REDD MONITORING AND MAPPING
IN THE
ENGLEBRIGHT DAM REACH OF THE LOWER YUBA RIVER, CA

SUMMARY REPORT

Prepared for: The U. S. Army Corps of Engineers

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1. INTRODUCTION

The lower Yuba River in Yuba County, California extends about 38.6 km (24 mi) from Englebright Dam, the first impassible fish barrier on the river, downstream to the confluence with the Feather River near Marysville, California. The lower Yuba River is host to a number of native fishes, including Federally- and State-protected species like spring-run Chinook salmon and Central Valley steelhead. In 2007, the National Marine Fisheries Service issued a Biological Opinion that required the United States Army Corps of Engineers (USACE) to develop a long-term gravel augmentation program downstream of Englebright Dam to restore quality spawning habitat to the area. The 2007 Biological Opinion was superseded in 2012 and again in 2014. USACE is currently implementing gravel augmentation in accordance with the 2014 Biological Opinion. A pilot gravel injection effort of 500 tons was placed below the Narrows 2 powerhouse in November 2007, with subsequent larger gravel injection efforts taking place from November 2010 through January 2011, and July through August 2012. Gravel injection efforts have continued to take place annually since 2012 as part of the long-term stream rehabilitation approach. Gravel substrates have been injected downstream of Englebright Dam for the purpose of rehabilitation and restoration of spawning habitat. The implementation of a long-term augmentation program is intended to improve the overall ecological functionality of the river channel by providing gravel and cobble suitable for anadromous salmonid adult spawning, embryo incubation, and survival.

The purpose of this summary report is to detail the temporal and spatial use of spawning substrates downstream of Englebright Dam by Chinook salmon.

1.1. Objectives

- Evaluate the spatial and temporal distribution of Chinook salmon redds in the Englebright Dam study area.
- Estimate the number of Chinook salmon redds located in the Englebright Dam study area.
- Estimate the level of redd superimposition for Chinook salmon in the Englebright Dam study area.
- Examine attributes for each individual redd encountered during the surveys; including the physical redd measurements, substrate and habitat characterizations.

2. FIELD METHODS

2.1. Gravel Mapping Methods

The gravel injection reach was mapped prior to and following the injection of gravels to quantify the total volume and to characterize the change in topography within the injection reach. Field crews mapped substrate depth on foot for water depths < 0.6 meters (2 feet) using Trimble R8 GPS receivers collecting points on an approximate grid pattern of 1 x 1 meters (3.3 x 3.3 feet). Water depths deeper than 0.6 meters (2 feet) were mapped using Trimble Navigation Limited® R8 GPS receivers and Seafloor Systems® Hydrolite sonar units recording measurements at one second intervals, mounted to a kayak.

2.2. General Redd Survey Methods

Approximately 1.6 kilometers (1 mile) of the lower Yuba River was surveyed to assess the temporal and spatial distribution of Chinook salmon and steelhead spawning. Surveys were conducted by two divers wearing wetsuits, mask/snorkel and fins. Divers searched and identified Chinook salmon spawning (redds) on the lower Yuba River from the Narrows 2 Powerhouse to approximately 0.4 kilometers (0.25 miles) downstream of the confluence with Deer Creek. Divers entered the river from the upstream end of the survey area near the powerhouse and systematically searched for evidence of Chinook salmon spawning. Each surveyor scanned the river bed from the shore to the middle of the river, working downstream. When redds were located, positional data and abiotic measurements were recorded for each observation. Surveyors were able to mark redds in water depths < 1.45 meters (4.75 feet).

2.3. Survey Location

The survey area was located at the uppermost reach of the lower Yuba River from the Narrows 2 Powerhouse to approximately 0.4 kilometers (0.25 miles) downstream of the confluence of Deer Creek **(Figure 1).**

Figure 1. Aerial image of the Englebright Dam study area (marked by red boundary lines) in the lower Yuba River, CA.

2.4. Survey Period

The survey period began on the week of September 16, 2024 and ended during the week of April 28, 2025.

2.5. Sampling Frequency

Surveys were conducted weekly as conditions allowed.

2.6. Sample Size

For estimates of total abundance and temporal distribution of salmonid redds, the sample size was the number of weekly surveys conducted for the entire survey period.

