LTO Action 5

Exhibit 5, Entrainment Management

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2. Natural-origin winter-run Chinook salmon (genetic data available for WY 2020–2025) never exceeded any thresholds.

3. Proportional loss ranged from 0.00% to 0.57% for hatchery-origin fish and 0.00% to 0.05% for natural-origin fish.

1.1.1.2 Background

To assess incidental loss ("take") of natural-origin and hatchery-origin juvenile winter-run Chinook salmon at the CVP and SWP fish facilities, historical loss was hindcast as a proportion of the annual juvenile production estimate (JPE) entering the Sacramento–San Joaquin Delta.

1.1.1.3 Methods

Separate JPEs were calculated for hatchery-origin and natural-origin winter-run Chinook salmon. Hatchery JPEs were derived from Livingston Stone NFH releases multiplied by telemetry-based survival rates. Natural-origin JPEs were obtained from SacPAS.

Thresholds were computed for each Water Year at 0.5%, 0.75%, and 1.0% of JPE.

Cumulative loss was computed for both hatchery and natural-origin fish, and the dates on which cumulative loss met or exceeded each threshold were identified.

1.1.1.4 Results

The 0.5% threshold for hatchery-origin fish was exceeded only in Water Year 2004, while 0.75% and 1.0% thresholds were never exceeded. Natural-origin winter-run Chinook never exceeded any threshold.

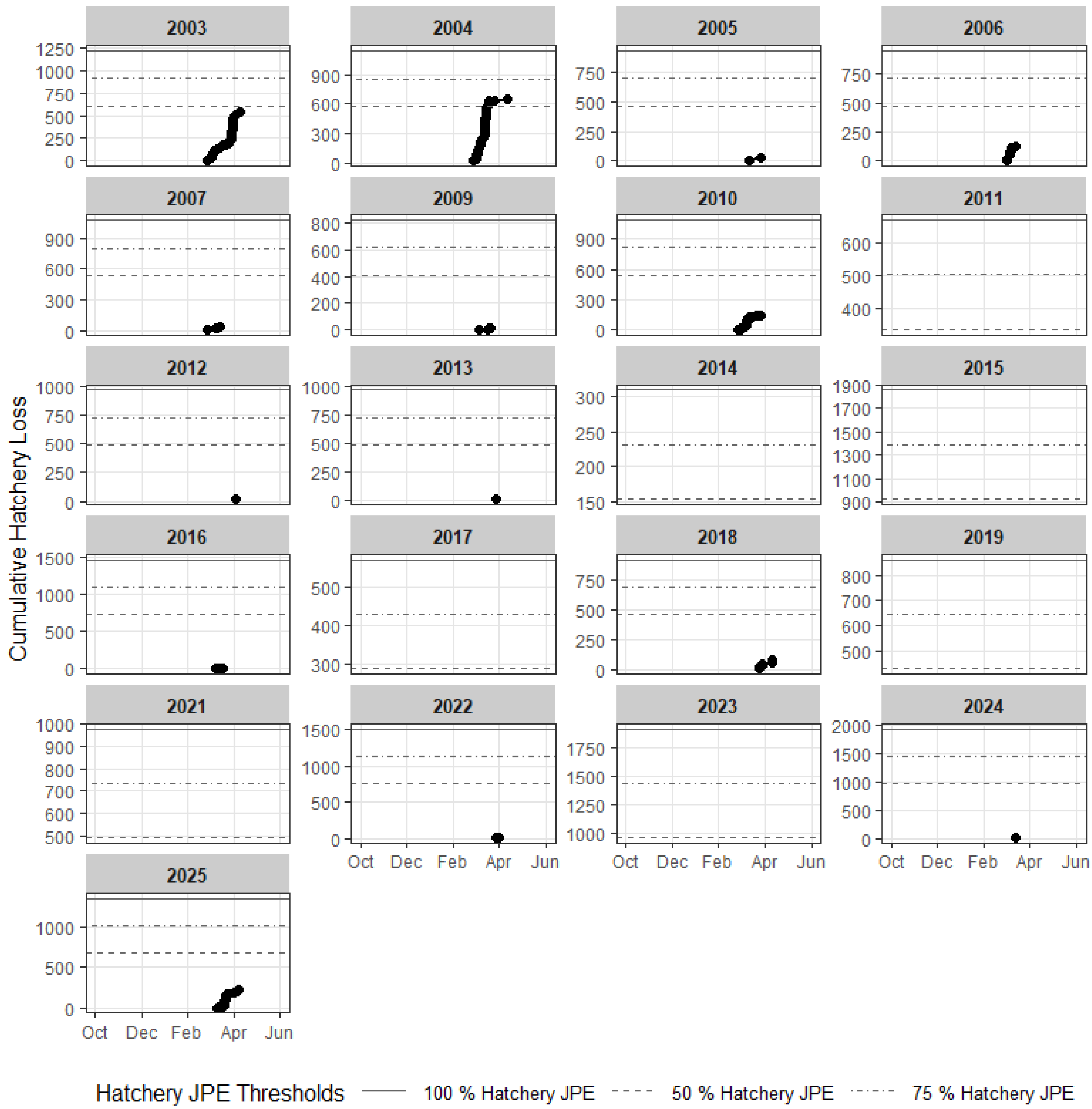


Figure 1. Each panel represents a single water year (WY) and displays the cumulative hatchery-origin Winter-run Chinook salmon loss at the fish facilities over time (October–June). Horizontal dashed lines indicate loss thresholds based on the Hatchery Juvenile Production Estimate (JPE), set at 50%, 75%, and 100%. Loss is shown as black points accumulated through time. Years with no data or loss below threshold may appear empty or flat.

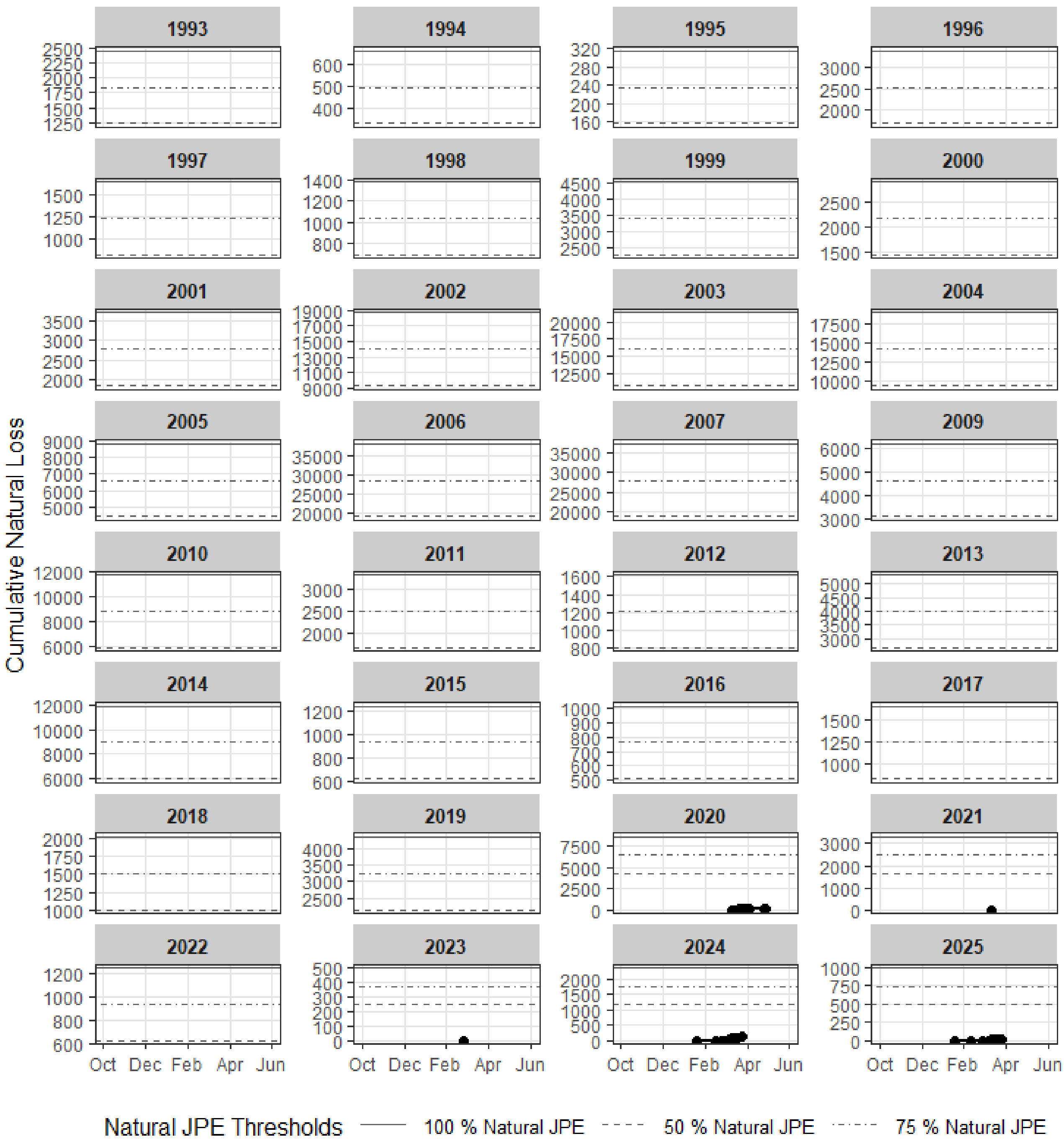


Figure 2. Each panel shows the cumulative natural-origin Winter-run Chinook salmon loss for a given water year (WY), from October to June. Horizontal dashed lines mark 50%, 75%, and 100% thresholds of the Natural Juvenile Production Estimate (JPE). These thresholds are used to inform and trigger management actions. Loss is plotted as black points; absence of points or flat lines indicate no substantial loss during those years. Recent years (e.g., WY 2024–2025) show higher loss events exceeding 100% of the JPE. Genetic data on natural origin Winter-run Chinook salmon only goes back to 2020.

Table 1. Summary of total and proportional hatchery loss and associated trigger dates for Winter-run Chinook Salmon by Water Year.

Water Year	Hatchery JPE	Total Loss	Proportion Loss (%)	50% Trigger	75% Trigger	100% Trigger
2003	121,617	541.32	0.45	–	–	–
2004	114,400	651.83	0.57	Mar 13	–	–
2005	92,748	33.54	0.04	–	–	–
2006	94,913	124.99	0.13	–	–	–
2007	107,239	41.50	0.04	–	–	–
2008	–	72.88	–	–	–	–
2009	82,050	10.99	0.01	–	–	–
2010	108,725	142.45	0.13	–	–	–
2012	96,525	16.96	0.02	–	–	–
2013	96,525	8.59	0.01	–	–	–
2016	148,000	11.18	0.01	–	–	–
2018	92,904	74.25	0.08	–	–	–
2022	151,544	6.71	0.00	–	–	–
2024	193,582	4.33	0.00	–	–	–
2025	135,342	216.58	0.16	–	–	–

Table 2. Summary of total and proportional natural (genetic) loss and associated trigger dates for Winter-run Chinook Salmon by Water Year (only years with nonzero genetic loss).

Water Year	Natural JPE	Total Loss	Proportion Loss (%)	50% Trigger	75% Trigger	100% Trigger
2020	854,941	76.93	0.01	–	–	–
2021	330,130	3.88	0.00	–	–	–
2023	49,924	2.88	0.01	–	–	–
2024	234,896	127.43	0.05	–	–	–
2025	98,893	28.82	0.03	–	–	–

1.1.2 Real-time Assessment Criteria for Spring-run Chinook Salmon

1.1.2.1 Key summary

1. Historical analysis (Water Years 2011–2025) indicates the 0.5% threshold was exceeded twice (December 26, 2011 and January 22, 2013).

2. The 0.75% threshold was exceeded once (February 22, 2011), and the 1.0% threshold was never exceeded.

3. Total loss ranged from 3 to 4,581 fish annually, with proportional loss ranging from 0.00% to 0.76% of JPE.

1.1.2.2 Background

To assess incidental loss ("salvage") of clipped, coded-wire-tagged juvenile spring-run Chinook salmon at the CVP and SWP fish facilities, historical loss was evaluated relative to the annual juvenile production estimate (JPE). JPEs were derived from Coleman National Fish Hatchery and Feather River Hatchery releases multiplied by telemetry-based survival rates.

