in data collection and sharing can slow management responses. We understand that reading coded wire tags (CWT) takes time, and that the practical aspects of fish handling and working around water mean that paper records for data collection are likely still preferred. However, winter-run is a highly endangered fish. While genetic confirmation for natural winter-run will take longer, all hatchery fish are visibly marked by an adipose clip, so - **particularly when loss trajectories are climbing as rapidly as they were in March 2025 - we recommend that systems are put in place to support rapid CWT reads and genetic screening, alongside online data sharing systems to enable rapid implementation of the actions stipulated by the ITP, and to assume that LAD assignments are correct until proven otherwise.**

It seems that - in WY 2025 - the confusion and delays highlighted by the above timeline did not have a major impact on hatchery or wild winter-run, with losses of natural winter-run low (0.029% of JPE) and the final loss of hatchery winter-run 0.16% of JPE (with only three more hatchery fish salvaged after March 23 - effectively the earliest date that exports could have been reduced by - equivalent to an additional loss of 38.23). **However, it is important to learn from this event (e.g., developing more rapid CWT reads, genetic tests and information sharing, and developing a hatchery fish predictive loss model- see Question 8), for there will undoubtedly be sudden increases in loss in the future that rely on urgent and coordinated responses by SaMT and WOMT. Obviously, prevention is always better, which is why we advocate for preseason planning and taking actions *before* 50% exceedance, not after.**

Here, we discuss the second part of Question 1 that focused on options to change a loss trajectory mid-season. Changing the loss trajectory once large numbers of winter-run are already in the interior or South Delta appears to be very difficult, particularly with how the rules are currently implemented. Currently, exports only need to be reduced *after* the 50% threshold is exceeded, then reduced further after

the 75% threshold is exceeded. In WY 2024, by the time the 50% threshold was exceeded, a high fraction (75-94%) of that year's cohort was already in the Delta, with routing probabilities into the interior Delta typically at about 10% (aside from a few weeks in February when Fremont Weir was overtopping; STARs model - <https://oceanview.pfeg.noaa.gov/shiny/FED/CalFishTrack/>). Thus, high numbers were likely to be in the zone of influence and vulnerable to entrainment. It is broadly agreed that more winter-run will be entrained in the export facilities at higher pumping rates (more negative OMRI) than at lower pumping rates (more positive OMRI) if present in the Delta (SST, 2017a). In WY 2024, the increases in OMRI performed after 50% exceedance were actually greater than mandated by the ITP for winter-run because of the high levels of steelhead loss, and these actions did not prevent 100% exceedance. However, as mentioned in the San Francisco Baykeeper comment and shown in Table 1, OMRI is often less negative than the USGS Tidally Filtered OMR. Therefore, it seems prudent to perform pre-emptive, preventative actions to avoid reaching the 50% threshold and avoid disproportionate loss of early migrants and clipping of life history diversity (discussed below).

Importantly, Figure 8 shows much higher loss rates at the SWP than CVP and strong correlation between daily loss and SWP export rate, suggesting that the most effective actions to reduce loss might be to treat the facilities separately in the future and experiment with alternative export schedules (e.g., reducing variance in exports through time to reduce entrainment cues).

The panel therefore recommends that loss prediction modelling and changes to exports should be performed separately for SWP and CVP (see Question 8), and for alternative hydrodynamic measures to be explored that can improve prediction accuracy and outcomes for winter-run (see Question 9).

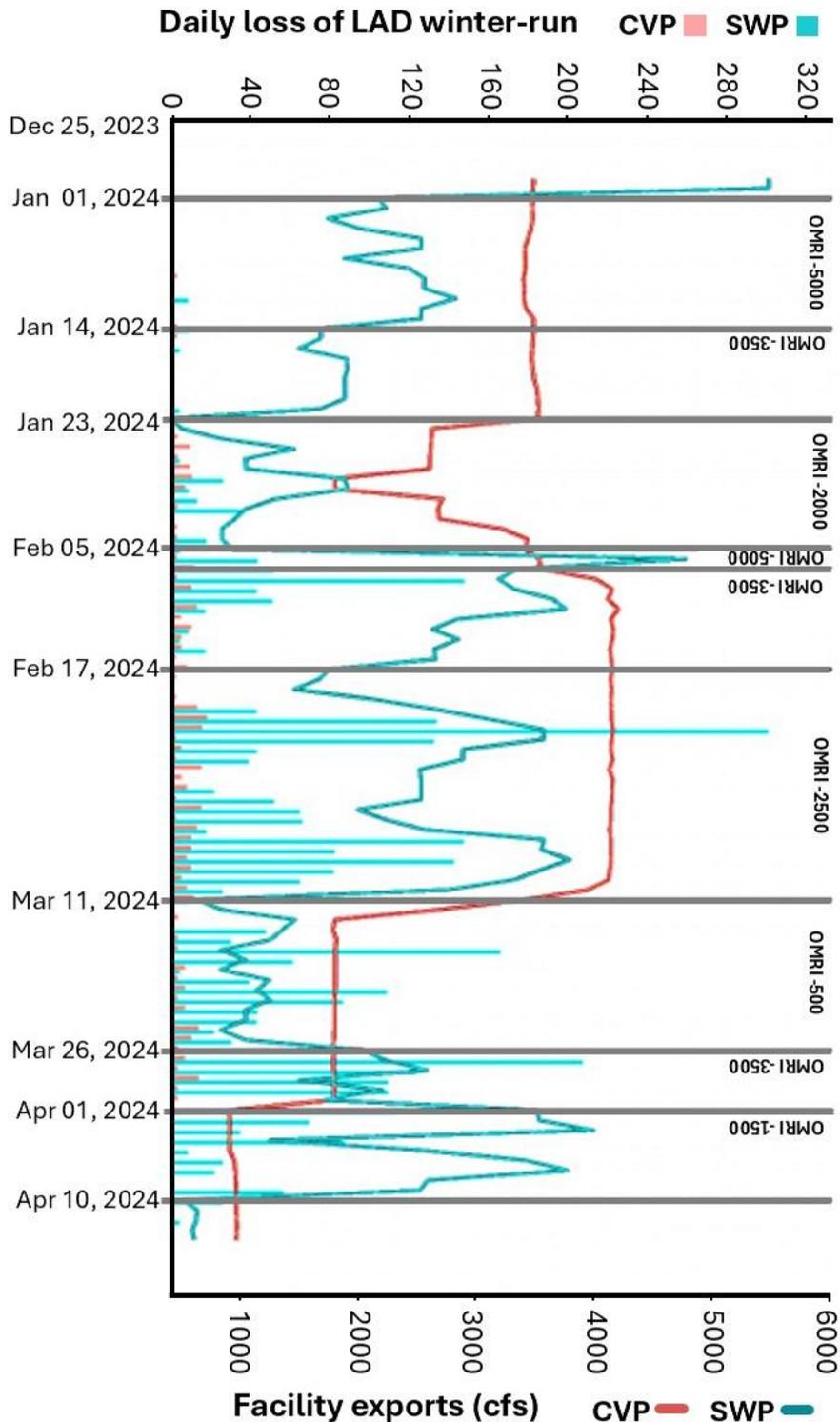


Fig. 8 Daily loss of LAD natural-origin winter-run Chinook salmon at the CVP (red bars) and SWP (turquoise bars) vs. daily exports at the CVP (red line) and SWP (turquoise line). Rotate 90° to view. Grey lines show approximate dates when OMRI controls were changed. Plot adapted from the 4/16/24 SaMT ITP risk assessment.

One way to change loss trajectories for winter-run fish *proactively* could be for operators to reduce exports *before* the 50% threshold has been exceeded to reduce entrainment rates. This could be - for example - as soon as (a) predicted loss (upper or "high" prediction) using the Tillotson model for the next week exceeded some pre-agreed fraction of the annual loss threshold (e.g., 20%), or (b) when the WRCML model predicts 'high' losses in three weeks' time (equivalent to a 7-day moving average loss ≥ 4.29). The reduction in exports that the facilities perform would not be prescribed by the current ITP (and thus could theoretically be less severe than the reductions currently mandated following $>50\%$ or $>75\%$ losses) but could be considered a precautionary step to slow down within-season loss rates, particularly of the earliest migrants. The issue with this suggestion is that - without performing experiments across a range of different flow and export levels using tagged fish of different sizes (see Recommendations #3 and #4) - such an action could potentially slow down salvage rates without having much/any of the desired reduction of mortality in the South Delta, and thus result in unacceptable but unknown rates of true loss. To forecast how different export scenarios influence winter-run survival, one really needs better data on how different export levels influence juvenile salmon routing and survival in the interior Delta, tested on different sized fish (Question 5).

In 2025, as no flow actions are mandated to occur before the 50% loss threshold is reached and the 100% threshold was exceeded three days later, by the time the 50% threshold was exceeded for hatchery winter-run, it was too late to avoid the 100% loss threshold as it takes three days to change the pumping schedule. However, they did not know this would be the case when they met on March 19, 2025. To avoid 100% exceedance in WY 2025 would have required action before the 50% threshold had been reached, for example using a predictive model similar to the WRCML (see Question 5). However, it is concerning that the ITP gives clear guidance for when 50% and 75% thresholds are exceeded, but these actions were not taken in WY 2025. Furthermore, guidance on OMRI levels to follow after the 100% threshold is exceeded is less clear, which risks inaction and among-agency disagreements, as observed in the WY 2025 WOMT meeting notes where consensus was often not reached (Appendix Table 2).

Question 2. What indicators could have been incorporated from WY 2024 and 2025 monitoring data or assessments that could have improved the prediction of winter-run detection trajectories at Central Valley Project (CVP) and State Water Project (SWP) export facilities?

As stated in Question 1 above, we believe that having a preseason forecast (for wild fish) will go a long way toward preventing surprises and will allow the management team to be more proactive. This would involve implementing some of the changes recommended in the response to Question 8. Also, given that for WY 2025, the hatchery fish exceeded their threshold, the Review Panel strongly suggests that the modeling team develop a tool (similar to the WRCML model) for hatchery fish to predict loss at the export facilities. The model could be based on coded wire tag (CWT) fish that the hatcheries already tag (100% of winter-run Chinook hatchery releases). These were the data used by Zeug and Cavallo (2014), but there are many more years of data that could now be included (see Question 8). Model inputs could include hatchery release size, dates, and location along with environmental variables. This model could also have a preseason mode, which could be run similarly to the wild fish model.