2.7. Redd Location

The following abiotic data were recorded during each survey: 1) survey date; 2) surveyors' initials; 3) survey section; 4) number of crews; 5) specific crew identification (Crew A or B); 6) weather; 7) stream flow; and 8) Secchi disk depth. Flow data were obtained from the Yuba River Below Englebright Dam station through the California Department of Water Resources' (CDWR) online California Data Exchange Center (CDEC).

Each redd was consecutively numbered through the sampling season. For each redd observed, the following data were recorded: 1) a positional data point taken at the center of the redd's pot with a unique identifying number (i.e., Date plus redd number; i.e., 20230101-001); 2) the time of observation; 3) redd species identification; 4) number of fish observed on the redd; 5) comments regarding observable redd superimposition (i.e., redd overlap); and 6) any additional comments.

A handheld global positioning system (GPS) manufactured by Juniper Systems® (Mesa3 Rugged Tablet®) and a data dictionary were used to record positional and abiotic data for each redd observation. In addition, surveyors marked each redd with a fluorescent-colored bed marker to ensure that redds observed during previous surveys were not double-counted.

2.8. Redd Area Measurements

The physical dimensions of each observed redd were measured using a fiberglass extendable rod demarcated at every 0.1 meters (0.32 feet) according to the procedures identified in **Table 1** and **Figures 2 – 3.**

Table 1. Description of redd dimension measurements.

Pot Length (PL)	Total length of the pot parallel to the stream flow, and should be measured in meters (to the nearest cm) from the top to bottom edge. When the pot is irregularly shaped, estimate the total length as accurately as possible.
Pot Width (PW)	Maximum width of the pot perpendicular to the stream flow or pot width in meters (to the nearest cm). When the pot is irregularly shaped, estimate the total width as accurately as possible.
Tail Spill Length (TSL)	Total length of the tail spill parallel to the stream flow (in meters to the nearest cm). Measurements will be taken from the top edge (i.e., downstream edge of the pot) to bottom edge of the tail spill.
Tail Spill Width 1 (TSW1)	Maximum width of the tail spill perpendicular to the stream flow or pot length (in meters to the nearest cm). Measurements will be taken from one edge to the other, about one-third of the distance downstream from the top edge of the tail spill
Tail Spill Width 2 (TSW2)	Maximum width of the tail spill perpendicular to the stream flow or pot length (in meters to the nearest cm). Measurements will be taken from one edge to the other, about two-thirds of the distance downstream from the top edge of the tail spill.

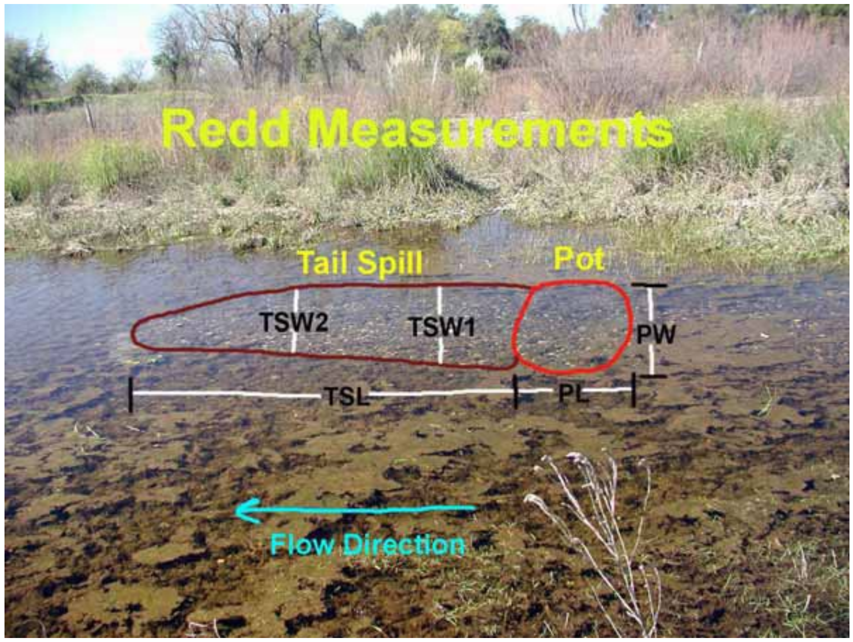


Figure 2. Illustration of redd measurements (PL = pot length; PW = pot width; TSL=tail-spill length; TSW2 and TSW1 = tail-spill widths), as presented in Hannon and Deason (2005).