1.1.2.3 Methods

Annual JPEs were computed from hatchery release totals combined with associated survival estimates. Missing survival estimates were set to zero.

Loss thresholds at 0.5%, 0.75%, and 1.0% of JPE were computed for each Water Year.

Cumulative daily loss was calculated and threshold-crossing dates were identified for each year.

1.1.2.4 Results

The 0.5% threshold was crossed in Water Years 2011 and 2013. The 0.75% threshold was crossed once in Water Year 2011, and the 1.0% threshold was never crossed.

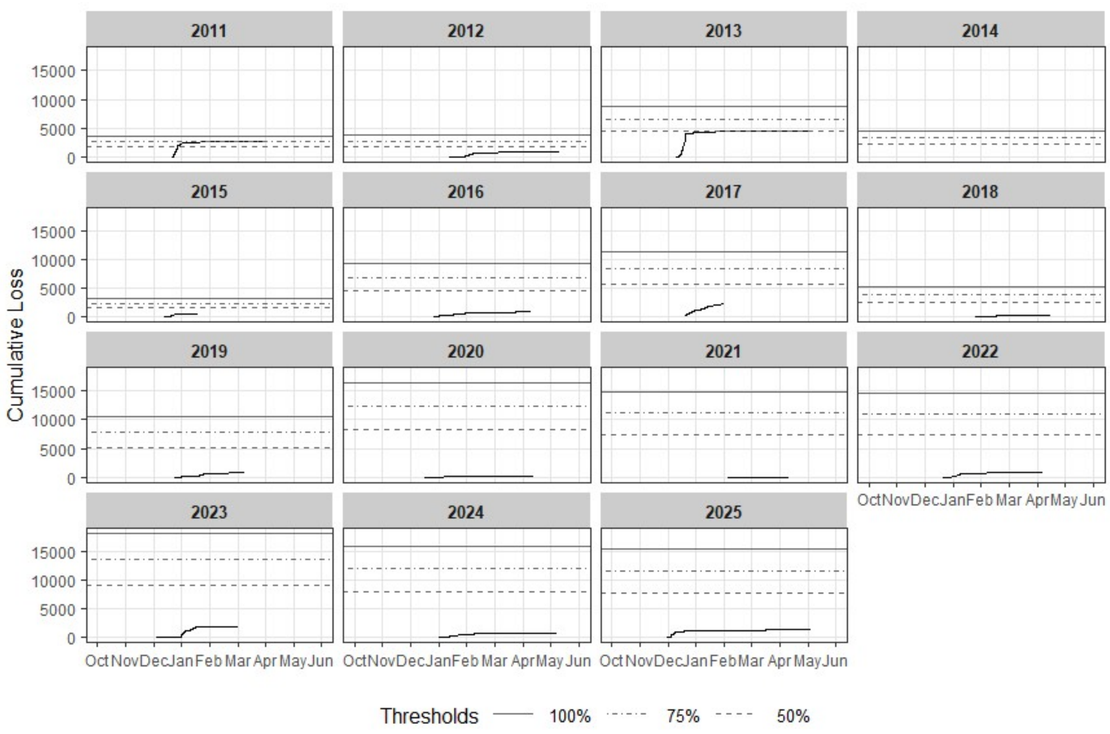


Figure 3. Summary of Spring-run Chinook Salmon cumulative loss and associated thresholds by year.

Table 3. Summary of total and proportional loss and any associated trigger actions for Spring-run Chinook Salmon by year.

Water Year	JPE	Total Loss	Proportion Loss	50% Trigger	75% Trigger	100% Trigger
2011	364,847	2,787.63	0.76	Dec 26	Feb 22	-
2012	373,100	960.78	0.26	-	-	-
2013	880,157	4,580.61	0.52	Jan 22	-	-
2014	438,354	2.88	0.00	-	-	-
2015	324,491	664.10	0.20	-	-	-
2016	923,465	989.07	0.11	-	-	-
2017	1,138,506	2,248.89	0.20	-	-	-
2018	529,889	369.00	0.07	-	-	-
2019	1,053,036	907.75	0.09	-	-	-
2020	1,649,951	112.31	0.01	-	-	-
2021	1,494,734	78.62	0.01	-	-	-
2022	1,469,694	840.38	0.06	-	-	-
2023	1,816,246	1,968.58	0.11	-	-	-
2024	1,592,433	828.71	0.05	-	-	-
2025	1,549,634	1,504.88	0.10	-	-	-

1.1.3 Real time assessment Criteria for juvenile steelhead

1.1.3.1 Key summary

1. Using survival estimates from past telemetry studies, a JPE from 2009-2024 ranged from 202,658 to 864,989 fish.

2. Total loss ranged from 164 to 6,548 fish annually, with proportional loss ranging from 0.03% to 1.07% of JPE.

3. The 0.5% threshold of the JPE was exceeded in 6 of 16 years (typically February-April), the 0.75% threshold in three years, and the 1.0% threshold only once (March 19, 2010).

1.1.3.2 Background

There is significant uncertainty about key biological traits of steelhead (*Oncorhynchus mykiss*) populations, which complicates management decisions for Delta water project operations, prompting state and federal agencies to commit to developing a steelhead JPE, the estimated number of juvenile fish migrating from tributaries into the Sacramento-San Joaquin Delta annually, by accelerating research to better understand steelhead biology and water operation impacts. Since full JPE implementation will require time for study expansion and coordination, a hatchery surrogate approach using existing stocking efforts and metrics could be implemented to measure operational effects on the species.

Table 4. Summary of total stocking numbers for CCV steelhead by water year for individual hatcheries and all hatcheries combined

Water Year	Coleman National fish Hatchery	Feather River Fish Hatchery	Mokelumne Fish Hatchery	Nimbus Fish Hatchery	TOTAL
2009	666,725	401,298	99,688	250,440	1,418,151
2010	594,387	273,398	169,862	439,490	1,477,137
2011	715,925	49,800	44,631	426,920	1,237,276
2012	665,939	420,747	211,977	483,610	1,782,273
2013	667,071	419,250	180,999	315,530	1,582,850
2014	655,789	377,536	78,877	757,638	1,869,840
2015	687,210	500,571	114,250	0	1,302,031
2016	591,362	331,719	116,120	118,337	1,157,538
2017	576,766	71,955	32,920	447,241	1,128,882
2018	610,939	465,000	144,000	45,000	1,264,939
2019	608,899	476,000	0	465,000	1,549,899
2020	632,751	430,500	350,000	440,500	1,853,751
2021	610,645	475,000	167,056	424,000	1,676,701
2022	614,702	408,900	152,881	447,000	1,623,483
2023	418,738	445,000	213,260	516,000	1,592,998
2024	415,500	445,000	138,260	516,000	1,514,760

1.1.3.3 Methods

Using hatchery releases and telemetry studies conducted on hatchery steelhead we hindcast hatchery steelhead JPE, the proportion of those lost to the facility, and note any exceedances of 0.5%, 0.75%, and 1.0% of those JPEs historically from WY 2009-2024. We used high and low survival estimates from telemetry studies at four hatcheries representing major Central Valley rivers: CNFH (Sacramento River, 18.8-39.7% survival) and Nimbus Fish Hatchery (NMFH)/American River (62-83% survival) where estimates were calculated using conditional probabilities of reach-specific survival from stocking location to delta entry, while FRFH 9-45% survival) and Mokelumne River Hatchery (MKFH) (25-33% survival) survivals were explicitly stated in the results of their respective studies (Table 4).

These survival ranges were applied across different water year types from critically dry to wet years, assuming higher survival in wetter conditions, then applied to annual stocking numbers from 2009-2024 to calculate hatchery-specific juvenile production estimates that were combined into a single Central Valley JPE. Historical proportional loss was estimated using loss data from SacPAS and the Salvage Access Database to hindcast exceedances under Alternative 5 criteria.

Table 5. Summary of hatchery specific CCV steelhead survival from stocking location to delta entry for each water year type.

Water Year Type	Coleman National Fish Hatchery	Feather River Fish Hatchery	Nimbus Fish Hatchery	Mokelumne Fish Hatchery
Critical	19%	9%	62%	25%
Dry	24%	18%	67%	27%
Below Normal	29%	27%	72%	29%
Above Normal	34%	36%	78%	31%
Wet	40%	45%	83%	33%

1.1.3.4 Results

Total fish stocked ranged between 1.3 and 1.86 million between 2009 and 2024 (Table 4). Individual hatchery releases varied annually, but generally CNFH had the highest stocking number and MKFH had the lowest stocking number (Table 4). Estimates for a JPE using total fish stocked at each hatchery coupled with survival estimates in above table ranged from 202,658 to 841,656 between 2009 and 2024 (Table 6), with the highest JPE coming from NMFH and lowest coming from MKFH. Total loss in the 16-year time span ranged between 164 and 6,548 and proportional loss of the JPE ranged between 0.03 and 1.07% (Figure 4; Table 7). A 50% threshold exceedance (0.5% of JPE) would have been triggered in 6 out of the 16 years analyzed (see graph above and table below). A total of three of these years would have exceeded the 75% (0.75% of JPE) threshold, and only a single year, 2010, would have exceeded the 100% (1% of JPE) threshold.

Table 6. Summary of juvenile production estimates for CCV steelhead by water year for individual hatcheries and all hatcheries combined.

Water Year	Coleman National fish Hatchery	Feather River Fish Hatchery	Mokelumne Fish Hatchery	Nimbus Fish Hatchery	TOTAL
2009	160,009	72,234	26,916	167,795	426,953
2010	173,682	73,817	49,260	316,433	613,192
2011	283,956	22,410	14,728	354,344	675,438
2012	194,590	113,602	61,473	348,199	717,864
2013	160,092	75,465	48,870	211,405	495,832
2014	123,144	33,978	19,719	469,736	646,577
2015	129,044	45,051	28,563	0	202,658
2016	172,798	89,564	33,675	85,203	381,240
2017	228,762	32,380	10,864	371,210	643,215
2018	178,519	125,550	41,760	32,400	378,229
2019	241,506	214,200	0	385,950	841,656

Water Year	Coleman National fish Hatchery	Feather River Fish Hatchery	Mokelumne Fish Hatchery	Nimbus Fish Hatchery	TOTAL
2020	151,855	77,490	94,500	295,135	618,980
2021	114,667	42,750	41,764	262,880	462,061
2022	115,429	36,801	38,220	277,140	467,590
2023	166,083	200,250	70,376	428,280	864,989
2024	143,105	160,200	42,861	402,480	748,645