Question 3. Recognizing the different loss trajectories in 2024 and 2025, were there any actions that could have been implemented once the 50% threshold exceedance occurred to have prevented the annual loss threshold being exceeded?

Interestingly, the loss trajectory for WY 2024 based on genetic winter-run did not exceed the 100% threshold based on the 2024 ITP. But based on the timeline and actions taken in WY 2024 for LAD winter-run and WY 2025 for hatchery winter-run **it seems that waiting until exceeding the 50% threshold to reduce exports carries significant risk of also exceeding the 100% annual loss threshold.** In WY 2025 the 50% threshold was exceeded at 11am on March 18 and the 100% threshold was exceeded at 4am on March 21. As it takes three days to power down the pumps, it seems that 100% exceedance was inevitable in WY 2025 with the rules currently in place.

Recommendations related to Question 3:

- As per Key Recommendation #1, we recommend a more proactive approach, making a preseason plan and reducing exports earlier in the loss trajectory (*before* 50% is reached - Question 1), using tagged salmon and predictive models to guide when to act (Questions 5 and 8), and exploring differential export reductions between the two facilities (Fig. 8; Question 8).
- To enable proactive management, give explicit, quantified risk characterization in weekly reports to provide decision-makers with actionable information about the probability and timeline of threshold exceedance. The 3/5/2024 SaMT ITP Risk Assessment Summary of Steelhead (Review Material 2c) is a good template for reporting winter-run take for proactive rather than reactive management. The summary reports (a) the current average loss, (b) the total loss to date, (c) the take limit threshold of concern, (d) when that threshold is predicted to be exceeded, (e) the target rate of take to avoid the threshold limit, and (f) supporting model evidence to support a change in operations.
- Particularly after a threshold is exceeded, subsequent weekly reports should give key statistics to show the significance of the loss. Currently, after a threshold was exceeded, all subsequent weekly assessments used identical boilerplate language: 'Risk of exceeding threshold: Not applicable since threshold has been exceeded.' Instead of this boilerplate language, consider including other information such as the magnitude of exceedance above the given threshold, trajectory of ongoing loss, projected end-of-season loss, and the biological significance of that loss. Also, we recommend SaMT and WOMT agreeing on the key metrics that support decision making and generate a compiled online table or suite of figures within a single webpage (that are updated in real-time) to support transparent, rapid responses (Key Recommendation #8).

Question 4. Does evidence suggest changes to OMRI or other operations would have resulted in changes to the observed loss trajectories in WY 2024 or WY 2025?

WY 2024 and WY 2025 had very different observed loss trajectories. In WY 2024, natural winter-run reached the different exceedance levels over the course of several weeks and continued to entrain natural winter-run beyond the 100%

threshold limits through April 16, 2024. In WY 2025, hatchery winter-run exceeded 50% through 100% thresholds over the course of three days (see timeline above).

The basic understanding of OMRI guidance is that more fish will be entrained in the export facilities at higher pumping rates (more negative OMRI) than at lower pumping rates (more positive OMRI). This statement makes intuitive sense and is known by all agencies.

As an example, the WOMT *ad hoc* meeting (March 25, 2024) had the following record:

“CDFW reads SaMT advice of “a decrease in exports through a more positive OMRI is expected to decrease future loss relative to higher export rates, therefore lowering exports would contribute to minimizing subsequent loss this year” was proposed in consideration of current operations where OMRI is -500 cfs. Reclamation does not consider statements like that to be advice because they are self-obvious.”

In both WY 2024 and WY 2025, it is clear from meeting notes that there is no knowledge base to explain how changes to OMRI change circulation patterns in the key South Delta region. And, in turn, how those circulation patterns relate to entrainment of winter-run into the SWP and CVP facilities. This conclusion is also supported by the Salmon Scoping Team (2017b, Vol 2, pg. 36) report that states: *“The SST did not specifically evaluate the effects of OMR flows on survival, and as referenced in Section 4.1.1, the effect of OMR flows on survival in the Delta remains a knowledge gap.”*

See Panel Report Question 9 Hydrodynamics for metrics and tools that could be used to build a hydrodynamic modeling framework as a start to address that knowledge gap.

WY 2024:

In WY 2024, natural winter-run reached the different exceedance levels over the course of several weeks (50% exceedance: February 25, 2024; 75% exceedance: March 7, 2024; 100% exceedance: March 20, 2024; Natural winter-run annual loss as of April 16, 2024: 4,192.06, 170% exceedance) (Fig. 3 and 8).

Recommendations related to Question 4:

- **Provide clear communication of predicted loss trajectories so decisions to change operations can be made in a proactive rather than a reactive manner (Key Recommendations #1 and #8).**

The 3/5/2024 SaMT ITP Risk Assessment Summary of Steelhead (Review Material 2c) is a good template for reporting winter-run take for predictive rather than reactive management. The summary reports (a) the current average loss, (b) the total loss to date, (c) the take limit threshold of concern, (d) when that threshold is predicted to be exceeded, (e) the target rate of take to avoid the threshold limit, and (f) supporting model evidence to support a change in operations.

“The current average loss of California Central Valley Steelhead is 53.55 per day over the last week while targeting an OMR of -2,500 cfs with a total loss of 2,152.81. At this rate the NMFS Incidental Take Limit of 2,760 for the December to March period will be exceeded before March 31. To remain under the Incidental Take Limit loss needs to be an average of 21 fish per day or less. According to the Tillotson Model runs, a more positive OMR flow would decrease loss of steelhead. Looking at the Tillotson Model results at OMR of 0 cfs to -500 cfs we would have an average loss of 49.89 per day. At an export level of 1,500 cfs (OMR of 3,900 cfs), the Tillotson Model predicts an average loss of 30.75 per day. Since the 100% threshold is exceeded and the Incidental Take Limit is likely to be exceeded this month then any decrease in loss of steelhead would benefit the species.”

In contrast, the 3/19/2024 SaMT ITP Risk Assessment Summary did not communicate an urgency to act on known information. The first bullet point of that assessment stated that “there was no advice to WOMT this week” and yet the 100% threshold exceedance happened the next day.

- **Reduce the extraneous data in the SaMT reports so that communication of key issues is clear to managers/decision makers (see Key Recommendation #8).** Eliminate boilerplate language that is repeated in every weekly report and non-applicable data. For example, information for thresholds that have already been exceeded should be removed from the status report or subsequent weekly reports or they should be reworded to give key statistics about the significance of the loss.

An example in the 3/19/2024 SaMT weekly assessment:

The statement *“If loss continues at the same rate at which was observed last week, then 100% Loss Threshold is likely to be exceeded by next week”* was buried on page 5 of the report and supporting Figure 5 on page 6 of the report. That threshold exceedance happened the next day.

WY 2025:

In WY 2025, hatchery winter-run exceeded 50% through 100% thresholds over the course of one weekend. (50% exceedance: 3/18/25; 100% exceedance: 3/22-23/2025). In March 2025, the Delta was in excess water conditions; this is a time period that is critical for the pumps to transfer water to reservoirs south of the Delta for summer use (SaMT, 2025). Reclamation needed more specific guidance because of conflicting mandates to (a) transfer as much water as possible south of Delta during this key operational window and (b) protect winter-run from entrainment.

Conflicts between agencies during WOMT meetings where the final decision had to be elevated to the Director level implies that there was no clear understanding of what a change in OMRI would do for the probability of entrainment of hatchery winter-run. This demonstrates a lack of understanding of circulation patterns in the Delta and the pump area of influence at different pumping rates. And, how that area of influence relates to the current location of winter-run fish in the South Delta.

Question 5. What information could have been incorporated into WY 2024 and 2025 monitoring data or assessments that could have informed routing, through-Delta survival, salvage loss, and other effects to the winter-run population from different export levels?

In regard to routing, when winter-run migrate south down the Sacramento River, about 30-40% will enter Sutter and Steamboat Sloughs after reaching Sherwood Harbor, and the remainder will continue along the mainstem then encounter the Delta Cross Channel (DCC) and the mouth of Georgiana Slough (Perry et al., 2010). This is important because juvenile salmon that enter the interior Delta (the network of channels south of the Sacramento River, Fig. 1) have lower survival rates than

fish that avoid the Delta by out-migrating via the Sacramento River, Sutter Slough or Steamboat Slough (Perry et al., 2018; Newman and Brandes, 2009).

Given that loss at the CVP and SWP facilities is only possible if winter-run move into the South Delta, the best strategy to avoid loss is to reduce winter-run from going into the Delta at all. Winter-run can enter the interior Delta via the DCC, and Newman (2008) and Newman and Brandes (2010) showed improved survival when the DCC was closed. In 2024 and 2025, the DCC gates were closed during the winter-run outmigration season, so this does not explain the losses.

Juvenile winter-run can also be diverted into the interior Delta through Georgiana Slough (SST, 2017a). The BioAcoustic Fish Fence (BAFF) reduces entrainment of fish into Georgiana Slough by more than half (22.3% to 7.7%; Perry et al., 2012). Entrainment rates of tagged hatchery winter-run released on February 16, 2024 were 8.8%, and almost double (16.7%) for releases on February 1 and 13, 2025, the latter likely to have contributed to the high losses that triggered this review (Fig. 9).

Specifically in WY 2025, 44 tagged hatchery fish migrated down Georgiana Slough (representing 16.7% of fish that made it to the confluence; Fig. 9). The first detection in Georgiana Slough was on February 23 and the latest on March 23, 2025, with 1-5 fish moving into Georgiana Slough daily from February 26 to March 7, 2025. The mean date of Georgiana Slough detections was March 7, 2025, 11 days before the 50% threshold was exceeded on March 18, 2025 and two weeks before the 100% threshold was exceeded March 21, 2025.