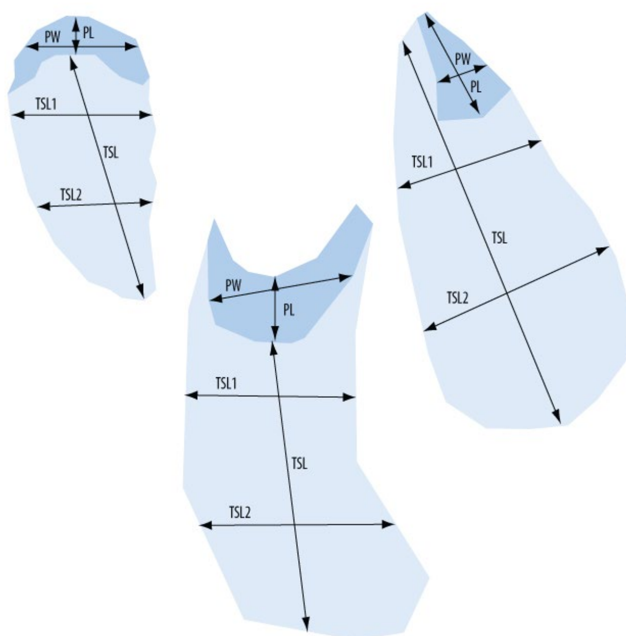


Figure 3. Measurements for unusually shaped redds (PL=pot length, PW=pot width, TSL=tail-spill length, TSL1 and TSL2=tail-spill widths). Illustration reproduced from Gallagher *et al.* (2007).

2.9. Habitat Utilization Characterization

At each fresh redd located, measurements of mean water column velocity, nose velocity[1], total water depth and visual estimates of substrate composition were made to approximate habitat conditions prior to gravel disturbance caused during redd construction. All measurements were taken 0.15 meters (0.49 feet) upstream of the leading edge of the pot along the mid-line of the redd, unless field personnel determined that measurements adjacent to the mid-point of the pot were more representative of undisturbed conditions for that specific location. The specific locations of the measurements were recorded on the data dictionary.

Total water depths were measured to the nearest 0.01 meter (0.03 feet) with a top-setting wading rod. Water velocities were measured with a Hach FH950 Handheld Flow Meter® water velocity meter to the nearest 0.01 meters/second (0.03 feet/second) parallel to the current according to methods described by Trihey and Wegner (1981). Mean water column velocity was measured at 60% of the distance from the surface in depths less than 0.77 meters (2.5 feet). In water between 0.77 meters (2.5 feet) and 1.22 meters (4 feet) deep, water velocities were measured at 20% and 80% of the total water depth, then were averaged to obtain mean column velocity (Buchanan and Somers 1969). Velocities at 20%, 60%, and 80% were measured and averaged in depths greater than 1.22 meters (4 feet), or where the velocity distribution in the water column was inconsistent. In addition to mean water column velocities, nose velocities were measured 0.15 meter (0.49 feet) above the undisturbed streambed.

Redd substrate composition was visually estimated as percentage composition (to the nearest 10 percent) of each of eight size categories **(Table 2).** Visual estimation of substrate sizes was taken along the *B* axis of the substrate elements.

Table 2. Substrate classification that links statistical properties of lower Yuba River bed material grain size distributions and physical habitat suitability (unpublished data - Yuba Accord RMT 2010).

Class	Particle Size Range (mm)	Habitat suitability
Bedrock	No alluvium	Periphyton only
Boulder Field*	D>256	Chinook salmon and steelhead fry, parr, and smolt cover and foraging
Large Cobble	128<D<256	Chinook salmon and steelhead fry and parr cover and foraging
Cobble	90<D< 128	Chinook salmon spawning, embryo incubation, and fry cover
Medium Gravel/Small Cobble	32<D<90	Chinook salmon and steelhead spawning, embryo incubation, and fry cover
Fine Gravel	2<D<32	Steelhead spawning and embryo incubation
Sand	0.0625<D<2	
Silt/Clay	D<0.0625	Submerged Aquatic Vegetation

[1] The nose velocity was taken at a predetermined distance of 0.15 meters above the undisturbed streambed to represent the velocity present at a fish's position during redd construction.

3. DATA ANALYSIS METHODS

3.1. Redd Survey Efficacy

The duration and number of days required to implement this redd survey were evaluated, including temporal sampling periods and causal descriptions for missed surveys.