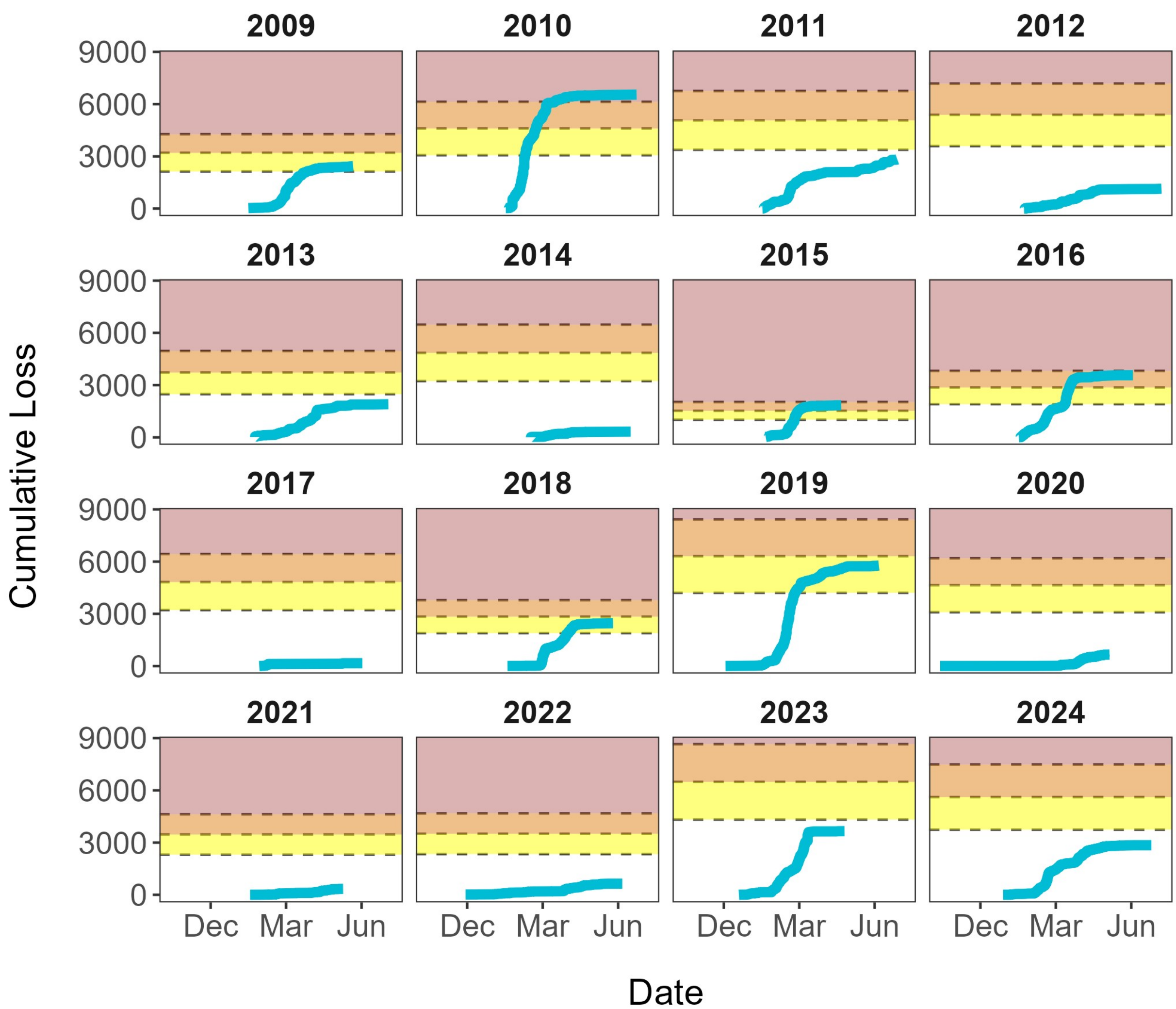


Figure 4. Summary of CCV steelhead cumulative loss and associated thresholds by year. Yellow shading indicates 50% threshold exceedance, orange shading 75% threshold exceedance, and red shading 100% threshold exceedance.

Table 7. Summary of total and proportional loss and any associated trigger actions for CCV steelhead by year.

Water Year	JPE	Total Loss	Proportion Loss	50% Trigger	75% Trigger	100% Trigger
2009	426,953	2,439.11	0.57	Mar 29	*NA*	*NA*
2010	613,192	6,548.28	1.07	Feb 11	Feb 24	Mar 19
2011	675,438	2,823.07	0.42	*NA*	*NA*	*NA*
2012	717,864	1,141.16	0.16	*NA*	*NA*	*NA*
2013	495,832	1,901.95	0.38	*NA*	*NA*	*NA*
2014	646,577	327.83	0.05	*NA*	*NA*	*NA*
2015	202,658	1,841.19	0.91	Feb 26	Mar 04	*NA*
2016	381,240	3,566.87	0.94	Mar 14	Mar 19	*NA*
2017	643,215	164.29	0.03	*NA*	*NA*	*NA*
2018	378,229	2,462.90	0.65	Apr 04	*NA*	*NA*
2019	841,656	5,777.70	0.69	Feb 27	*NA*	*NA*
2020	618,980	659.44	0.11	*NA*	*NA*	*NA*
2021	462,061	341.69	0.07	*NA*	*NA*	*NA*
2022	467,590	639.79	0.14	*NA*	*NA*	*NA*
2023	864,989	3,655.74	0.42	*NA*	*NA*	*NA*
2024	748,645	2,850.32	0.38	*NA*	*NA*	*NA*

1.1.4 Turbidity Measurement in the South Delta

Objective: Developing real-time equivalents for determining South Delta turbidity conditions.

1.1.4.1 Key Summary

1. There is good overlap between stations that are used to calculate south Delta average Secchi depth and stations that collect real-time turbidity.

2. Using averaged turbidity data (e.g., over 3-day, 5-day, and 7-day periods) generally removes some of the natural variability in turbidity. Using lagged turbidity data may increase correlation with Secchi depth.

3. Thresholds of 3-day and 5-day mean turbidity values at stations FAL (16.6, 16.7 FNU, respectively), ORQ (9.2, 9.7 FNU, respectively), OSJ (13.3, 13.6 FNU, respectively), SJJ (17.9, 18.0 FNU, respectively), and TWI (15.1, 14.8 NTU, respectively) predict South Delta mean Secchi depth < 100 cm at an 80% probability**.** Using combinations of stations does not increase the percentage of correct predictions to Secchi depth but may reduce the number of times the trigger would happen.

4. This analysis indicates that if the objective is to reduce pumping only when fish are most likely to be present, station combinations with TWI (SJJ-TWI, ORQ-TWI, OSJ-TWI, or FAL-TWI) would be best. If the objective is to reduce false negatives (potentially more

days when turbidity triggers, but more likely to reduce pumping when fish are present), the combination of ORQ-OSJ is best.

1.1.4.2 Background

Due to the decreased likelihood of capturing enough Delta smelt in monitoring surveys, management of this species has moved towards using environmental surrogates as indicators of when and where Delta smelt may be present. In the 2024 LTO ROD, the *Larval and Juvenile Delta Smelt Protection Action* is triggered when the average South Delta Secchi depth is less than 1 m (100 cm). Real-time operations currently rely on the California Department of Fish and Wildlife (CDFW) 20-mm survey that collects data on the relative abundance of larvae concurrently with Secchi depth measurements at 12 stations across the Bay-Delta estuary. These surveys are conducted every two weeks, while turbidity data are collected at multiple stations in the south Delta at 15-minute intervals. Using turbidity rather than Secchi depth as the action trigger may require less effort and may be more reliable and objective as turbidity sensors collect data at higher frequencies.

1.1.4.3 Questions

1. How does turbidity at these stations correlate to the mean South Delta Secchi depth?

2. What is the appropriate time lag, if any, between turbidity and mean South Delta Secchi depth that should be accounted for in this analysis?

3. Can real-time turbidity data from one or multiple sites replace Secchi depth data for the Larval and Juvenile Delta Smelt Protection Action?

4. How well do the selected sites and turbidity thresholds predict Secchi depth < 100 cm?

5. How well do the selected sites and turbidity thresholds correspond to fish catch data (both from surveys and salvage)?

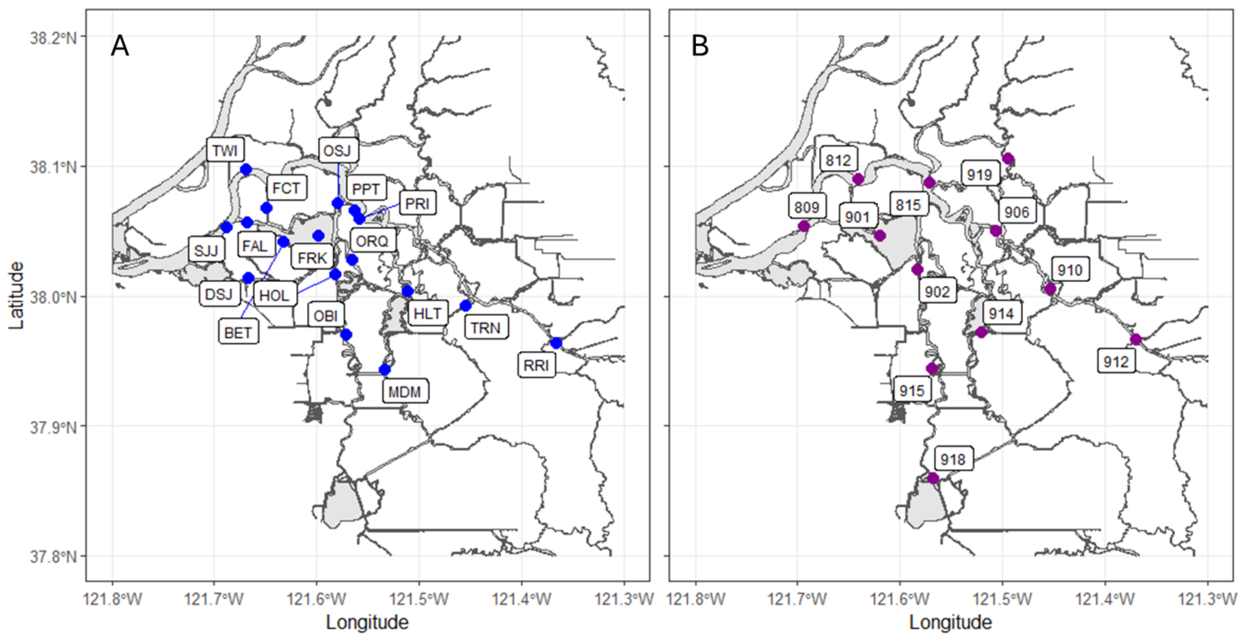
6. Which turbidity station or combination of turbidity stations would be the most accurate replacement for average South Delta Secchi depth (has the greatest probability of correctly predicting Secchi depth < 100 cm)?

1.1.4.4 Methods

The 20-mm survey stations that contribute to the mean Secchi depth for the South Delta are stations 809, 812, 901, 815, 919, 902, 906, 915, 914, 910, 918, and 912 (Figure 5B). Secchi depth was taken from 20-mm survey data and averaged across the stations listed to create a daily mean South Delta Secchi depth value. Data were pulled from CDEC stations that were nearby and had continuous turbidity measurements: San Joaquin River at Twitchell Island (TWI), Prisoner's Point (PPT), Franks Tract at mid-tract (FRK), Rough and Ready Island (RRI), Holland Cut near Bethel Island (HOL), San Joaquin River at Jersey Point (SJJ), False River near Oakley (FAL), Old River at Franks Tract near terminus (OSJ), San Joaquin River near Prisoner's Point near terminus (PRI), Bethel Island (BET), Dutch Slough at Jersey Island (DSJ), Old River at Quimby Island near Bethel Island (ORQ), Old River at Bacon Island (OBI), Middle River at

Middle River (MDM), Middle River near Holt (HLT), and Turner Cut near Holt (TRN) (Figure 5, Table 8).

Turbidity data are highly variable and needed QA/QC prior to this analysis, either a standard deviation removal criteria or set threshold for removing outlier points that may skew the modeling results. Even a threshold of 10 standard deviations of the mean at each site may remove data that seemed ecologically legitimate, and so data were filtered with a consistent threshold of 500 NTU/FNU (removed all points above that threshold). The following analyses and results are from data where these outliers were removed. Additional analyses and figures can be found in Appendix 1.



A) Environmental monitoring stations considered in this analysis to compare with the B) locations of the South Delta Secchi depth sample stations.

Figure 5. Maps showing stations involved in this analysis.

Table 8. Description of turbidity stations used in this analysis.

Station Name	Station Code	Turbidity Unit	Sampling start date	Closest matching 20-mm station
Bethel Island	BET	FNU	06/17/2014	901
Dutch Slough at Jersey Island	DSJ	FNU	12/09/2009	NA
False River near Oakley	FAL	FNU	01/03/2008	901
Franks Tract Mid Tract	FRK	NTU	06/19/2015	901
Middle River near Holt	HLT	FNU	12/01/2009	914
Holland Cut near Bethel Island	HOL	FNU	10/01/2007	902
Middle River at Middle River	MDM	FNU	12/01/2009	915

Station Name	Station Code	Turbidity Unit	Sampling start date	Closest matching 20-mm station
Mokelumne River at San Joaquin River	MOK	FNU	06/17/2008	815
Old River at Bacon Island	OBI	FNU	01/09/2008	915
Old River at Quimby Island near Bethel Island	ORQ	FNU	12/01/2009	902
Old River at Franks Tract near Terminus	OSJ	FNU	12/01/2009	815
Prisoners Point	PPT	NTU	03/02/2006	906
San Joaquin River at Prisoners Point near Terminus	PRI	FNU	12/03/2009	906
Rough and Ready Island	RRI	NTU	11/13/2001	912
San Joaquin River at Jersey Point	SJJ	FNU	12/01/2009	809
Turner Cut near Holt	TRN	FNU	12/02/2009	910
San Joaquin River at Twitchell Island	TWI	NTU	06/5/2015	812

1.1.4.4.1 Linear Regressions

Linear regressions of turbidity at each station and average Secchi depth were used to examine linear correlations between Secchi depth and various turbidity stations. To help understand the best averaging window for turbidity data, daily mean, 3-day mean, 5-day mean, and 7-day mean data were used. Data were paired by the date they were collected. Running means are leading (i.e., 3-day mean for 03/25 would be the mean of daily turbidity on 03/23, 03/24, and 03/25). All paired data were examined, but only instances where Secchi depth was <= 110 cm, and the corresponding turbidity data were included in the linear regressions (the trend dissociated at higher Secchi depth values). R2 values and p-values were used to evaluate the fits between stations and using different averaging windows for turbidity data.