Knowledge gaps relating to routing of winter-run into and within the Delta

- Despite a plethora of information about hatchery winter-run routing from acoustic telemetry (e.g., Fig. 9), we still know very little about in-Delta routing of natural winter-run given very low numbers sampled by the Delta Juvenile Fish Monitoring Program from beach seine sites within the Delta (Fig. 2). While acoustic tagged hatchery fish are typically >95 mm FL, approximately 80% of natural winter-run pass RBDD as fry and enter the Delta much earlier and smaller than hatchery smolts (often in December to January), so their in-Delta movements and survival rates will likely be quite different.

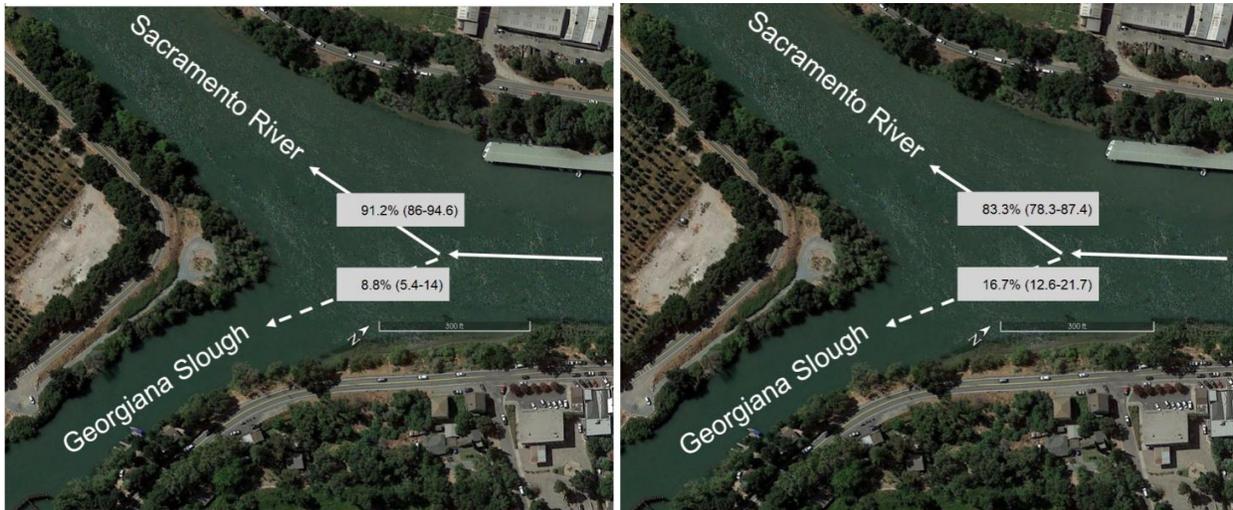
- It is unknown what fraction of juvenile winter-run enter the interior Delta via Threemile Slough (Fig. 1) and how this varies under different flow and temperature conditions (SST, 2017a).
- Currently, little is known about the routes that winter-run take *within* the interior Delta and the influence of exports, OMR, and OMRI on fine scale routing patterns (SST, 2017a). While data from steelhead telemetry experiments can provide some inference, with thousands tagged and released from 2011-2016 in Pope et al. (2025), these fish were much larger than most winter-run juveniles entering the Delta, averaging 212-277mm FL (*cf.* 80-110 mm typical for hatchery winter-run and 40-100 mm typical for natural winter-run). Thus, their foraging behaviors and swimming ability will be very different to the early migrating natural and hatchery origin winter-run entering the Delta in December to March.
- Another challenge to understanding in-Delta routing and survival is that exports, flow, OMR, and OMRI tend to be highly collinear, and predation rates and alternative route options are high, requiring large numbers of fish to be tagged in order to detect and separate the difference effects: *“Uncertainty in the relationship between E:I and survival may be caused by the confounding influence of correlated variables and low power to detect differences”* SST (2017a). Pope et al. (2025) also state: *“Because freshwater export facilities typically pump more during periods of higher flows, and because those exports can drive hydrology in their vicinity, including the OMR flow index, these three variables are usually tightly linked.”*

Recommendations related to Question 5 and winter-run routing:

- **To support real-time, responsive management, we recommend using acoustic tagged fish more as ‘sentinels’ (see Key Recommendation #4)**

Tag detections can be used to track Delta arrival timing (i.e., using all receivers in the lower Sacramento River) and the fraction entrained into the interior Delta (i.e., using the receiver in Georgiana Slough). Even if they are imperfect surrogates for the diversity of natural winter-run outmigrants, these detections - provided to the SaMT in real time via <https://oceanview.pfeg.noaa.gov/CalFishTrack> - could provide valuable data to avoid loss exceedance of hatchery winter-run. Working with WY

2025 acoustic data as an example, we recommend exploring scenarios using the numbers or proportions of fish entrained into Georgiana Slough to identify a threshold that would have allowed SaMT to have advised WOMT early enough (e.g., around March 6/7, 2025) so that they could have reduced exports long enough before the large loss events of March 18 to 21, 2025, to avoid so many winter-run being entrained into the South Delta and into the facilities.



3.3 Routing Probabilities at Georgiana Slough Junction (with 95% C.I.s)

3.3 Routing Probabilities at Georgiana Slough Junction (with 95% C.I.s)

Routing probabilities of tagged juvenile hatchery winter-run from the Sacramento River into Georgiana Slough in WY 2024 released February 16, 2024 (8.8%; left) and in WY 2025 released February 1 and 13, 2025 (16.7%; right). Images copied from https://oceanview.pfeg.noaa.gov/CalFishTrack/pageLSWR_2024.html (WY 2024) and https://oceanview.pfeg.noaa.gov/CalFishTrack/pageLSWR_2025.html (WY 2025).

- **To improve our understanding of routing and survival of natural origin winter-run we recommend performing telemetry experiments using earlier releases of smaller hatchery fish that represent better surrogates for natural winter-run (see Key Recommendation #4).**

This could be achieved using miniaturized acoustic tags such as ‘shad tags’ and ‘Eel-Lamprey Acoustic Tags’ (ELATs) (Fischer et al., 2019; Deters et al., 2024). If the question is focused on routing and survival within the Delta, we recognize that these fish will likely need to be trucked downstream, as survival rates will be low

and their migratory behaviors more dispersed, and there will likely be cost or hatchery production limits to the number that can be released.

- **To better understand routing of winter-run into the interior Delta, we recommend acoustic receivers to be placed in Threemile Slough and for tagging studies to be performed (for all key junctions) under a range of flow and temperature conditions.**

If Threemile Slough turns out to be a key route, then we recommend exploring options to install a BAFF on Threemile Slough. The continued monitoring of routing into Georgiana Sloughs under different flow conditions will also be valuable to inform efforts to improve and adapt the BAFF in the future.

- **We recommend a series of bold, large-scale experiments, where exports are manipulated under a range of flow conditions, paired with releases of tagged hatchery fish of a wide range of sizes (Key Recommendations #3 and #4).**

Tags could be a combination of miniaturized acoustic tags (necessary for routing questions) and coded-wire tags (which can suffice for questions regarding loss and survival rates) and analyzing these data alongside the historic acoustic tag and CWT release datasets to build a better understanding of the impacts of exports on routing, travel times, loss and survival. Some experiments could focus on testing the effects of (a) sustained high/low export rates and export:inflow ratios (E:I), while others could focus on (b) shorter variations in exports and E:I ratio (Fig. 8). Such experiments would require large numbers of tagged fish, so surrogates from other runs may need to be considered. It would just be important to match timings and fish sizes with natural winter-run to make winter-run-relevant inferences from the results. Such experiments carry risk of increased loss of natural and hatchery winter-run as well as other endangered fishes, so it is important to be clear and in agreement about the methods, goals and risks, and probably to only perform them during years of above average cohort strength.

This recommendation was mirrored and well-articulated by Pope et al. (2025): *“To separate these effects from one another [exports, flow and OMRI], researchers will need to observe greater variability in operational data, preferably in the context of randomized, experimental trials. In all studies, sample size, release timing, and receiver monitoring configuration should be motivated by a clear and focused articulation of specific research questions, including the spatial and temporal scales over which inference is desired. In addition, an appropriate statistical mark-recapture model can overcome some of these challenges to a degree by leveraging as much information as possible from the acoustic data.”*

In-Delta survival

Multiple lines of evidence suggest that juvenile salmon of all runs survive at higher rates in the CCV when river flows (natural or via reservoir releases) are higher (SST 2017; Sturrock et al., 2020; Michel et al., 2021; Perry et al., 2018). Thus, we see merit in the suggestion of San Francisco Baykeeper’s comments to use more conservative export rates in drier years to reduce impacts on winter-run. However, if reassessment of the JPE is performed in February based on flow- and temperature-informed survival estimates (see Question 7) then this should help account for such reductions in survival.

The influence of exports on in-Delta survival is less understood, and difficult to tease apart given the collinearity between flow and OMRI described above. Models have suggested weak, negative effects of increased exports to Delta inflow ratio (E:I) on the survival of fall-run, but not late-fall-run Chinook salmon (SST 2017a). According to SST (2017a) *“survival data are not available to assess potential relationships between E:I and survival for winter-run”* and *“The relationships between water project operations and survival on various spatial and temporal scales are poorly understood.”*

Zeug et al. (2012) developed a life cycle model that included a term relating survival to exports based on Newman and Brandes (2010). However, the relationship was weak and noisy, leading Newman and Brandes (2010) to conclude that “the predictive ability of models without exports is equivalent to that of models which included exports”. Pope et al. (2025) found spatial heterogeneity in the survival of steelhead in the Delta, and noted *“...once steelhead enter the interior Delta via HOR*

[Head of Old River], the slope parameters on transitions from B5 to B7, C7, or B/C9 suggest that survival to Chipps Island is higher for fish that enter the export facilities and are transported relative to those that migrate northward via Old and Middle Rivers (Table S1), and further, that this survival may increase with increasing exports.”

However, we would be very cautious about applying these findings to winter-run, as these results are based on (a) a different species (steelhead), (b) fish 2-6 times larger than the size of natural winter-run at Delta entry (~35-100 mm FL vs >200 mm FL), (c) releases performed primarily in March to May, when natural winter-run typically enter the Delta in December to March.