3.2. Abundance

Redd data were used to enumerate Chinook salmon redds in the study area. The temporal distribution of spawning Chinook salmon was identified using the number of redds observed and the number of redds documented for each survey stratum through the survey period.

Dates associated with percentile expressions (1%, 10%, 25%, 50%, 75%, 90% and 99%) of the cumulative temporal distribution of Chinook salmon spawning were identified by fitting an asymmetric logistic function to the cumulative temporal distribution of fresh redds from the redd survey data (Richards 1959):

$$\sum_{i=1}^{D_i=n} Y_i\,(\%) = 100\ \times \left[A + \frac{K-A}{\left(1+\ e^{-B*\,(X-M)}\right)^{\frac{1}{10^{v}}}}\right]$$

where $\sum_{i=1}^{D_i=n} Y_i(\%)$ is the percentage of the cumulative temporal distribution of each run of Chinook salmon from day 1 through time D_i, *K* and *A* are upper and lower asymptotes (set to 1 and 0 in this analysis), *B* is a growth rate parameter, *M* is analogous to an inflection point parameter, and *v* is an asymmetry parameter, together which describe the resulting cumulative curve. The values of these parameters were obtained through simulated annealing on least squares fit criteria. Once the asymmetric logistic function curve was fitted to the data, the dates at which a particular percentage (X) of Chinook salmon were spawning ($\hat{D}_{X\%}$) was identified using the inverse estimation:

$$\hat{D}_{X\%} = \ log_e\left(\left(\left(\frac{K-A}{Y-A}\right)^{v} - 1\right)^{\frac{1}{-B}}\right) + M$$

where *K* and *A* were set to 1 and 0 respectively, B, *M* and *v* were the parameter values obtained from the asymmetric logistic function, and *X* was the proportion of interest (e.g., 0.01, 0.1, 0.25, 0.5, 0.75, 0.9 and 0.99). For example, the resulting estimates of $\hat{D}_{10\%}$, $\hat{D}_{25\%}$, $\hat{D}_{50\%}$, $\hat{D}_{75\%}$ and $\hat{D}_{90\%}$ summarized the characteristics of the corresponding temporal distribution of spawning Chinook salmon.

An analysis of potential redd superimposition impact was conducted using redd GPS locations, field measurements of redd dimensions, and modeled flow data to create ellipse polygons in the R Environment for Statistical Computing (R Core Team 2016), using packages “rgeos” and “rgdal”, (Bivand and Rundel 2016; Bivand et al. 2016). The modeled polygons represented three areas of the redd structure: the pot, the egg pocket, and the tail spill. The orientation of the pot and tail spill ellipses were determined by the direction of the river’s flow at each individual redd location, according to flow vectors calculated at base flow using an SRH-2D flow model developed by Dr. Greg Pasternack and Dr. Josh Wyrick from the University of California Davis. The dimensions of these ellipses were based on measurements recorded for each observed redd during the survey year. The length of the recorded pot was increased by a factor of two and used with the original pot width measurement to construct an ellipse that was representative of the total excavated pot dimensions for each redd observed. The tail spill ellipses were drawn downstream of the recorded redd locations at a length equaling the original pot measurements. The location of the redd egg pocket was then defined as the area of overlap between the pot and tail spill ellipses **(Figure 4)**.

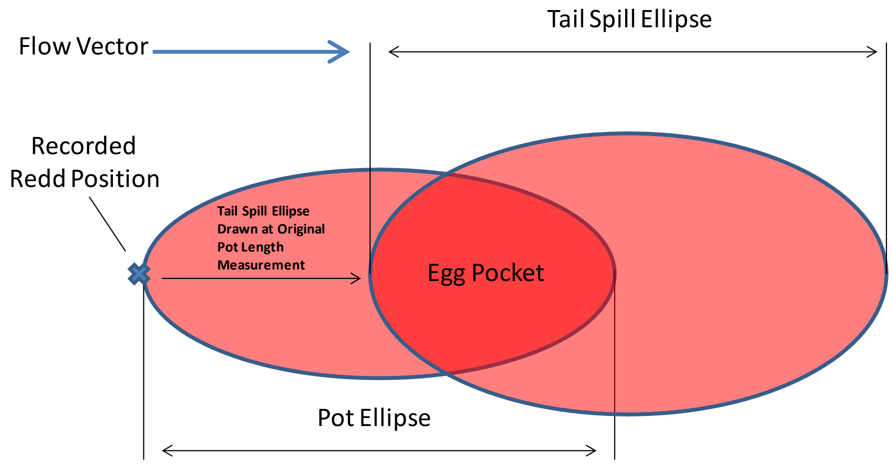


Figure 4. Conceptual view of the pot and tail spill ellipses used to indicate the relative location of the egg pocket.