1.1.4.4.2 Cross-Correlations

To determine the appropriate lag time for turbidity for each station as well as compare across 3-day, 5-day, and 7-day turbidity averaging windows, a cross-correlation analysis was used. Only leading lag times (i.e. when turbidity preceded Secchi) were used to determine the negative or zero lag time with the highest correlation for station and turbidity averaging period. For this analysis, more negative correlations indicated best fits (e.g., approaching –1.0) because of the expected negative relationship between turbidity and Secchi depth (high turbidity corresponds with low Secchi depth).

For both the linear regression and cross correlation analyses, there was little difference between using 5-day mean turbidity data and 7-day mean turbidity data (R^2, p-values, correlation values) (see results). To simplify the number of variables in the analysis, all remaining analyses examined 3-day and 5-day averaging periods only.

1.1.4.4.3 Logistic Regressions

Linear regressions are best for predicting correlation between raw values of turbidity and Secchi depth. Because Secchi depth is used as a binary value in current management, for example when Secchi depth is less than 100 cm vs. greater than 100 cm depth, logistic regressions were used to calculate turbidity thresholds at each site that would predict Secchi depth < 100 cm. To combine the cross-correlation analysis results (which determined the appropriate lag time for each station) and determine the best thresholds for turbidity predictors of Secchi depth, the appropriate lagged turbidity data for both 3-day and 5-day averages were used in the logistic regressions.

For the logistic regressions, probability levels of 0.8, 0.9, and 0.99 (80%, 90%, and 99% probability of predicting Secchi depth < 100 cm) were used to calculate turbidity thresholds at each station and for 3-day and 5-day averaging periods.

The modeled output gave a standard error for the turbidity threshold, a pseudo-R^2 value, and an AUC value. Area Under Curve (AUC) is a statistical measure used to evaluate the effectiveness of binary classification models. The values range from 0-1 and higher values indicate a better performance. To compare model fits between stations and understand any differences between using 3-day and 5-day mean turbidity data, the goal was to minimize standard error, maximize the pseudo-R^2 value, and maximize the AUC value.

1.1.4.4.4 Checking results against Secchi depth

For each station, days when the 80%, 90%, and 99% probability turbidity thresholds were exceeded were compared to days when the South Delta Secchi depth was < 100 cm. Days that matched (turbidity trigger exceeded and Secchi depth < 100 cm) were marked "TRUE" and days that didn't match were marked "FALSE". This information was used to calculate the number of times the 3- and 5-day mean turbidity thresholds correctly predicted Secchi < 100 cm for each station, and the number of times it did not. The calculated probability of correctly predicting Secchi depth < 100 cm was combined with the AUC) values from logistic regressions to understand which stations had the highest model fits and highest probability of correctly predicting Secchi < 100 cm.

A generalized linear model using a binomial distribution was run to compare the proportion of correctly predicted Secchi < 100 cm across stations, the threshold probability (80, 90, 99%), and turbidity averaging period (3-day and 5-day) [equation: (Number true, number false) ~ Station + threshold level * averaging period]. Model results were examined to determine differences between threshold levels and averaging period.

1.1.4.4.5 Station Comparison

Based on results (e.g., statistical differences between threshold probability levels, see results), a generalized linear model was modified and rerun using only one threshold probability level (80%) to understand differences between stations [equation: (Number true, number false) ~ Station + averaging period]. To examine for statistical differences across stations, Estimated Marginal Means (EMM) from the binomial model results were compared to determine the stations that had higher probabilities of correctly predicting Secchi depth < 100 cm.

1.1.4.4.6 Station Combination

Each of the five best performing stations (stations with the highest probability of correctly predicting Secchi depth < 100 cm) was paired with remaining top five stations for a total of 10 station pairs (combinations); incidences of triggering turbidity for each combination of stations was then compared with instances in which Secchi depth triggered, as described above ("*Checking Results Against Secchi Depth Data*"). In addition, the number of times each combination of stations would have triggered in past years (from 2010-2023) was calculated to compare the frequency of triggers across station combinations. In addition, calculated annual trigger totals were compared with actual annual totals listed in previous Old and Middle River Seasonal reports, which were based off operations of the Central Valley Water Project during the Old and Middle River Management periods.

1.1.4.4.7 Matching to Fish Capture Data

Fish data were obtained from the salvage database, Smelt Larva Survey (SLS), and 20-mm survey. Fish salvage data were obtained from a SacPAS query on 7/10/2025 (Juvenile Salvage & Loss Detail: SacPAS Central Valley Prediction and Assessment of Salmon and other fishes) and other catch data were obtained from the "deltafish" R package. Turbidity stations were each matched with the closest SLS/20-mm survey station (see Table 8) to compare catch at each survey station with turbidity from monitoring stations. Similar to the Secchi depth and turbidity comparison, the times when fish were caught (any catch > 0) at each combination of survey stations (corresponding from the turbidity station combinations) were compared to salvage, to determine whether there was overlap. Finally, a timeline of catch data from surveys and salvage (to indicate fish presence in the south Delta) was compared to dates of turbidity triggers from each station combination to determine which stations best correspond to fish detections.

1.1.4.5 Results

1.1.4.5.1 Linear Regressions

All stations had statistically significant fits with mean Secchi depth, but R^2 values were generally low. The stations that had best fits between daily turbidity values and mean Secchi depth were OSJ (R^2= 0.48, p <0.001) and TWI (R^2=0.46, p <0.001) (Table 9). The stations with best fits were generally highest at TWI, OSJ, FAL, FRK, and ORQ when multi-day averages (3-day, 5-day, 7-day) of turbidity were used. In general, R^2 values were higher at these stations when a 3-day lagged average was used (average starting two days prior to the date of the average) (Table 9).

Table 9. Linear regression results for daily, 3-day average, 5-day, and 7-day average turbidity with South Delta Secchi depth averages < 110 cm, showing R2 and p-values for each station.

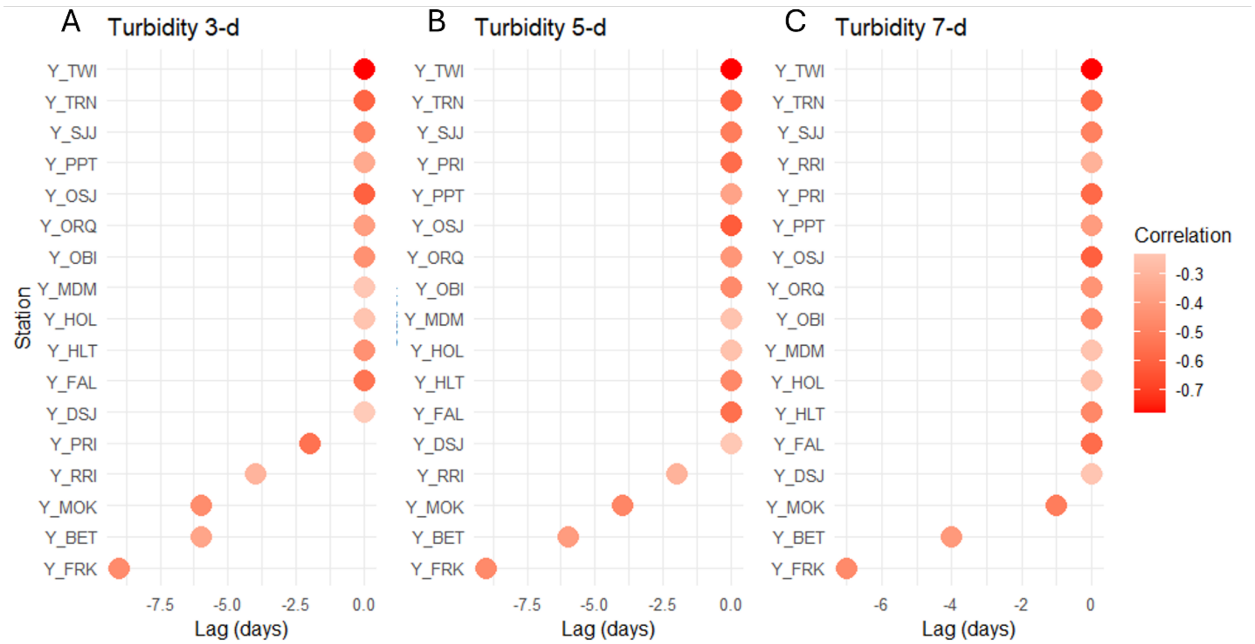
Station	Daily R2	Daily p-value	3-d mean R2	3-d mean p-value	5-d mean R2	5-d mean p-value	7-d mean R2	7-d mean p-value
BET	0.25	1.56E-08	0.25	1.53E-08	0.24	3.70E-08	0.17	5.44E-06
DSJ	0.03	3.56E-02	0.03	2.15E-02	0.04	1.30E-02	0.04	9.43E-03

Station	Daily R2	Daily p-value	3-d mean R2	3-d mean p-value	5-d mean R2	5-d mean p-value	7-d mean R2	7-d mean p-value
FAL	0.39	7.20E-24	0.41	3.50E-25	0.40	9.61E-25	0.40	1.58E-24
FRK	0.31	3.08E-09	0.42	8.53E-13	0.46	2.28E-14	0.42	7.62E-13
HLT	0.11	8.12E-06	0.30	7.90E-15	0.39	3.38E-20	0.39	7.30E-20
HOL	0.16	3.39E-09	0.20	9.43E-12	0.20	1.11E-11	0.16	3.59E-09
MDM	0.07	5.60E-04	0.08	1.43E-04	0.12	3.37E-06	0.14	4.05E-07
MOK	0.27	1.08E-14	0.32	1.81E-17	0.35	5.80E-19	0.34	1.51E-18
OBI	0.23	2.31E-13	0.21	5.17E-12	0.19	7.05E-11	0.18	2.80E-10
ORQ	0.41	1.15E-21	0.40	7.05E-21	0.35	4.05E-18	0.32	9.25E-16
OSJ	0.48	2.27E-25	0.49	4.08E-26	0.47	2.07E-24	0.44	1.36E-22
PPT	0.10	1.23E-06	0.07	5.19E-05	0.08	1.63E-05	0.14	8.07E-09
PRI	0.18	1.86E-07	0.36	3.55E-15	0.40	1.15E-16	0.37	2.64E-15
RRI	0.13	3.18E-10	0.14	4.31E-11	0.15	4.64E-12	0.16	2.23E-12
SJJ	0.13	1.24E-06	0.15	3.35E-07	0.16	6.42E-08	0.18	1.27E-08
TRN	0.24	7.93E-12	0.28	5.57E-14	0.34	2.58E-17	0.34	3.10E-17
TWI	0.46	1.09E-13	0.51	1.31E-15	0.49	4.42E-15	0.46	1.20E-13

Color shading for p-values indicate no significance (white), $p < 0.05$ (lightest green), $p < 0.01$ (medium green), or <0.001 (dark green). Bold values indicate the 3 stations with the highest R^2 values for each of the data types (daily, 3-day, 5-day, and 7-day averages).

1.1.4.5.2 Cross Correlations

Cross correlations were helpful for determining the best time lag for turbidity measurements to predict Secchi depth < 100 cm (i.e., number of days before Secchi depth measurement). In addition, lags were examined for different turbidity averaging periods (i.e. either 3-, 5-, or 7-day means). Since the primary interest is in determining any negative lag time (turbidity leads Secchi), only zero (same day) or negative lag times were considered (Figure 6). For 3-day, 5-day, and 7-day mean turbidity, TWI was a strong predictor of Secchi depth with no lag (0 d lag, ~ 0.80 correlation for 3-day and 5-day, 0.78 for 7-day). For 3-day, 5-day, and 7-day turbidity, OSJ and TRN were moderate predictors of Secchi depth with zero lead time (0 d lag, 0.57- 0.62 correlations). PRI was also a moderate predictor of Secchi depth with 2-day lag time using 3-day mean turbidity (0.57), and 0-day lag time using 5-day and 7-day turbidity (0.58).