As mentioned above, nearly all in-Delta survival studies to date are based on large (>95 mm FL) juveniles that may exhibit quite different levels of sea readiness and movement behaviors (e.g., more center channel and downstream directed movement) and thus different behavioral responses to changes in hydrology and OMRI compared with the earlier migrating natural origin juveniles that need to grow somewhere in freshwater in order to reach sufficient size and undergo smoltification (Phillis et al., 2018; Chen et al., 2025).

Recommendations related to Question 5 and winter-run in-Delta survival:

- **To fill these data gaps around the influence of exports on in-Delta survival we recommend large scale experiments using different sized juveniles, repeated across years and flow conditions (as detailed above and in Key Recommendations #3 and #4).**
- **But the best solution wherever possible is to reduce the number of winter-run entering the interior Delta at all (Key Recommendation #10).**

This can be achieved partly by barriers such as DCC and BAFF, but better yet (as it boosts survival *and* reduces loss *and* benefits other runs and species) would be to perform upstream habitat restoration, floodplain reconnection and flow actions that enables natural winter-run to achieve sufficient freshwater growth to undergo smoltification *before* reaching the Delta, thus increasing the fraction migrating directly out to the Ocean.

Salvage loss

Here, we focus on LAD vs genetic assignment for loss assessment. Importantly, large differences in loss of natural winter-run were observed in WY 2024 depending

on whether you used LAD vs. genetic assignment criteria (4,209 vs. 127, respectively, the latter excluding the 3 unclipped LAD winter-run with no genetic data). However, SaMT made the following observation that despite this large discrepancy, the losses of genetic winter-run in that WY 2024 still represented "... *the highest genetic loss observed in the previous four years as well as the sixth's highest genetic loss in the previous 14 years. CDFW noted that although the total genetic WR [winter-run] loss is much lower in comparison to the total LAD WR loss this water year, thresholds have not been established yet to analyze how the genetic loss is impacting the genetic winter-run population. Since the SWP's ITP COA 8.6.1 was only evaluated and analyzed using LAD WR, it is in CDFW's best interest to only provide the data on genetic WR rather than making assumptions on how the genetic WR population has been affected.*"

It is well established that LAD is imperfect for identifying winter-run, particularly after RBDD and lower in the system when many populations mix that have experienced a diversity of spawn timings and growth schedules (Perry et al., 2016; Johnson et al., 2017). This is why there has been a strong push to monitor winter-run progression through the system and to manage for loss based on genetic assignment. Indeed, the annual loss thresholds for natural origin winter-run decreased from 1.17% of JPE based on LAD (CDFW, 2020b) to 0.5% JPE based on genetic winter-run (CDFW, 2024). Had genetic winter-run assignment been used in WY 2024, neither the 2020 or 2024 ITP 100% loss thresholds would have been exceeded, with the final loss observed being 0.054% genetic winter-run (or 0.058% if the three LAD winter-run with missing genetic information were assumed to be genetic winter-run). However, exports would have been curtailed anyway, given exceedance of the annual 100% threshold for steelhead, which occurred on February 23, 2024.

Recommendation related to Question 5 and winter-run loss:

- **As per Key Recommendation #2, the panel strongly recommends increasing the speed of genetic screening across monitoring sites *and* salvage (relevant for both years) and increasing the speed of CWT reads and reporting (relevant for WY 2025, see Question 1).**

Given the need to make rapid decisions and the longer time and higher cost associated with GT-seq analyses, we recommend using CRISPR-based SHERLOCK

assays wherever possible, as they can be completed within the facilities in <1 hour and at low cost (~\$30 per assay) (CDFW, 2025; Baerwald et al., 2025). The method choice and decision tree suggested by CDFW (2025) and Baerwald et al., (2025) slightly differ, but both are sensible. Clearly, the final protocol will need to balance tradeoffs between analysis times, cost, complexity and reaching the genetic resolution/certainty required. We recommend piloting alternative protocols, but - at least when losses rise rapidly - we recommend relying on rapid, on-site assays such as SHERLOCK for decision making, even if a subset need to be later refined based on the results of GT-seq analysis. Obviously, the online data platform for reporting information in real-time (Key Recommendation #8) will need to be set up to allow for such reassignments and data corrections.

Question 6. Were the conclusions of the assessments regarding export operations supported by the information available at the time the assessment was prepared?

Winter-run migration patterns in the South Delta (south of the San Joaquin River) and their relationship to facility export rates remain a large knowledge gap. This knowledge gap is discussed extensively in the SST 2017 report and in Question 5.

During the 2024 early season, the focus of operations guidance was on Steelhead not winter-run guidelines. Once the winter-run thresholds were exceeded, the predictions were essentially “more of what we saw last week.” The assessments lacked information about how changing operations would alter the area of influence of the export facilities for the benefit of winter-run migration.

During the 2025 season, the 3/20/2025 weekly assessment tried to incorporate hydrodynamic information from a previously published Delta Simulation Model II (DSM2) study to estimate export facility area of influence. A new DSM2 simulation driven by current boundary conditions (tidal stage, river flows, export rates, gate operations, and barrier configurations) could have been run. Model results beyond the number of feet of channel influenced by the pump operations could have been presented. See the discussion in Question 9 for other information that can be extracted from hydrodynamic models in the context of salmon migration.

Key Panel Recommendations #1 (proactive vs. reactive), #4 (acoustic monitoring) and #7 (hydrodynamic models) apply to Question 6.

Question 7. What monitoring data and assumptions could have been incorporated into the Water Year (WY) 2024 and 2025 Juvenile Production Estimate (JPE) to improve the establishment of the winter-run threshold?

The JPE is a forecast of the number of winter-run Chinook Salmon juveniles expected to reach the Delta each year. It is used to set loss thresholds for the SWP and CVP pumps; thus, if the JPE is inaccurate, the threshold becomes a moving target that fails to reflect actual biological risk.

Hatchery origin winter-run JPE

As pointed out in San Francisco Baykeeper's letter, the trigger for WY 2025 was based on 100% loss exceedance of hatchery produced winter-run (50% exceedance: 3/18/25; 100% exceedance: 3/21/2025). Hatchery produced winter-run are 100% marked and release numbers are known with relatively high accuracy. Error in the hatchery origin winter-run JPE can be introduced by interannual variation in smolt survival from RBDD to the Delta entrance. Hatchery fish tend to be released large and thus experience relatively high survival rates. They also tend to out-migrate more directly to the ocean; however, otolith chemistry data indicate that hatchery winter-run can spend multiple weeks in the Delta and survive to return (mean = 24 d, SE = 2 d, SD = 15 d; Chen et al., 2025). If the BY 2024 hatchery fish that were released in Redding on February 1 and 13, 2025 had experienced survival higher than the median value used to estimate their JPE, then higher-than-expected numbers would have entered the Delta in 2025, which likely would have contributed to the 100% loss exceedance event on March 21, 2025.

While inaccuracies in the WY 2025 JPE for hatchery winter-run may have contributed to the observed loss exceedances - so we do recommend attempting to produce year-specific smolt survival forecasts to improve the accuracy of the JPE (Key Recommendation #9) - we believe that the main issue contributing to the 2025 loss exceedance event was lack of a hatchery-specific loss prediction model (Key Recommendation #5). The mean time between release date in the upper

Sacramento River (Redding) and salvage in the South Delta in WY 2025 was 39 days (min = 24, max = 58), which is ample time to pre-emptively reduce exports, so to avoid future triggers, actions should be taken before large numbers arrive at the facilities (Key Recommendation #1).

Note: while some people consider losses of hatchery fish to be less important than losses of natural origin winter-run, it is important to remember that LSNFH is a conservation hatchery, which carefully chooses its broodstock from the limited numbers of natural winter-run returns, and that winter-run hatchery fish have already rescued natural winter-run in previous years and will undoubtedly continue to provide a lifeline to this endangered fish in the future.

Natural origin winter-run JPE

With regards to natural origin winter-run, the panel firstly recognizes the increased complexity (over hatchery produced salmon) associated with developing an accurate estimate of JPE each year. We feel that the changes instigated in 2014 - i.e., the shift to the "JPI Method", which estimates JPE from juvenile production estimates derived from catches in the RBDD rotary screw trap, rather than estimate numbers of spawners derived from carcass surveys - make sense in terms of reducing complexity and uncertainty. However, as outlined below, we also agree with O'Farrell et al. (2018) that improvements to JPE forecasts could be made by attempting to develop year-specific predictions of fry and smolt survival rates.

Since WY 2019, the JPE has been calculated using 'Method 2' from O'Farrell et al. (2018) (Fig. 10). For the first part of the calculation, all life stages of winter-run salmon that have passed RBDD by the time the estimate is generated are converted into an estimated number of "fry equivalents" (Juvenile Production Index or JPI_{Fry}). This is performed using a fry-to-smolt survival rate ($Survival_{Fry-to-Smolt}$) that is based on the slope of a zero-intercept linear model fitted to paired estimates of hatchery vs. natural-origin juvenile survival rates (O'Farrell et al., 2018). The JPI_{Fry} is then multiplied by that same fry-to-smolt survival rate ($Survival_{Fry-to-Smolt}$) to convert the estimated number of fry-equivalents into an estimate of the number of smolts that would have passed RBDD had they reared upstream and passed that location as smolts (N_{Smolt}). Finally, N_{Smolt} is multiplied by a smolt-specific survival rate from RBDD to the Delta ($Survival_{Smolt}$), which is based on variance-weighted mean survival rates of acoustic tagged hatchery winter-run from LSNFH from RBDD

(specifically, Salt Creek) to the entrance of the Delta (specifically, Tower Bridge in Sacramento) (O'Farrell et al., 2018).