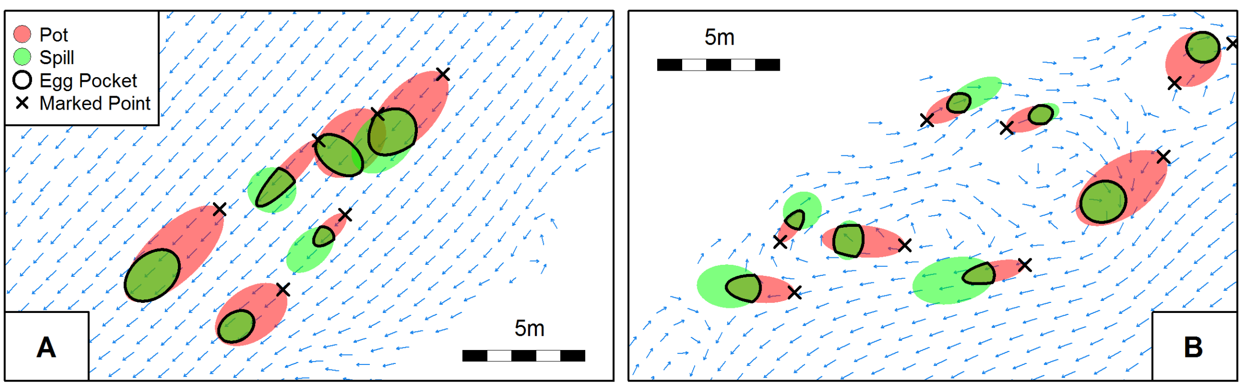


Figure 5. Examples of modelled redd pots (red), spills (green), and egg pockets (bold line) in a laminar flow environment (A) and turbulent eddy (B).

Weekly and cumulative estimates of potential redd superimposition impact were estimated using GIS-based spatial output. Potential superimposition impact was defined as the overlap of a neighboring redd's pot ellipse over a modeled egg pocket polygon for the cumulative analysis **(Figure 6)** and the overlap of the pot and egg pocket polygons within each survey stratum for the weekly analysis **(Figure 7)**. For the weekly estimates of redd superimposition impact, statistics were calculated based on the amount of overlap and the number of overlapping pot polygons. For the cumulative estimates of redd superimposition impact, metrics were calculated based on the cumulative amount of egg pocket overlap. As an indicator of superimposition impact, an index was developed to better understand the actual potential for egg pocket disturbance relative to the number of Chinook salmon redds observed for each survey year and during each weekly stratum. An index of redd superimposition impact was calculated for each stratum and cumulatively for the season. The index was expressed as the frequency of redds that exhibited overlap multiplied by the average egg pocket overlap. The index of potential superimposition impact was calculated as:

$$I = \frac{R_o}{R_{tot}} \times R_{o_f} \text{, where}$$

R_o is the total number of redds demonstrating a measurable degree of superimposition,

R_{tot} is the total number of redds observed during the survey season,

And R_{o_f} is the average measure of overlap for redds exhibiting superimposition.

Using this method, we can infer that index values ranging from 0-1 can represent varying degrees of increasing potential for redd superimposition impact, with values approximating zero representing a low potential for redd superimposition impact. A trend analysis using simple linear regression of the weekly and cumulative indices of superimposition impact for Chinook salmon redds during the spawning period was performed.