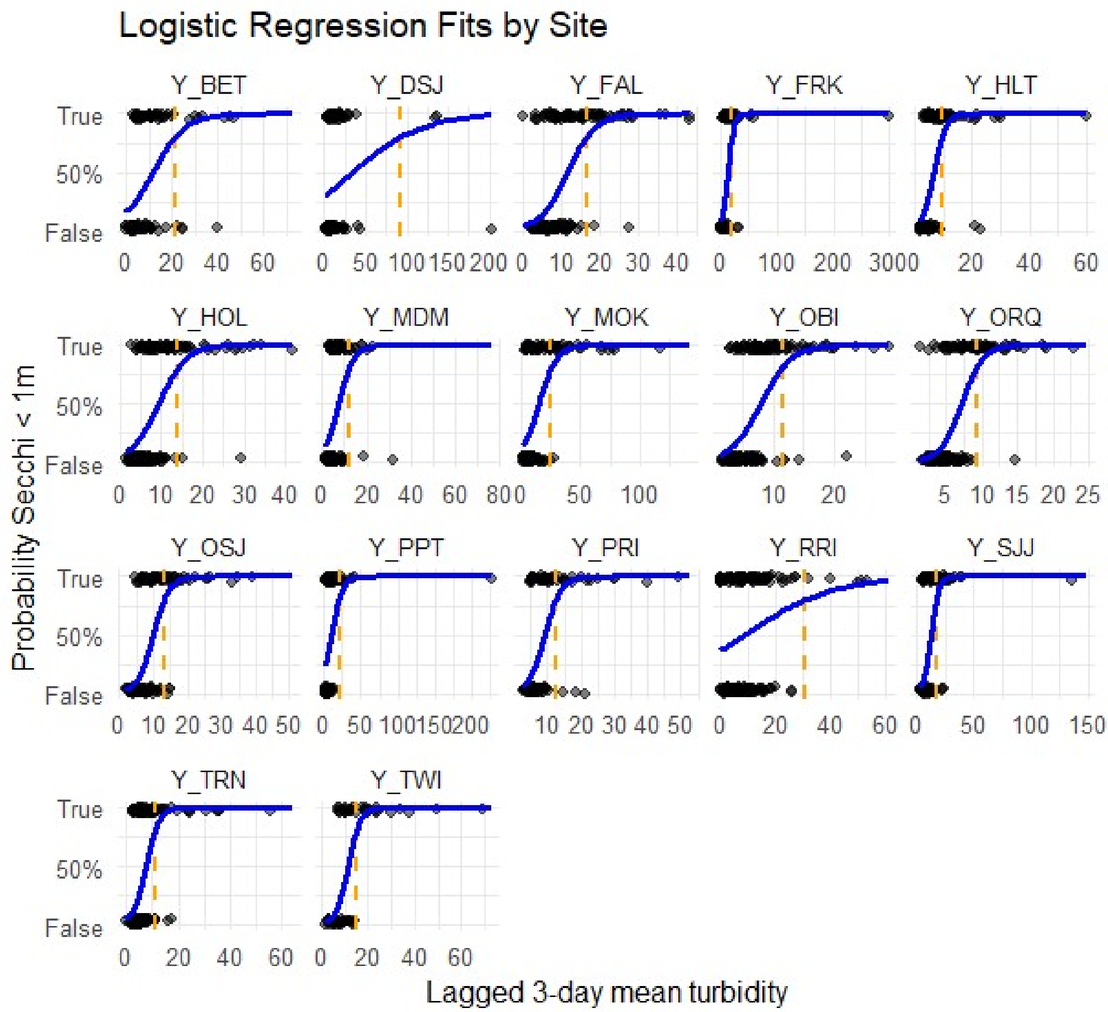
Lag time is shown on the x axis, with negative lag indicating days before Secchi depth measurement. Color indicates correlation, with darker color indicating higher correlation.

Figure 6. Visual of the best zero or negative predictive lag per station of (A) 3-day, (B) 5-day, and (C) 7-day running mean turbidity.

For linear regressions, there was little difference between using 5-day mean turbidity data and 7-day mean turbidity data (R^2 and p-values) (Table 9). Similarly, correlation values changed very little for all stations between 5-day mean data and 7-day mean data in the cross-correlation analysis (Figure 6). As a result, all remaining analyses examine 3-day and 5-day means only.

1.1.4.5.3 Logistic Regressions

Using logistic regressions (Figure 7), thresholds for lagged 3-day mean (Table 10) and lagged 5-day mean (Table 11) turbidity were calculated that would give an 80%, 90%, and 99% probability of a south Delta average Secchi depth < 100cm (Figure 8). Standard error (SE), Pseudo-R^2, and Area Under Curve (AUC) were calculated to understand the fit of the logistic regression. For pseudo-R2 calculations, close to 1 indicates a better fit. For AUC, the value should be closest to 1 for best fits.



Points show values of turbidity and the probability the South Delta Secchi depth will be < 100 cm, while blue lines show a logistic regression. Orange dashed vertical lines show calculated turbidity thresholds for each station. Station abbreviations as in Table 8, statistics for regressions in Table 9.

Figure 7. Three-day average turbidity values (FNU/NTU) as a function of the probability the South Delta average Secchi depth is < 100 cm.

Table 10. Three-day mean turbidity thresholds that have an 80% probability of predicting south Delta mean Secchi depth <100 cm.

Station	Best zero or negative lag (days)	Lag correlation	3-day mean turbidity threshold for Secchi <100 cm	SE	Pseudo-R^2	AUC
BET	-6	-0.374	21.529	2.899	0.142	0.799
DSJ	0	-0.218	91.232	30.845	0.022	0.735
FAL	0	-0.560	16.573	0.889	0.306	0.846
FRK	-9	-0.474	19.656	1.931	0.265	0.851

Station	Best zero or negative lag (days)	Lag correlation	3-day mean turbidity threshold for Secchi <100 cm	SE	Pseudo-R^2	AUC
HLT	0	-0.450	9.553	0.608	0.265	0.894
HOL	0	-0.246	14.036	0.843	0.234	0.823
MDM	0	-0.233	12.193	1.110	0.149	0.815
MOK	-6	-0.468	25.677	2.238	0.236	0.819
OBI	0	-0.451	11.496	0.575	0.286	0.854
ORQ	0	-0.401	9.241	0.396	0.394	0.892
OSJ	0	-0.623	13.259	0.623	0.367	0.879
PPT	0	-0.354	20.910	2.407	0.085	0.842
PRI	-2	-0.565	12.586	0.765	0.304	0.855
RRI	-4	-0.311	30.901	5.618	0.033	0.595
SJJ	0	-0.510	17.892	0.959	0.319	0.843
TRN	0	-0.613	11.084	0.743	0.232	0.810
TWI	0	-0.802	15.094	0.961	0.455	0.921

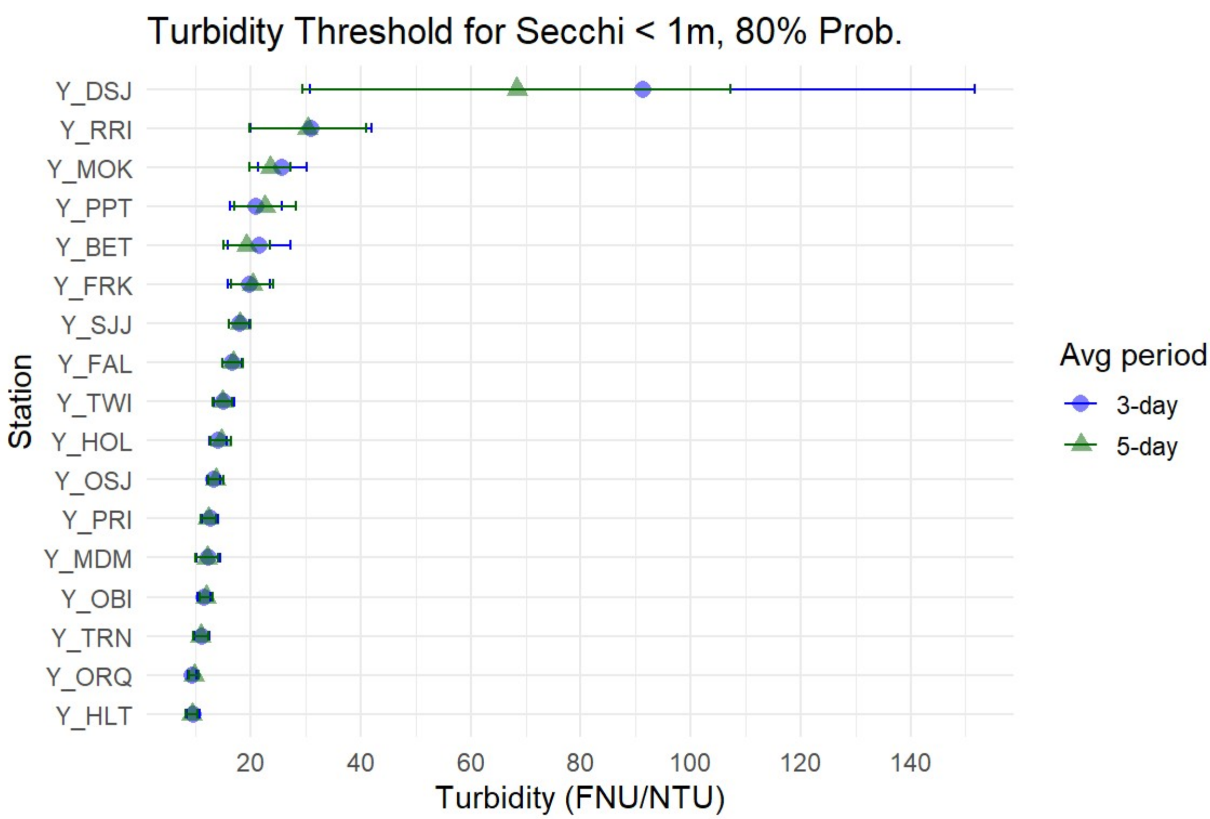
Statistical analysis of lag and logistic regression for 3-day mean turbidity data are included. SE= Standard Error; AUC= Area Under Curve.

Table 11. Five-day mean turbidity thresholds that have an 80% probability of predicting south Delta mean Secchi depth <100 cm.

Station	Best negative lag (days)	Lag correlation	5-day mean turbidity threshold for Secchi <100 cm	SE	Pseudo- R2	AUC
BET	-6	-0.402	19.212	2.130	0.177	0.805
DSJ	0	-0.229	68.335	19.861	0.027	0.737
FAL	0	-0.566	16.702	0.912	0.304	0.844
FRK	-9	-0.473	20.279	1.959	0.248	0.849
HLT	0	-0.478	9.231	0.550	0.284	0.889
HOL	0	-0.253	14.547	0.939	0.210	0.809
MDM	0	-0.246	11.992	1.035	0.162	0.813
MOK	-4	-0.485	23.491	1.947	0.253	0.818
OBI	0	-0.470	11.866	0.642	0.263	0.850
ORQ	0	-0.426	9.701	0.451	0.351	0.882
OSJ	0	-0.629	13.615	0.695	0.343	0.870

Station	Best negative lag (days)	Lag correlation	5-day mean turbidity threshold for Secchi <100 cm	SE	Pseudo- R2	AUC
PPT	0	-0.374	22.559	2.875	0.072	0.836
PRI	0	-0.578	12.236	0.718	0.314	0.865
RRI	-2	-0.311	30.340	5.423	0.033	0.595
SJJ	0	-0.518	17.999	0.972	0.317	0.839
TRN	0	-0.604	10.836	0.702	0.236	0.805
TWI	0	-0.791	14.847	0.921	0.466	0.917

Statistical analysis of lag and logistic regression for 3-day mean turbidity data are included. SE= Standard Error; AUC= Area Under Curve.