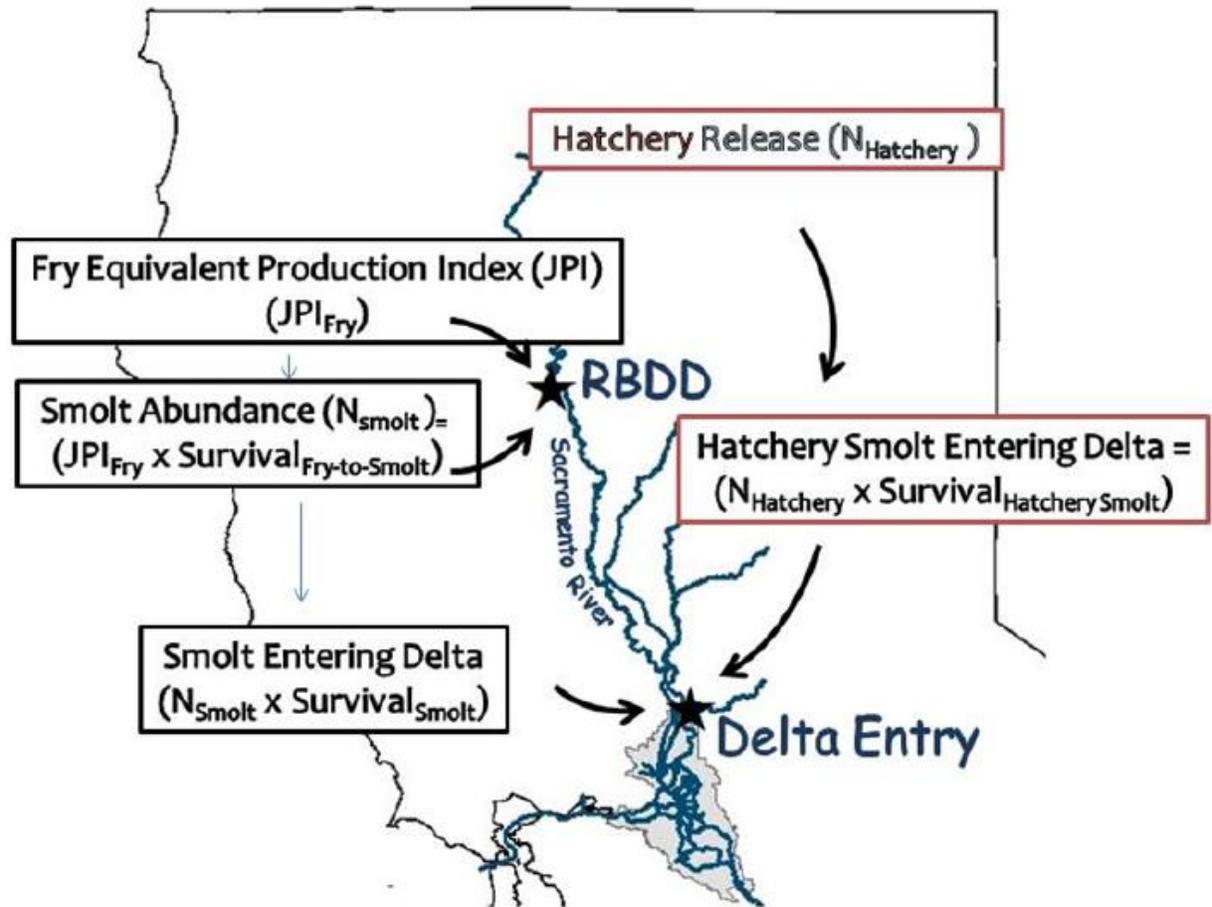


Fig. 10 Locations and formulas used to calculate the hatchery and natural origin winter-run Juvenile Production Estimate (JPE) from 2014-present. Copied from CDWR (2023), methods detailed in O'Farrell et al. (2018)

As mentioned in San Francisco Baykeeper's public comments and O'Farrell et al. (2018), there is considerable uncertainty in the survival estimates used to estimate JPE. $Survival_{Fry-to-Smolt}$ and $Survival_{Smolt}$ are updated annually to incorporate new data collected in the previous year; however, they do not account for year-to-year variation. Both survival terms are based on historical data, and $Survival_{Smolt}$ is based

solely on hatchery-origin smolts (typically >95 mm fork length) which likely exhibit higher survival and different behaviors to wild winter-run (discussed above).

As stated in O'Farrell et al. (2018): *“variance in the forecast JPE does not include uncertainty associated with year-to-year variation in the survival rates f [$Survival_{Fry-to-Smolt}$] and \hat{S}_n [$Survival_{Smolt}$], nor does it account for the covariance between them, in part because of the lack of data adequate to characterize annual variability in f ”.*

Yet, it is well established that survival of fry and outmigrating smolts are highly variable and strongly influenced by environmental factors such as flow and temperature, often in non-linear ways (Michel et al., 2021; Nobriga et al., 2021). Indeed, even in just the five years of acoustic tagging studies shown in O'Farrell et al. (2018) and the relatively narrow range of fish sizes, smolt survival ranged from 0.17 ('Below Normal' WY 2013) to 0.64 (wet WY 2017), although interestingly survival rates were intermediate in critically dry WYs 2014 and 2015 (0.42-0.48). Such variation in survival could also be explained by differences in fish condition or size, release date and short-duration variation in temperature, flow and turbidity. Analyzing these survival rates using models including fish age, size, condition, temperature and flow experience, and time at liberty would be useful to assess whether year-specific survival forecasts could be generated.

JPE values also typically have wide error bars (Fig. 5) based on variance in the survival estimates mentioned above, but it is likely that the true uncertainty is higher. To the best of our knowledge - uncertainty in the JPI_{Fry} relating to expansion of the RBDD screw trap catches using flow-related trap efficiencies (Poytress et al., 2014) - is not incorporated into the JPE. Despite all this, the JPE is applied to CVP/SWP management as a point estimate. This, alongside likely inaccuracies in the JPE caused by year-specific variation in survival relating to temperature and flow, could exacerbate problems for winter-run in certain years. **For example, if the true numbers of winter-run reaching the Delta are lower than the estimated JPE (e.g., due to low river flows and poor survival), then there is a lower chance that loss thresholds will be exceeded, and protective measures put in place. Ironically, in this scenario - when the true JPE is lower than predicted - winter-run need more protection, not less.**

Recommendations related to Question 7

- **While we recognize the value of reducing complexity via a single annual JPE value, the panel recommends exploring options to develop year-specific fry-to-smolt and smolt survival rates using covariates such as river flow, temperature and detections from early releases of acoustic tagged fish (“sentinels”) to generate more accurate JPE estimates (Key Recommendation #9).**

We recommend continuing with the current methods and using an averaged survival estimate for generating a JPE at the start of January to give SaMT and WOMT something to work with during ‘pre-season planning’ (Question 1). However, as December to January weather patterns could dramatically alter winter-run migration patterns and survival, we think the JPE should be re-estimated in early to mid-February using year-specific survival estimates informed by observed and predicted flow and temperature patterns. This would allow the SaMT to recalibrate their loss predictions for that cohort before major losses occurred.

Suggested within-season timeline to support proactive management:

1. Pre-season planning with the 'normal JPE' at the start of January (Question 1).
 2. In January to February, monitor the loss trajectory and be ready to start reducing exports if losses start to climb (Question 1).
 3. Gather temperature and flow observations and forecasts to estimate year-specific fry-to-smolt and smolt survival estimates, then use them to update the JPE in early Feb and reassess the loss trajectory (this Question).
- **We also recommend considering and adapting JPE-based loss thresholds against longer term tracking of winter-run population trends and forecasts (Key Recommendation #6 and #10)**

Ultimately, it is important to take a holistic view to winter-run management. As mentioned by the public comments by the PCFFA, winter-run are not targeted, but *“depleted numbers of winter-run Chinook severely constrain our access to other, more abundant stocks in our mixed-stock ocean fisheries”*. Thus, recovering this population

has far-reaching benefits for a variety of stakeholders, but will require joined-up, system-wide habitat restoration, floodplain reconnection, flow and export management (see Question 5). It is thus important to (a) monitor longer-term patterns in winter-run survival and population growth or decline, (b) to forecast population trends using life cycle models (Hendrix et al., 2022), and (c) to review and adapt annual loss thresholds at CVP/SWP accordingly.

Currently, once winter-run juveniles pass RBDD, we have limited understanding about their consequent fate - *“the duration of their residency and habitat use are relatively unknown due to the lack of reliability of the length-at-date (LAD) criteria ... and because monitoring farther downstream is less intensive.”* (CDFW, 2020b). Yet winter-run survival along the migratory pathway and Delta can be highly tied to flow and temperature, and their influence on predation rates (Michel et al., 2021; Nobriga et al., 2021). To fill this knowledge gap will require robust estimates of the number of genetic winter-run leaving the spawning grounds (RBDD), exiting the system (Chippis Island midwater trawl) and returning to spawn (CDFW Grandtab escapement estimates) (Johnson et al., 2017). The panel therefore strongly supports current efforts to expand Chippis Island catches in order to obtain robust estimates of the numbers of winter-run leaving freshwater (<https://sciencetracker.deltacouncil.ca.gov/activities/estimating-abundance-juvenile-winter-run-chinook-salmon-entering-and-exiting-delta-sail>).

Question 8. What is the best framework for incorporating relevant sources of information and data into real-time management decisions for the SWP to estimate and manage population impacts to the winter-run population, including but not limited to informing operational decisions to change the loss trajectory and avoid exceeding the annual loss threshold? Specifically, how can prediction tools such as the Winter-run Chinook Salmon Machine Learning (WRCML) Model be modified, adjusted, or used complimentary with relevant real-time data, including but not limited to, the juvenile production estimate (JPE), reach-specific survival, real-time acoustic data, non-physical barrier operations, river inflows, physical conditions, and other relevant information?

The goal of the WRCML is to develop a tool that can predict loss (estimated from salvage) of winter-run Chinook at the pumping stations at least a week in advance. Presumably this information can then inform management decisions about the level of OMRI to implement the following week.

The approach seems reasonable, although we were not provided with full model documentation. Therefore, our strongest recommendation is that the model should be more thoroughly documented, and the code and documentation should be made publicly available on a site such as GitHub. This is a standard requirement for the publication of models.

We note that the process from emigration as juveniles to salvage at the pumping stations is very complex. From time of capture at the Red Bluff Diversion Dam and in the beach seines near Sacramento (which only represents the smaller segment of the population) to salvage at the pumping station, many complex behaviors occur: downstream migration (whose rate can vary with flow and through the season), alternative migration routes (which depends on flow and whether certain pathways are opened or closed), fish survival (which likely varies with temperature and flow among other factors).