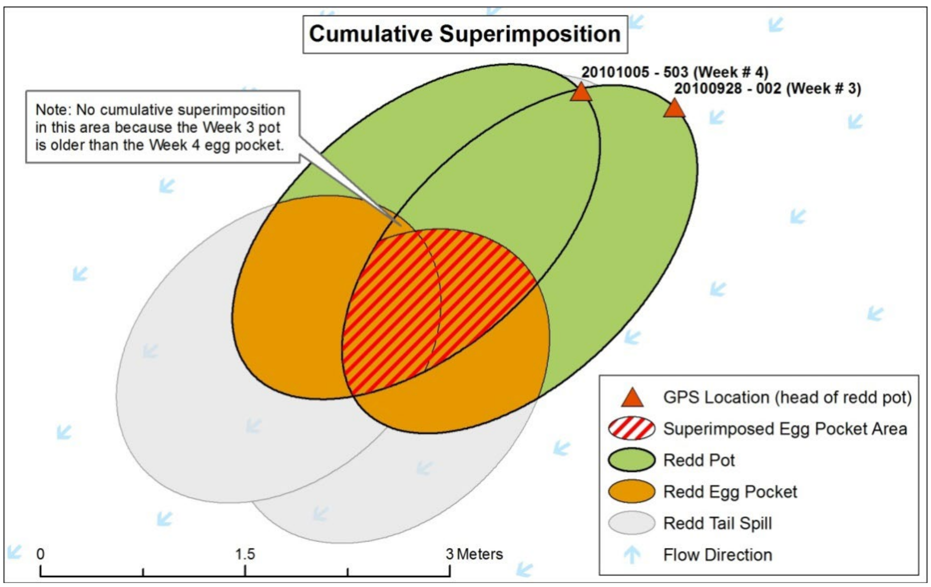


Figure 6. Sample map showing potential superimposition impact from subsequent redd pot construction on existing egg pocket.

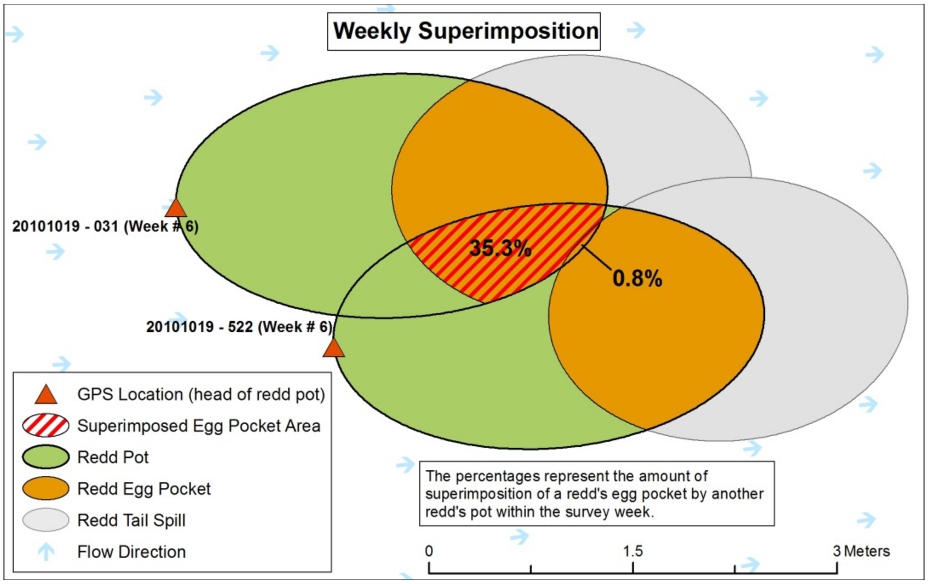


Figure 7. Sample map showing potential superimposition impact from within-stratum pot and egg pocket overlap.

3.3. Diversity

Redd attribute data were used to examine redd physical size attributes. Redd size was described using standard metrics (i.e., minimum, maximum, mean, median and variance of redd measurements).

Redd attribute data were used to examine microhabitat features encountered at redd locations. Redd microhabitat features were described using standard metrics (i.e., minimum, maximum, mean, median and variance of measurements).

Redd attribute data were used to examine substrate characterizations. Substrate characterizations were described using standard metrics (i.e., minimum, maximum, mean, median and variance of substrate characterizations).

4. RESULTS

4.1. Gravel Mapping

Pre-injection gravel mapping was conducted on June 17, 2024 using kayaks with mounted RTK receivers as well as on-foot. Gravel injection began on July 15, 2024. Post-injection mapping in the vicinity of the gravel injection site was conducted on September 10, 2024 using kayak and on-foot mapping. The pre-injection median elevation was 86.5 m (283.7 ft.) and the median post-injection elevation was 86.6 m (284.0 ft.). with an overall, positive mean elevation difference of 0.1 m (0.3 ft., **Figure 8**). The positive change between post- and pre-injection of gravel was concentrated along the bank near the injection site with slight change downstream.