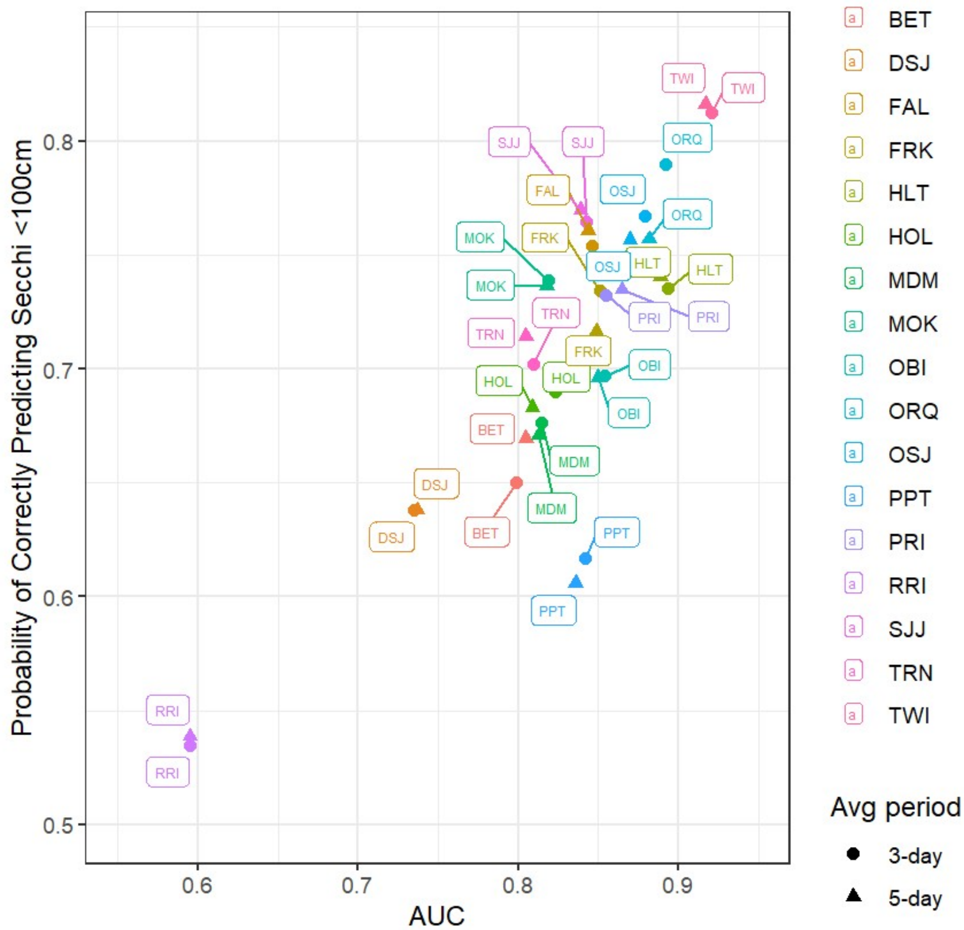
Results and standard deviation are shown for both 3-day mean lagged data (blue circles) and 5-day mean lagged data (green triangles). Turbidity data were lagged according to the highest negative correlation for a negative lead time (see Tables 10 and 11).

Figure 8. Turbidity thresholds for predicting south Delta mean Secchi depth < 100cm calculated using logistic regressions with an 80% probability.

For the lagged-logistic regressions, the stations that performed best (higher AUC and pseudo-R^2 values) for 3-day mean turbidity and 5-day mean turbidity at 80%, 90%, and 99% probability levels were OSJ (0-day lag), PRI (2-day lag for 3-day mean, 0-day lag for 5-day mean), TRN (0-day lag), and TWI (0-day lag).

1.1.4.5.4 Checking results against Secchi depth

For this analysis, it was important to determine turbidity thresholds from the logistic regressions that could accurately predict when Secchi depth would be <100 cm. The predicted results were compared against the existing Secchi depth data to understand when the 80%, 90%, and 99% turbidity thresholds for each station correctly predicted Secchi <100 cm. In addition, understanding which logistic regressions had good fits was important, so results for the proportion of correctly predicting Secchi depth < 100 cm was compared with the AUC of the logistic regression for each station, for 3-day and 5-day means, and for both 80%, 90%, and 99% probability thresholds (Figure 9, showing results for 80% probability thresholds).



Using these thresholds for lagged 3-day mean and 5-day mean turbidity values (circles and triangles, respectively) for each turbidity station (colors/labels) the probability of correctly predicting Secchi depth < 100 cm is shown compared to the Area Under Curve (AUC), which is an indicator for the fit of the logistic regression used to determine the turbidity threshold.

Figure 9. Performance of turbidity thresholds calculated from logistic regressions with an 80% probability to predict Secchi Depth < 100cm.

In general, the 80% probability thresholds of turbidity had higher probabilities of correctly predicting Secchi depth <100 cm (Figure 10). Similar to results shown in Tables 10 and 11 the stations that showed the highest probability of correctly predicting Secchi depth < 100 cm and highest AUC (using 80% probability thresholds) were TWI (0.81, 0.82), ORQ (0.79, 0.76), and OSJ (0.77, 0.76) for 3-day and 5-day means, respectively (Figure 10).

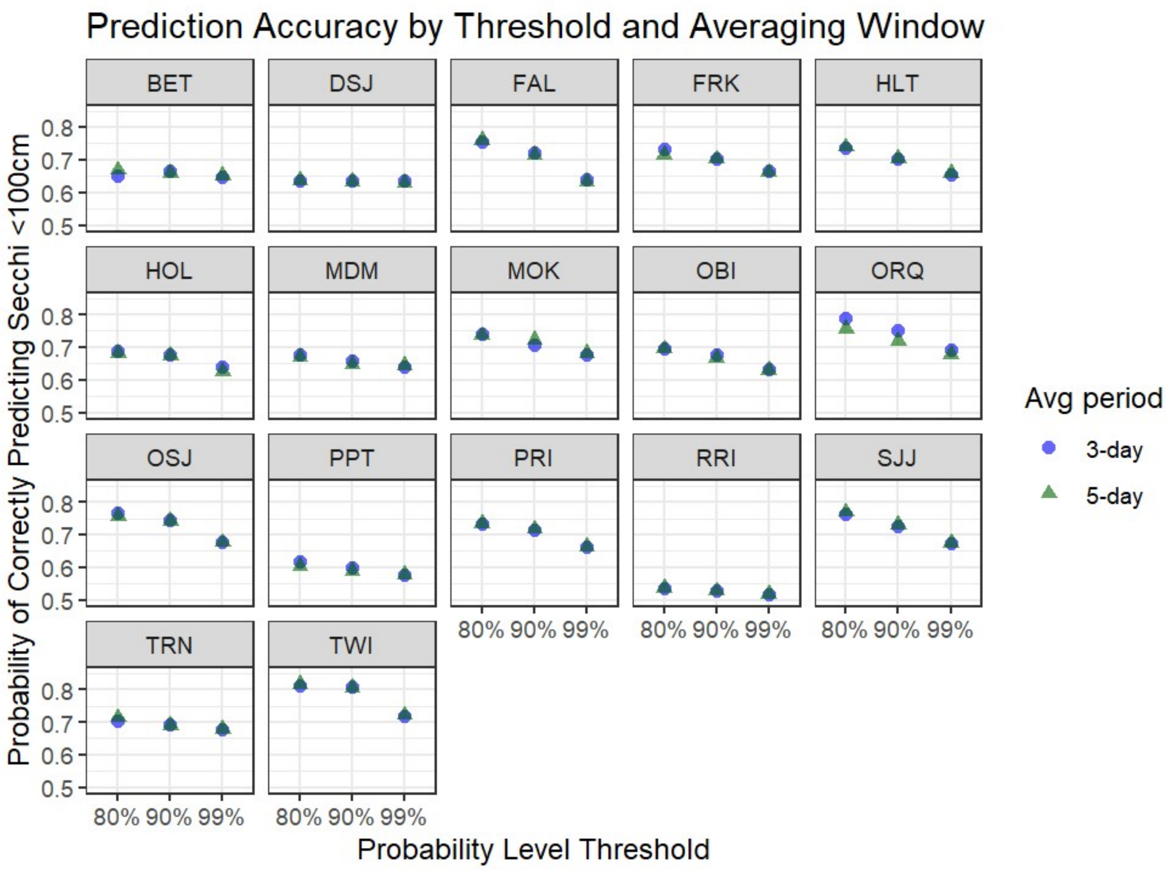


Figure 10. Prediction accuracy of turbidity thresholds at different stations and using 80%, 90%, and 99% probability thresholds and 3-day and 5-day mean turbidity values (colors, shapes).

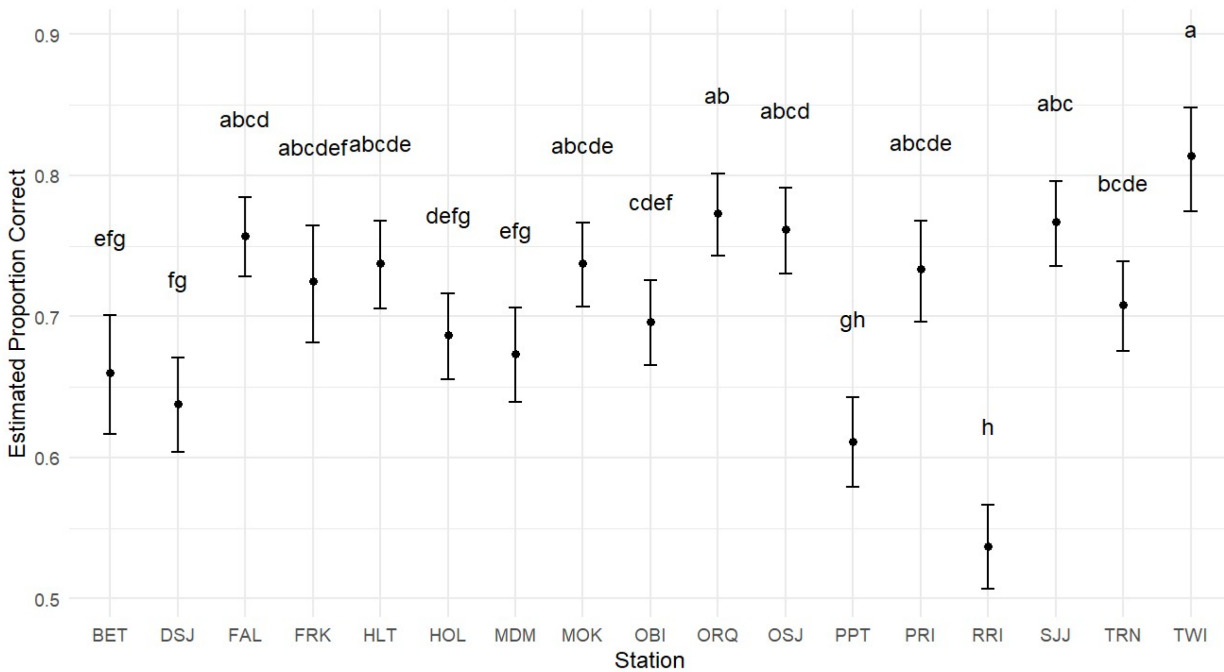
A generalized linear model was used to understand differences in the probability of correctly predicting Secchi depth < 100 cm between stations, and examine effects between the 80%, 90%, and 99% turbidity thresholds and in using 3-day or 5-day mean turbidity data. Using 90% turbidity thresholds instead of 80% thresholds significantly decreased the probability of correctly predicting Secchi < 100 cm ($p = 0.01$). Using 99% turbidity thresholds instead of 80% thresholds significantly decreased the probability of correctly predicting Secchi < 100 cm ($p<0.001$). There was little to no difference between using 3-day and 5-day mean turbidity values ($p=0.81$). Interactions between probability threshold level and turbidity averaging period were negligible and not significant.

These results suggest the 80% turbidity thresholds produce higher likelihood of predicting when Secchi depth would be under 100 cm. Either 3-day or 5-day mean turbidity data can be used.