Before discussing the WRCML Model, we'll discuss other types of models that could be (and have been) used to develop the relationship between fish loss at the pumping stations (or fish salvaged there).

Cavallo (in public comments) suggested using a life-cycle mode for this application. Although we believe life-cycle models are highly applicable to assess the viability of winter-run Chinook, they would not be of much utility to predict loss. Life-cycle models tend to be “broad brush”, combining several life stages into a single viability model. As such they rarely go into the detail necessary to address the problem of predicting salvage and loss. Further, life-cycle models would typically take the output from changes in operations (leading to changes in survival) as an input and then assess the sensitivity of population viability to such changes. Thus, we do recommend inputting presumed increases in survival derived from actions taken at the pumping stations into existing winter-run Chinook life-cycle models, such as the one developed by Hendrix et al. (2022). We note that Zeug et al. (2012) developed a life cycle model that included a term relating survival to exports based on Newman and Brandes (2010). However, the relationship was weak and noisy, leading Newman and Brandes (2010) to conclude that “the predictive ability of models without exports is equivalent to that of models which included exports.”

A mechanistic model that represented the several processes mentioned above could be useful for this application. However, in conservation settings, a mechanistic model would need to be supported by a great deal of data, which simply does not exist in this situation. Also, given the complexity of the system, we don't think that the type of data needed to support a mechanistic model could be collected. We note that the COMPASS model, used for management in the Columbia River system, is supported by decades of Passive Integrated Transponder (PIT) tag studies and dozens of radio and acoustic tag studies. Also in that system, bypass systems in dams create ideal PIT tag detection sites and fish don't have much of an option other than migrating straight downstream. Researchers at the University of Washington (who, along with NOAA, developed COMPASS) have developed SacPAS (www.cbr.washington.sacramento), which models migration and survival of winter-run Chinook through the mainstem Sacramento River. However, the SacPAS does not model migration through the interior Delta, so it is not useful for this application.

We believe that there might be benefits to including some aspects of a mechanistic model into the current modeling. A simple mechanistic model could better capture the downstream movement of juvenile Chinook – migration rate is related to river flow (Hance et al., 2022) and “migrational readiness” (Zabel, 2002), and cohorts spread out as they move downstream (Zabel, 2002; Michel et al., 2013). In addition,

this could account for systematic changes in the system, such as a reduction in the probability of entering the lower Delta after the BAFF was installed.

Nonetheless, we strongly support the use of statistical modeling to relate exports to loss, particularly *predictive* statistical models. As mentioned above, the system is quite complex, and any statistical model needs to summarize several behavior processes.

Zeug and Cavallo (2014) modeled the relationship between loss or salvage and the level of exports using a Generalized Linear Model (GLM) approach. Zeug and Cavallo (2014) analyzed 15 years of release and recovery data for coded wire tagged salmon reared at hatcheries throughout the Central Valley of California. The response variable in all statistical models was the number of fish salvaged. Screening of the response variable indicated that many releases in both rivers resulted in zero salvage. Thus, a zero-inflated negative binomial regression was employed. These models are composed of two parts: a count model that explains salvage as a function of covariates and a zero-inflated model that accounts for the processes that result in zero salvage as a function of covariates. They found strong influences of river flow and diversion flow on fish salvaged. Other factors (DCC open, fork length, distance of release from salvage facilities, adult recoveries) were important in some cases. Notable from this study were that the authors used CWT hatchery fish and they treated the two pumping facilities separately.

Tillotson et al. (2022) use a machine learning model approach to predict loss at the two major water pumping stations. Their approach is quite similar to the methods used by the WRCML model. They used a quantile random forest approach (i.e., they predict the entire distribution of salmon loss) compared to the categorical approach adopted by the WRCML mode. They also examined a hurdle model approach where they first predicted presence/absence and if they predicted presence, then they predicted abundance. The main factors included in the model were previous week's salvage and week in the season. They also produced a web-based application that is user friendly and is readily available in real time to decision makers (<https://www.cbr.washington.edu/sacramento/lossandsalvage/>). They looked at total salvage and salvage at each project as response variables although they did not report results (magnitude of salvage) at each project.

The WRCML model differs from the Tillotson et al. (2022) model in several significant ways:

- Predicts loss more than a week ahead;
- Uses 3 categories for the response variable;
- Uses a DART (Differentiable ARchiTecture Search or Dropout for Additive Regression Trees) algorithm that uses so-called “dropouts”.

Machine Learning Models are a family of statistical models that exploit the relatively recent developments in computing power, accessible to most researchers. They are amenable to complex ecological problems (Olden et al., 2008), such as modeling salvage or loss at pumping stations.

Regression Trees are a particular form of machine learning. They are models that relate response variables to predictor variables by recursive binary splitting. They have several advantages over standard statistical approaches (i.e., GLMs): they handle nonlinear relationships without having to specify a parametric form; they easily handle interactions in the data and can express the interactions in output; they do not require any data transformations; and they easily accommodate outliers (Elith, 2008).

Regression trees can take on several different forms depending on how the response variable is specified. The response variable can be continuous, and the response is depicted similarly to that of linear or nonlinear regression. A specific type of this is quantile random forests, which specifies model predictions as a particular quantile (as was done in Tillotson et al., 2022). Tillotson et al. (2022) focused on the 75th quantile of loss per time period to be conservative in their recommendations from their output.

The WRCML model used a categorical response variable – they split loss into three states: no loss, low loss, and high loss. Low loss and high loss were defined by whether observed (or predicted) loss was lower or higher, respectively, than the historical median loss observed on weeks when loss occurred.

Regression trees operate by recursively splitting the predictor variable into two groups based on maximizing the distance between the groups (e.g., maximizing the difference in mean values) while minimizing the variability within groups. The exact form of how this takes place depends on the type of response variable. Once the

first split is chosen, and two “child” groups are selected, these child groups can be further split into recursively smaller groups. The process stops when the number of data points in each child group is a preselected number (or more) or the number of splits reaches a maximum threshold. These criteria are chosen by the researcher.

To use the model predictively, the researcher either applies new data, or a portion of the retrospective data that was not used in the fitting process, to the fitted tree. Following the splits with the novel data, the researcher obtains a prediction of the response variable associated with the novel data. In the case of the WRCML model, the novel data yields a prediction of whether the predictor variables were associated with no loss, low loss or high loss.

One of the limitations of this approach is that single predictions are not very reliable. A “Random Forest” approach obviates this limitation to a certain extent by combining results from many independently generated trees into a single prediction.

Boosted regression trees (BRTs) take this process one step further by fitting successive trees to the errors (predicted results minus the observed results) obtained from the previous tree. The Multiple Additive Regression Trees (MART) approach involves setting a “learning parameter” that scales the results from successive trees; that is successive trees have less of an effect on the final predicted value.

One issue with BRTs and MART is overspecialization. That is, the model fit to data is better than the ability of the model to predict novel data. Several methods have been proposed to overcome this. MART with dropouts (termed Dropout for Additive Regression Trees or DART) is an approach that attempts to overcome this problem of overspecialization (Rashmi and Gilad-Bachrach, 2015). DART removes some of the trees from the MART algorithm (those trees that add little to the predictive ability) to create an ensemble of trees with enhanced predictability as compared to MART. This is the approach adopted by the WRCML model.

Typically, prediction models are validated by leaving out some of the data from the training set and then applying the fitted model to the novel data. This is what was done with the WRCML.

Overall, the approach adopted by the WRCML model is cutting edge and sophisticated, but also quite complex. We believe the model has great potential to be a useful tool to predict loss of winter-run Chinook at the pumping facilities. Below we have some suggestions to improve the model and suggestions for managers.

Recommendations to improve the current WRCML (summarized in Key Recommendation #5)

- **Move beyond three states**

By only specifying three states for the response variable ('absent', 'low' being a 7-day moving average predicted loss of LAD winter-run of >0 to <4.29 , and 'high' being a 7-day moving average predicted loss of LAD winter-run ≥ 4.29 , the threshold being based on historical median daily loss), the WRCML model increases its ability to predict those three states. However, along with this improved predictability comes a loss in utility. Because the annual loss threshold is an absolute number (tied to JPE), the ability of the model to inform managers is somewhat limited. Loss magnitude has different implications depending on estimates of JPE. We suggest the modeling team consider alternative approaches than just specifying three states. This could take the form of increasing the number of states (to say, ten) or using weekly loss as a continuous response variable.

- **Reconsider travel time from beach seines and RBDD to pumping facilities**

The 21-day and 162-day lag to account for fish travel time from the beach seines and Red Bluff Diversion Dam, respectively, seems like an oversimplification. This appears to be a limitation of the model as formulated. We understand that interactions in the data can be captured in the machine learning approach, but we're having a hard time comprehending how this could occur when the lags are hard-coded in the data. We suggest that the authors consider other approaches to incorporating the count data into the model. Perhaps the count data could have a variable lag based on an approach similar to that of Michel et al. (2021) before they enter the data into the model. The lag (or travel time) could also be related to river flow, as has been demonstrated by the STARS model (Perry et al., 2019).

- **Treat pumping stations individually and differentially**

The Central Valley Project (CVP) and The State Water Project (SWP) are fundamentally different. Zeug and Cavallo (2014) treated the two projects separately as response variables, and salvage at each project was related to a different suite of predictors. Could efficiency be gained by treating the projects separately, and depending on conditions, differentially export flow? To fully understand how the two projects entrain fish differentially may require some experimentation.

- **Develop the model to use genetic data only**

A very high priority is to retool the model to represent genetically determined winter-run Chinook, given that the 2024 ITP now mandates actions based on loss of genetic winter-run. We understand that this may limit the amount of historical data available. But based on the loss of predictive power when the WRCML model is applied to these data, it makes sense to reparameterize the model to these data.

- **Develop a model for hatchery fish using CWT data.**

All winter-run hatchery Chinook are coded wire tagged. The WRCML model could be retooled for CWT hatchery Chinook, as was done by Zeug and Cavallo (2014). These fish are of known origin and can be identified in the salvage. Also, hatchery fish are important because they can trigger a management response, as was the case in 2025.