1.1.4.5.5 Station Comparison

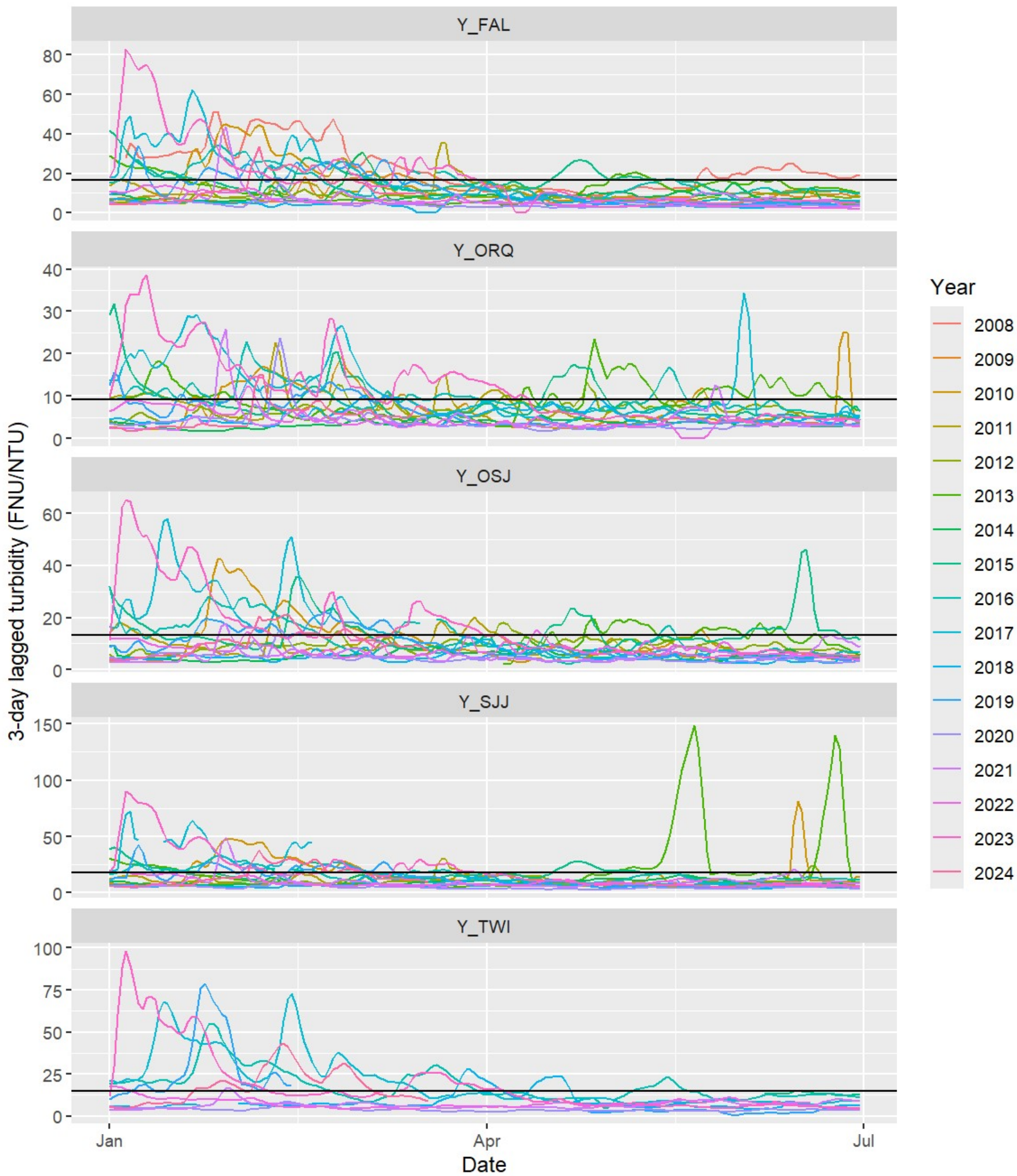
Using a linear mixed model on the 80% turbidity threshold predictability results only (still including both 3- and 5-day averaging period data), differences in the Estimated Marginal Means (EMM) between turbidity stations were compared to understand whether certain stations were better at predicting South Delta mean Secchi depth < 100 cm (Figure 11). The stations that had the highest EMM representing the highest probabilities of correctly predicting Secchi depth < 100 cm were TWI (0.81, $p < 0.001$), ORQ (0.77, $p < 0.001$), SJJ (0.77, $p < 0.001$), OSJ (0.76, $p < 0.001$), and FAL (0.76, $p < 0.001$). Based on EMM (Figure 11), PPT and RRI performed more poorly than the other stations.

Using the five stations that gave the best prediction levels (TWI, SJJ, OSJ, ORQ, and FAL), the number of times each individual station was above the threshold in previous years was calculated (data not shown). All stations had relatively similar totals using both 3-day mean and 5-day mean data (463-585 days total, 461-583 days total, respectively) except TWI (337 for 3-day, 348 for 5-day), which only had data since 2015, whereas other stations started collecting data since 2008 or 2009 (Figure 12). The number of triggers was about equal between 3-day mean thresholds and 5-day mean thresholds.



Letters indicate statistical differences between stations identified using a generalized linear model.

Figure 11. Estimated marginal means for the proportion of correctly predicting Secchi depth < 100 cm using the 80% probability turbidity thresholds at each station, with error bars showing standard deviation.



Colored lines represent different years, and horizontal lines represent the 3-day mean turbidity threshold for each station. Scales for turbidity are different between stations to better display data.

Figure 12. Historic 3-day lagged turbidity for five stations.

1.1.4.5.6 Station Combinations

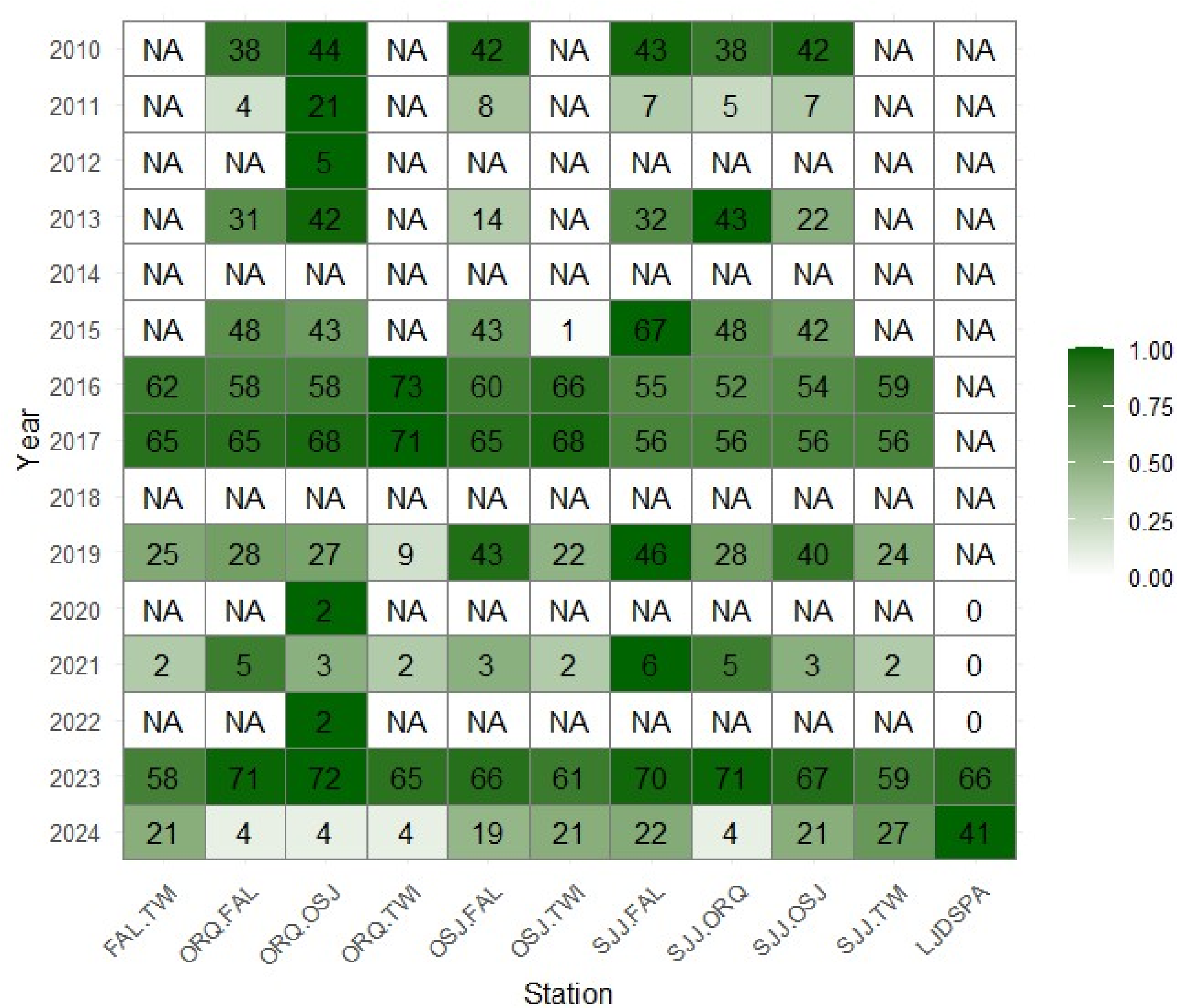
Due to the variability of turbidity at each station, using turbidity as a threshold for management would likely benefit from combining stations, for example, only triggering an action if turbidity thresholds were exceeded at Station X AND Station Y. Combinations of the five best performing stations (FAL, ORQ, OSJ, SJJ, and TWI; highest probability of correctly predicting Secchi depth < 100 cm) were analyzed to 1) compare to when South Delta mean Secchi depth < 100 cm, and 2) understand how often each combination of stations would have triggered in the past.

When compared to South Delta mean Secchi depth, all stations performed similarly, each correctly identifying when south Delta mean Secchi < 100 cm 75-80% of the time (Table 12). When compared to previous triggers of the Larval and Juvenile Delta Smelt Protection Action in previous years, the station combination triggers (Figure 13 were about equal with actual triggers in 2023 and were fewer than actual triggers in 2024 (Table 13). For 2024, Secchi depth data only included until March 2024, so this likely accounts for the much lower number. A comparison of when each station combination would have triggered can be found in Figure 14.

Table 12. Proportion of times the turbidity trigger at each station combination correctly predicted when South Delta Secchi depth < 100 cm.

Station Combination	Proportion Correctly Predicted Secchi < 100 cm	Number of paired samples
SJJ.ORQ	0.76	340
SJJ.OSJ	0.76	323
SJJ.FAL	0.76	340
SJJ.TWI	0.78	170
ORQ.OSJ	0.76	334
ORQ.FAL	0.76	351
ORQ.TWI	0.80	181
OSJ.FAL	0.76	334
OSJ.TWI	0.80	181
FAL.TWI	0.80	181

Data are restricted to January-June (inclusive). The total number of paired turbidity and Secchi depth measurements were used to calculate the percent of time the trigger correctly predicted Secchi depth < 100 cm.