Recommendations for managers (linked to Key Recommendations #1 and #5)

We believe the WRCML model is a powerful tool that should be used by managers in both a real-time and a pre-season context. In the pre-season mode, the tool would allow managers to think on a holistic and season-wide basis. If managers consistently begin to take action only after 50% of the run has passed, this could differentially affect the earlier part of the run; i.e., more of the early part of the run would be lost compared to the later part of the run. As a long-term strategy, this could reduce life history diversity.

Question 9. Are there new or alternate approaches to incorporate into assessments to inform real-time estimates on effects to fish from CVP and SWP export operations?

Throughout this review, we have suggested new and alternative approaches to consider informing real-time management of winter-run and reduce loss. These include (a) prediction model improvements, (b) experiments to better understand relationships between exports and winter-run routing, survival and loss rates, and (c) alternative hydrodynamic modelling approaches. As (a) and (b) have already been explored in detail in Questions 1, 5 and 8, we only briefly summarize them below, but we use this response to explore more deeply the options to improve hydrodynamic modelling to support real-time management.

a) Model and data sharing improvements (summarized in Key Recommendations #5 and #8)

As per our response to Question 8 above, we believe the WRCML model could and should be used more effectively to inform managers about upcoming salvage events. The model has the capability of presenting real-time forecasts of salvage in the next few weeks. These forecasts should be presented to SaMT and should be used to support proactive management (Question 1). The modeling team should work with SaMT and WOMT to develop a web page, much like that of the Tillotson et al. group (<https://www.cbr.washington.edu/sacramento/lossandsalvage/>) with current forecasts. This should be combined with a dynamic, online table where key variables are updated as soon as they become available, with links to other figures and webpages useful for SaMT, such as https://oceanview.pfeg.noaa.gov/CalFishTrack/pageGSSMB_LFCS_2025.html#Acoustic_Tagging_Project. The WRCML model will also have more utility in this context if it presents continuous output instead of three states. The output could also be presented in terms of JPE and the exceedance threshold. We also recommend development of a model to predict future loss of hatchery fish (Question 5 and 8).

b) Experiments to test effects of exports on routing, survival and loss (summarized in Key Recommendations #3 and #4)

As detailed in Question 5, significant knowledge gaps exist regarding relationships between exports, export to inflow ratios (E:I), OMR and OMRI and juvenile winter-run salmon behavior, survival and entrainment into the export facilities. We recommend designing a series of experiments manipulating export levels and timings from CVP and SWP (individually and in combination) and using detections of acoustic tagged fish to test their effects on winter-run routing, survival and loss.

Obviously, such experiments carry risk of increased loss of multiple species, so risk tolerance should be discussed in advance, perhaps only performing higher export rates in years with higher juvenile production. Importantly, these experiments need to include tagged fish of a wider range of sizes, released over a broader time window to fill critical data gaps around routing and survival of natural origin winter-run. To support tagging of smaller fish, we recommend exploring miniaturized acoustic tags such as “shad tags” and ELATs that can be applied to salmon as small as 55 mm FL, as different sized fish likely exhibit different behaviors and survival, but most of our existing knowledge is based on >95 mm FL hatchery fish.

Without better understanding of these relationships between export rates and loss, it is extremely challenging to design - and agree on - what “proactive management” truly looks like. In general, we agree with the public comments from San Francisco Baykeeper and Defenders of Wildlife that applying the precautionary principle is advisable, given just how vulnerable this salmon population is (e.g., assuming LAD winter-run are genetic winter-run until confirmation from genetic screening or CWT reads). Even without these large-scale experiments, existing data suggest that managing the two facilities individually and differentially could be best to reduce winter-run loss (Fig. 8).

c) Hydrodynamic Observations and Modeling Recommendations to understand South Delta circulation patterns with relationship to winter-run migration in this region (summarized in Key Recommendations #3 and #7).

Delta hydrodynamic modeling of the South Delta region was used sparsely by SaMT and WOMT in 2024 and 2025 to support the CVP and SWP export operations decision making process. Hydrodynamic models are valuable tools that should be utilized, sometimes in real time, to support both SaMT and WOMT meetings in future years.

Remember that the Delta is a freshwater tidal system. Even though regulations such as OMR are based on tidally- or daily-averaged values, these are significant over-simplifications of the water transport mechanisms actually occurring in these channels. Old and Middle River are bi-directional distributaries, not rivers in the traditional sense. As such, hydrodynamic models should be utilized as much as possible to understand the true transport mechanisms and the influence of exports, gate operations, and barrier placement.

In 2017, the Salmon Scoping Team (SST) invited non-SST scientists with expertise in Delta hydrodynamics and hydrodynamic simulation modeling to contribute to the SST analysis of the effects of water project operations on juvenile salmonid migration and survival in the South Delta.

This hydrodynamic sub-group made five specific recommendations for alternative flow metrics. These metrics can be extracted from hydrodynamic model output and USGS flow measurement stations to understand water circulation in the South Delta in the context of salmon migration. None of these approaches were utilized in either the 2024 or 2025 analysis by SaMT or WOMT.

We highlight three of their key recommendations (SST 2017b, p. 35-40) and suggest implementing these types of analysis as first steps to building a hydrodynamic modeling infrastructure to support the SaMT/WOMT decision making process.

SST Hydrodynamic Recommendation 2 (SST 2017b): Hydraulic Residence Times in the South Delta

Delta hydrodynamic models should be used to define appropriate representative transport time scales in sub-regions of the South Delta. This would produce a better understanding of how long water resides in the various sub-regions of the South Delta and the interactions between those different sub-regions. This analysis would add to the understanding of how varying export rates at the SWP and CVP facilities influence circulation patterns in this key region on a tidal timescale. The SST (2017) explanation of the linkage of this metric to the conceptual model description is spot on (SST, 2027b, p. 35). See Monsen et al. (2002) for an example of how this concept was applied in the Mildred Island region.

SST Hydrodynamic Recommendation 3: Percentage of Positive (Downstream) Flow in Old River, Middle River, and Other Interior Delta Locations

This recommendation can be implemented with either observations at flow measurement stations throughout the South Delta or with hydrodynamic models. For example, the flow direction for OM4, directly north of the SWP on Old River at Hwy 4, is upstream towards the pumps the majority of time. This indicates that outmigrating juvenile fish near OMR4 need to resist an upstream flow (south; towards pumps) the majority of a day with a limited window of time during a tidal cycle when flows are downstream (north). See SST (2017c) for examples of USGS

flow stations throughout the South Delta and hydrodynamic model simulations of those same signals.

SST Hydrodynamic Recommendation 4: The relative proportion of CVP exports during the juvenile Salmonid migration period.

Figure 8 (from SaMT ITP Risk Assessment for April 16, 2024) provides an important comparison of export rates (CVP, SWP) with Natural winter-run LAD loss in WY 2024. There are clear signal differences between the two facilities. This figure should be used to start a discussion of whether preferential withdrawal from the CVP pumps during winter-run migration would reduce direct winter-run mortality. See the SST hydrodynamics discussion of this topic (SST, 2017b, p. 38).

Three comments regarding Delta hydrodynamics as related to winter-run migration:

Comment #1: Threemile Slough

As discussed in Question 5, Threemile Slough may be another key entrainment junction to the South Delta based on SaMT risk assessments and fish tagging studies. The SaMT ITP Risk Assessment for April 9, 2024, (Review Material #2h) mentions "*alternative entrainment routes such as Threemile Slough that still are likely entraining juveniles even with the current hydrology.*" Newman and Brandes (2009) also mentions Threemile Slough as a potential entrainment junction from the Sacramento River to the export facilities.

The Threemile Slough region is a highly dispersive environment from a Lagrangian (particle) point of view. Exchange through this channel is controlled by a very complex bi-directional tidal signal rather than river inflows. From a scalar (i.e., salt) transport point of view, dispersive flux due to tides rather than residual advective flux controls scalar transport in this region (Monsen 2001).

It is highly plausible that "particles" (tag fish releases) starting at Ryde, directly upstream of Threemile Slough on the Sacramento side can be tidally pumped into the San Joaquin River and subsequently tidally pumped into the False River and

Franks Track flooded island region. Monsen (2001) did an extensive two-dimensional hydrodynamic modeling study of this transport mechanism in Chapter 10 of her PhD thesis. This document could be a starting place for understanding fish migration patterns in the Threemile Slough region.

Comment #2: Strength of velocity during radial gate operations at Clifton Court Forebay

The flow dynamics around Clifton Court Forebay (CCF) is another suggested area of hydrodynamic research to understand fish entrainment into Clifton Court Forebay. When the radial gates are opened “maximum hourly water velocities through the radial gates can exceed 20 ft/s (Clark et al., 2009), which is double the burst speed of adult salmonids (CDFG 2010). As the radial gates are opened, water flow and water velocities are typically quite strong depending on the difference in water surface elevation between Old River and CCF. This makes egress from CCF difficult until the flow and velocities diminish as the water surface elevations begin to equalize.” (CDFW, 2020a). Even though salmon will try to resist the flow, are they capable of doing that at these flow volumes and velocities?

Comment #3: Tidally-averaged flow on Old River and Middle River

A frequent overarching issue when discussing reducing SWP/CVP exports for the benefit of fish is the concept of the cumulative tidally-averaged flow on Old River and Middle River in the South Delta.

In this review, public comments by Baykeeper pointed out that: “[b]etter utilization of actual OMR data is needed. USGS gauges monitor actual flows in Old and Middle River (OMR). The Old and Middle River Index (OMRI, the metric for management in the NMFS 2019 and 2024 BiOps) is supposed to approximate OMR. However, data from SacPAS reveal that OMRI regularly underestimated the magnitude of negative flows during the 2024 and 2025 OMR management season ... Because the relationships between negative OMR flow and impacts to native fishes are power functions, even seemingly small deviations from required flow minima (e.g., the difference between OMR and OMRI) can lead to large impacts, especially for highly imperiled species that are disproportionately susceptible to the effects of water exports.”

Finding the “right” representation of this OMR regulation is difficult. The value is either calculated as an index value based on a regression equation, OMRI, or the value is calculated by tidally-filtering the flow measurements from two USGS flow

stations on Old and Middle River. The two downsides to the observed flow approach are that 1) there is a time delay in calculating this value because of requirements for tidally-filtering observed data and 2) missing sampling data from instrument failure cause gaps in data for the calculation (DWR, 2017).

The South Delta is a tidal system. Therefore, any tidally-averaged representation of flow on Old and Middle Rivers does not accurately represent hydrodynamic circulation patterns of the South Delta. A real-time, tidal, hydrodynamic modeling infrastructure needs to be developed to support the SaMT/WOMT decision making process. This would allow both the tidally-averaged OMR values and tidal hydrodynamic information to be available to decision makers.

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Nancy Monsen uploaded the panel's review and supplemental reading material into Claude by Anthropic to understand the timelines of actions and the types of models used by SaMT and WOMT in the decision-making process in 2024 and 2025. All AI results were cross-validated by manually checking all review materials.

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Appendix Table 1 - SaMT meeting notes from the weekly assessments and ITP risk assessments for WY 2024

Date	Notes / Action suggested
2024-02-06	Final JPE calculations have been established for brood year (BY) 2023 winter-run Chinook salmon. Also the first LAD winter-run reach salvage.
2024-02-13	Loss of LAD winter-run much higher the last week than predicted (>6 times higher than the predicted median loss based on Tillotson Model)
2024-02-20	First genetically confirmed winter-run salvaged on Feb 12. ITP risk assessment: "WOMT recommended OMRI be further restricted to -2,500 cfs through 2/28/24". "SaMT...are uncertain if loss occurring in the next week will lead to exceedance of the 50% single-year loss threshold. It is possible that the 50% annual loss threshold (1,374), 75% annual loss threshold (2,061), 90% annual loss threshold (2,473) and incidental take limit (4,698) will be exceeded this year, based on length at date. Based on historical pattern, the 50% single-year loss threshold may be exceeded around mid-March."
2024-02-27	50% single year loss threshold for winter-run was exceeded Feb 25. Loss of LAD winter-run was much higher than the median loss predicted by Tillotson model and up to 94% of this cohort of winter-run estimated to be in the Delta. The 100% single year loss threshold for steelhead was exceeded Feb 23. SaMT assessment based on winter-run loss: "export facilities will operate such that the fourteen-day average OMRI flow is no more negative than -3,500 cfs through the end of OMR management season". From ITP risk assessment: "SaMT agreed that having an incremental stepdown from -2,500 cfs to a more positive OMRI may be beneficial for decreasing loss of steelhead at the export facilities. SaMT decided that WOMT would be best suited for determining the magnitude of the stepdown approach (i.e -2,500 cfs to -2,000 cfs, or -2,500 cfs to -1,500 cfs)."
2024-03-05	From ITP Risk Assessment based on steelhead (at top of document, underlined): "To avoid exceeding the annual Incidental Take Limit, SaMT recommends an OMRI from 0 cfs to -500 cfs. SaMT will reassess next week to see if a decrease in salvage has occurred and compare loss rates relative to the Tillotson Model predictions to make a further recommendation"
2024-03-12	75% single year loss threshold for winter-run was exceeded March 7. SaMT weekly assessment: "The 100% single year loss threshold for LAD winter-run Chinook Salmon may be exceeded during the upcoming week if salvage trends continue." Based on steelhead: "the 100% single year loss threshold was exceeded on 2/23/2024. The CVP and SWP will operate to -500 OMRI in order to reduce Steelhead loss in response to the 100% exceedance and encroachment of the incidental take limit."
2024-03-19	ITP risk assessment: "The agencies in the SaMT assessed the likelihood of exceeding the annual loss threshold and believe the loss occurring in the next week may lead to exceedance of the 100% single-year loss threshold." Based on steelhead losses: "The CVP and SWP have been operating to OMRI of no more negative than -500 cfs beginning on 3/11/2024. "

Date	Notes / Action suggested
2024-03-26	100% single year loss threshold for winter-run was exceeded March 20. SaMT ITP risk assessment: "CDFW recommends that OMRI should remain more positive than -500 cfs in order to minimize subsequent loss of winter-run Chinook salmon due to the 100% Annual Loss Threshold exceedance", "Expected OMRI flows are targeting between -500 and -2,500 cfs for the next week." "winter-run still continue to be salvaged in high numbers at an OMRI of -500 cfs; therefore, decreasing OMRI to anything more negative than -500 cfs increases the risk of entraining more winter-run into the facilities." however the ITP actually only requires OMRI "no more negative than -2,500 cfs through the end of OMR management season or until the risk of entrainment is no longer present based on a SaMT risk assessment". The realised OMRI was more positive than this due to loss of steelhead.
2024-04-02	From ITP risk assessment: CDFW refrains from providing a different recommendation from last week due to ongoing high salvage rates that are being observed when operations target an OMRI more negative than -500 cfs. The increased loss of LAD winter-run when projects decreased OMRI to -1,500 cfs last week did not minimize loss of LAD winter-run and continuing to decrease OMRI is likely to further increase loss and have an impact to the population.
2024-04-09	From ITP risk assessment: "CDFW continues to recommend an OMRI of -500 cfs due to the decreased salvage that was observed when operations were targeting an OMRI of -500 cfs. The SWP ITP COA 8.6.1 states that any subsequent loss should be minimized after the 100% Annual Loss Threshold is exceeded.... CDFW will recommend a more negative OMRI than -500 cfs once risk of entraining LAD winter-run into the salvage facilities is no longer present." "CDFW notes that increasing OMRI to -2,500 cfs also increases exports, which is not supported by SaMT's off-cycle meeting on 3/22/24 which states "advice regarding future project operations to minimize subsequent loss during the year" (as required by ITP COA 8.6.1) which was clear that "lowering exports would contribute to minimizing subsequent loss [of winter-run] this year."
2024-04-16	From ITP risk assessment: "CDFW recommends continuing operating to a positive OMRI this week due to the decreased salvage of LAD winter-run that has been observed since operations targeted a positive OMRI over the previous week."
2024-04-09	From ITP risk assessment: "CDFW continues to recommend an OMRI of -500 cfs due to the decreased salvage that was observed when operations were targeting an OMRI of -500 cfs. The SWP ITP COA 8.6.1 states that any subsequent loss should be minimized after the 100% Annual Loss Threshold is exceeded.... CDFW will recommend a more negative OMRI than -500 cfs once risk of entraining LAD winter-run into the salvage facilities is no longer present." "CDFW notes that increasing OMRI to -2,500 cfs also increases exports, which is not supported by SaMT's off-cycle meeting on 3/22/24 which states "advice regarding future project operations to minimize subsequent loss during the year" (as required by ITP COA 8.6.1) which was clear that "lowering exports would contribute to minimizing subsequent loss [of winter-run] this year."

Date	Notes / Action suggested
2024-04-16	From ITP risk assessment: "CDFW recommends continuing operating to a positive OMRI this week due to the decreased salvage of LAD winter-run that has been observed since operations targeted a positive OMRI over the previous week. CDFW will recommend a less positive OMRI once risk of entraining LAD winter-run into the salvage facilities is no longer present."

Appendix Table 2 - WOMT Meeting Timelines for WY 2025

Meeting	Reclamation	CDFW	DWR	NMFS
2025-03-19 Regular	Current salvage: 73 fish; 1-4 more fish: trigger 50% exceedance (-3500 cfs OMRI; 7 days)	N/A	N/A	N/A
2025-03-25 Ad Hoc Held because of exceedance No Consensus Requested Directors meeting	Based on 3/24/25 Reclamation Assessment: Recommends -5000 cfs OMRI Unlikely to reduce loss at export facility or change population level export effects on winter-run with more positive OMRI Reclamation advocated for immediate relief from -3500 cfs OMRI (see 3/21/2025 in timeline)	Based on 3/25/25 SaMT meeting: Recommends -3500 cfs OMRI; but ideally -2500 cfs OMRI Based on updated modeling runs and recent loss data Agrees with NMFS recommendation to reassess 4/2/2025	Operating OMRI more positive than -5000 cfs will not reduce the risk of winter- run from entering the Delta. An assessment is only allowed for hatchery winter- run because of the 100% exceedance of annual loss threshold	Based on 3/25/25 SaMT meeting: Recommends -3500 cfs OMRI for a week, reassess on 4/2/2025 Based on understanding that more positive OMRI provides more protection
2025-03-26 Regular	Discussion notes in 3/24/25 Ad Hoc Meeting Notes	N/A	N/A	N/A

Meeting	Reclamation	CDFW	DWR	NMFS
<p>2025-04-01</p> <p>Ad Hoc</p> <p>No Consensus</p> <p>Requested Directors meeting</p>	<p>Based on 3/24/25 Reclamation Assessment showing no population benefits of more positive than -5000 cfs OMRI</p> <p>Recommends -5000 cfs OMRI</p>	<p>Fishery models show benefits to continuing with a -3500 cfs OMRI Operation</p> <p>Even more benefits to a -2500 cfs OMRI operation</p> <p>Degradation of benefits occurs at -5000 cfs OMRI operation</p>	<p>Recommend -5000 cfs OMRI for this week</p> <p>No winter-run in salvage since 3/24</p> <p>Tillotson winter-run model predicted modest salvage but large error bars</p> <p>Survival has been high this year. 50k more hatchery made it to Delta than hatchery run estimated in JPE</p>	<p>Recommends -3500 cfs OMRI</p> <p>There have been no significant changes to last week's conditions</p>

Meeting	Reclamation	CDFW	DWR	NMFS
<p>2025-04-09</p> <p>Regular</p> <p>OMR limit elevated to Directors meeting</p>	<p>1 juvenile hatchery winter-run observed at SWP, triggered the annual loss threshold</p> <p>No natural winter-run observed since 3/24/2025</p> <p>Recommends -5000 cfs since OMRI more positive than -5000 cfs are unlikely to reduce loss or change population level effects.</p> <p>Also included Tillotson model (available on SacPAS)</p> <p>Spring outflow will be controlling tomorrow, SWP exports at 600 cfs.</p>	<p>N/A</p>	<p>N/A</p>	<p>The issue of the OMR limit as already been elevated to the Directors and is being handled at that level.</p>