Year	FAL.TWI	ORQ.FAL	ORQ.OSJ	ORQ.TWI	OSJ.FAL	OSJ.TWI	SJJ.FAL	SJJ.ORQ	SJJ.OSJ	SJJ.TWI	LJDSPA
2010	NA	38	44	NA	42	NA	43	38	42	NA	NA
2011	NA	4	21	NA	8	NA	7	5	7	NA	NA
2012	NA	NA	5	NA	NA	NA	NA	NA	NA	NA	NA
2013	NA	31	42	NA	14	NA	32	43	22	NA	NA
2014	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2015	NA	48	43	NA	43	1	67	48	42	NA	NA
2016	62	58	58	73	60	66	55	52	54	59	NA
2017	65	65	68	71	65	68	56	56	56	56	NA
2018	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2019	25	28	27	9	43	22	46	28	40	24	NA
2020	NA	NA	2	NA	NA	NA	NA	NA	NA	NA	0
2021	2	5	3	2	3	2	6	5	3	2	0
2022	NA	NA	2	NA	NA	NA	NA	NA	NA	NA	0
2023	58	71	72	65	66	61	70	71	67	59	66
2024	21	4	4	4	19	21	22	4	21	27	41

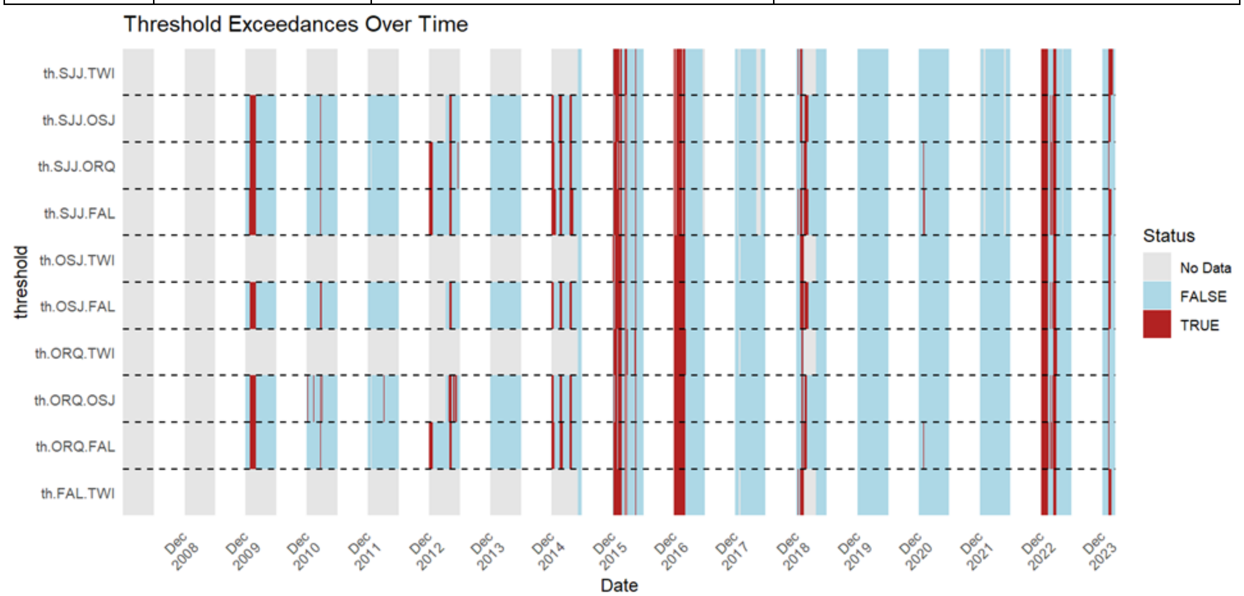
Each station has a unique turbidity threshold, with 3-day turbidity threshold used for all stations. Count of 2024 days only covers through 3/18/2024. Color scale shows normalized value within each year for visual comparison (darker colors indicate higher values). No TWI data between 2010-2014. For comparison, dates when the Larval and Juvenile Protection Action (LJDSPA; or equivalent in previous PAs) was triggered are included; data were obtained from the 2020-2024 OMR seasonal reports.

Figure 13. Numbers of spring days each year (January-June) when combinations of stations would have exceeded turbidity triggers.

Table 13. Larval and juvenile Delta smelt triggers from previous OMR management seasons.

Water Year	Date	Secchi depth trigger	Total days
2024	2/5/2024-3/17/2024	Secchi depth from most recent survey is <= 100 cm	41 days: Secchi depth
2023	3/18/2023-5/9/2023	Secchi depth from most recent survey is <= 100 cm	52 days: Secchi depth

Water Year	Date	Secchi depth trigger	Total days
	6/6/2023-6/20/2023		14 days: Secchi depth
2022	NA	Secchi depth from most recent survey is <= 100 cm	0 days: NA
2021	NA	Secchi depth from most recent survey is <= 100 cm	0 days: NA
2020	NA	If QWEST is negative AND if DS were detected within entrainment zone AND if Secchi depth in South Delta < 100 cm	0 days: All conditions met separately, not all together (Secchi depth was exceeded at times)

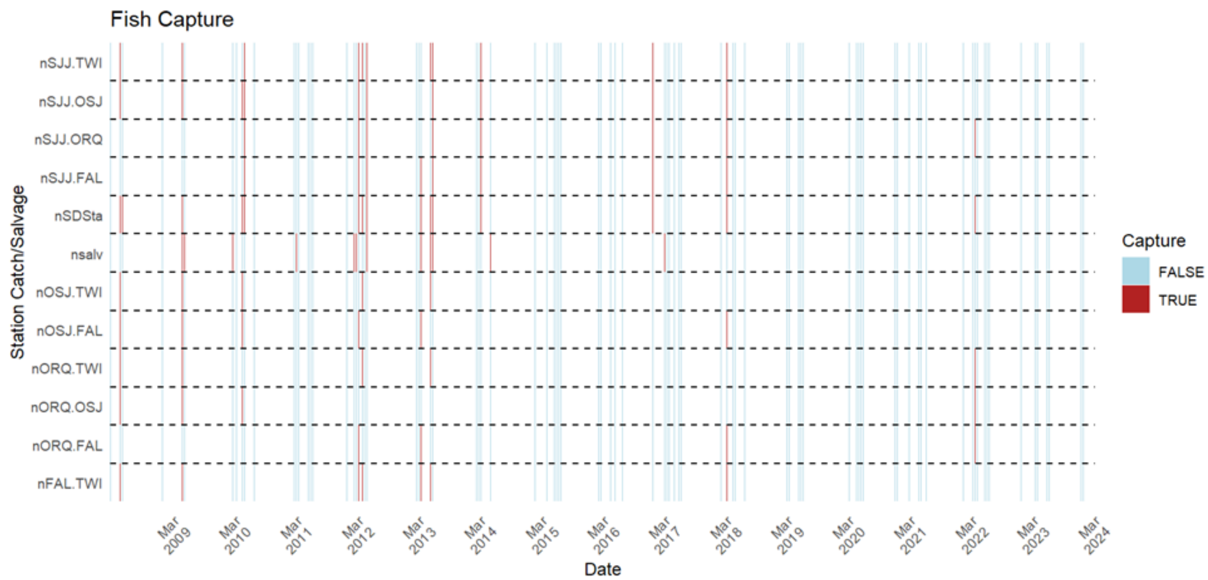


Grey bars indicate times with no data, blue bars indicate periods where the threshold was not reached, and red bars indicate periods when the threshold was met or exceeded. Note that TWI does not have data prior to 2015.

Figure 14. Threshold exceedances of turbidity over time for combinations of stations during spring between 2008 and early 2024, using 3-day mean turbidity data for all stations.

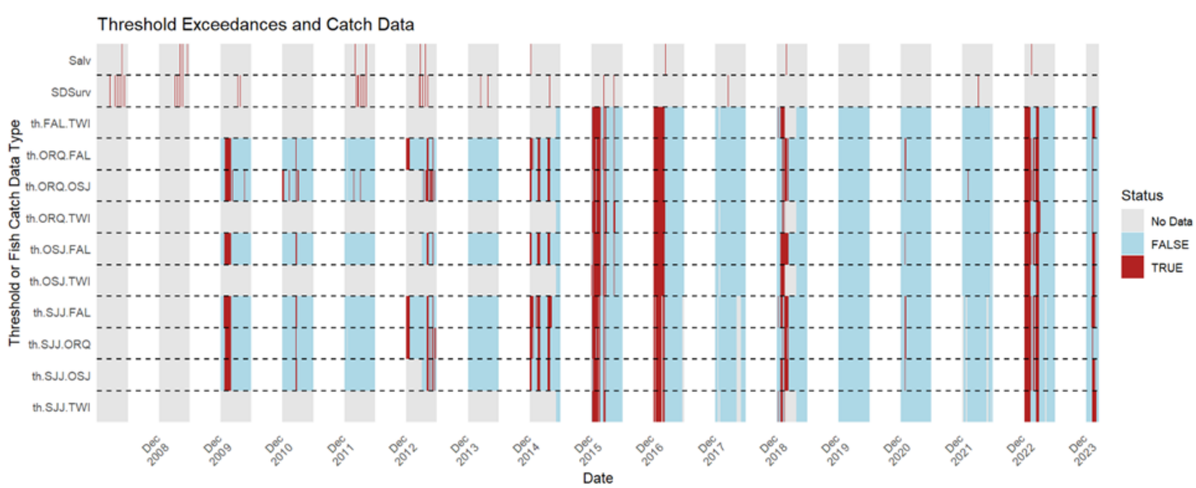
1.1.4.5.7 Matching to Fish Capture Data

Combinations of stations were then matched to fish capture data (Table 13), both from surveys (20-mm and SLS) and from salvage data at both facilities (Figure 15). This analysis was modeled after a similar one done for adult Delta smelt in the State Water Project Effects Analysis for Longfin and Delta Smelt (their Figure 34). As in other analyses, low fish capture data in years when real-time turbidity data are available from stations makes comparisons between turbidity at particular stations and fish presence difficult to compare. However, when station combination thresholds were compared to Delta smelt catch from SLS and 20-mm surveys at the South Delta stations (see Table 13), there is good overlap where records of fish collected at salvage or in south Delta surveys occurred during or after turbidity triggers at station combinations were reached (Figure 16).



South Delta 20-mm and SLS stations include: 809, 812, 815, 901, 902, 906, 910, 912, 914, 915, 918, and 919 (for map, see Figure 8B). For matched stations (turbidity to fish survey data), see Table 9.

Figure 15. Timeline of fish catch at combinations of stations, for all south Delta stations (nSDSta), and salvage at both facilities (nsalv).



Gray areas indicate times with no data, only spring data are included here (January through June, inclusive). Fish capture data includes both salvaged fish (Salv) and fish collected from the South Delta Stations of the SLS and 20-mm surveys (SDSurv); see Figure 1 for station maps. For fish capture data, "TRUE" indicates catch of 1 or greater fish.

Figure 16. Timeline of turbidity threshold exceedances and fish capture data. Three-day turbidity thresholds for different combinations of stations ("TRUE" indicates turbidity thresholds at both stations was exceeded).

All station combinations performed similarly. There were two occasions where fish were detected in salvage or the surveys and none of the stations would have triggered (spring 2014 and spring 2018). On a positive note, these fish were detected in the surveys and not in salvage, indicating low risk of false negatives (no trigger, but fish are detected). There were two occasions where station turbidity triggers were met, but no fish were detected. This could indicate a (false positive or fish could have been present but not detected. Station combinations that included TWI (FAL-TWI, ORQ-TWI, OSJ-TWI, and SJJ-TWI) did not trigger for one of those instances. There were two occasions where only one station combination (ORQ-OSJ) triggered based on turbidity and fish were detected in both surveys and salvage. No other combinations were triggered at this time.

1.1.4.6 Conclusions and Next Steps

This analysis indicates that **if the management goal is a water-conservative approach (reduce pumping only when fish are most likely to be present), station combinations with TWI would be best**. Out of the combinations with TWI, ORQ-TWI had the highest ability to correctly predict Secchi depth < 100 cm (Table 4).

If the management goal is to reduce false negatives (potentially more days when turbidity triggers, but more likely to reduce pumping when fish are present), the combination of ORQ-OSJ is best. Options for turbidity station combinations and their respective turbidity thresholds are summarized in Table 14.

Table 14. Turbidity thresholds calculated for 80% probability of predicting South Delta Secchi depth < 100 cm for different combinations of stations.

Station Combinations	Station 1 3-day mean turbidity threshold	Station 2 3-day mean turbidity threshold
SJJ-ORQ	17.892 FNU	9.241 FNU
SJJ-OSJ	17.892 FNU	13.259 FNU
SJJ-FAL	17.892 FNU	16.573 FNU
SJJ-TWI	**17.892 FNU**	**15.094 NTU**
ORQ-OSJ	**9.241 FNU**	**13.259 FNU**
ORQ-FAL	9.241 FNU	16.573 FNU
ORQ-TWI	**9.241 FNU**	**15.094 NTU**
OSJ-FAL	13.259 FNU	16.573 FNU
OSJ-TWI	**13.259 FNU**	**15.094 NTU**
FAL-TWI	**16.573 FNU**	**15.094 NTU**

For a combination trigger to be met, the threshold must have been met or exceeded for both stations. Station combinations in bold are recommended.

There are additional steps that can be taken to improve this analysis. The Secchi depth data and fish catch data (from surveys) only went until March 2024. It would be helpful to add in data from the remainder of the 2024 OMR season, as well as to add in 2025 data to extend this analysis. However, larval detections now rely on genetic analysis of individuals due to the challenge of visual identification of Delta smelt larvae vs. Wakasagi larvae. Data should be genetically verified before including in any analyses.

Conducting an additional analysis that directly relates turbidity data to fish catch at specific stations would be helpful (i.e., bypassing the comparison to Secchi depth data). Turbidity data for most of these stations only started in 2008 or 2009, so it may be helpful to create a conversion from turbidity data and Secchi depth data that are collected simultaneously by the surveys, so turbidity could be back-calculated from some of the survey data.

1.2 References

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