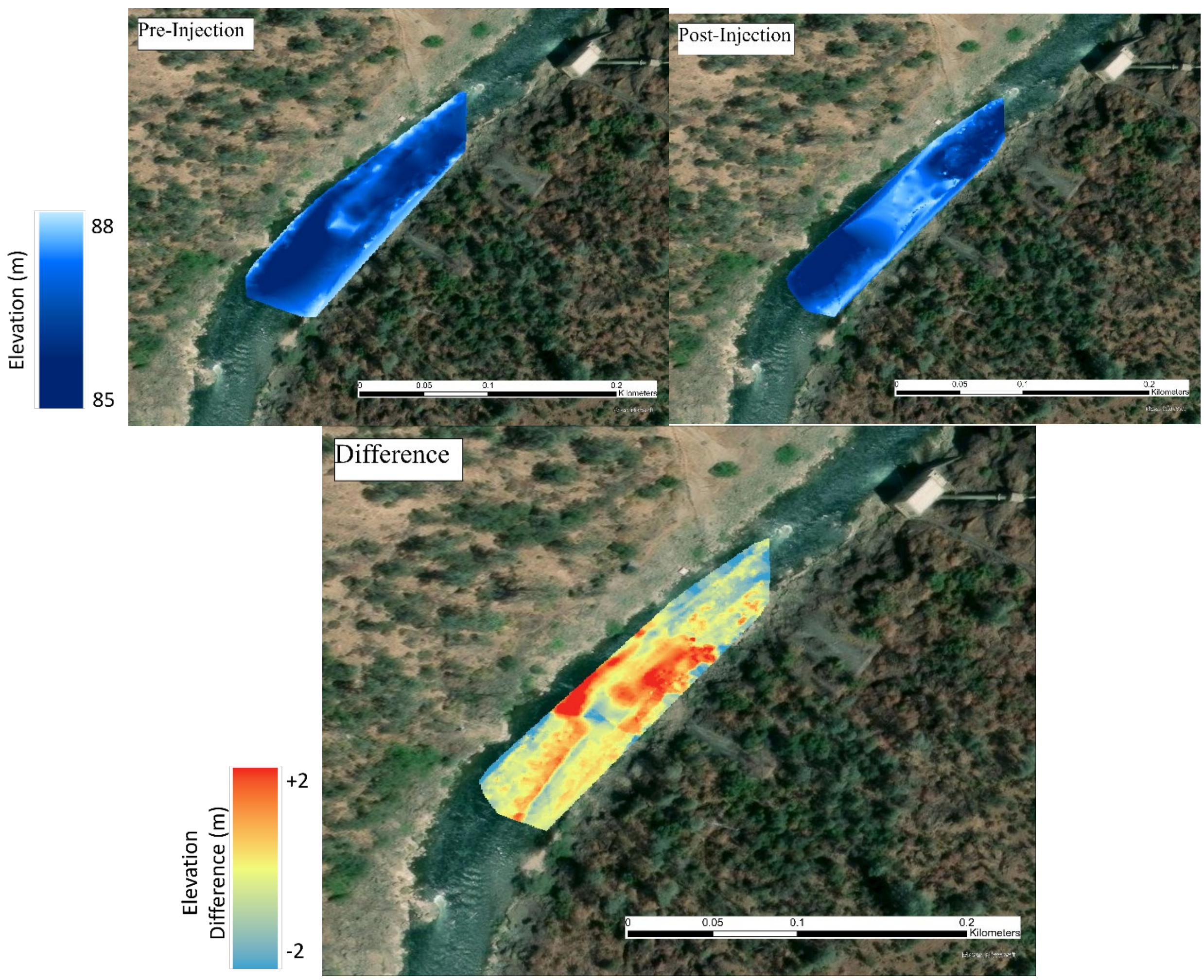


Figure 8. Elevation in meters (m) of the riverbed pre-injection and post-injection (top) with the lighter coloration corresponding to shallower areas. The elevation change between pre- and post-injections is included (bottom) with cooler colors representing positive change, yellows and oranges representing little to no change, and red representing negative change.

4.2. Redd Survey Efficacy

Redd surveys began on September 16, 2024 following preliminary field reconnaissance surveys that observed Chinook salmon adults staging proximal to known spawning areas. Except for the week of January 20, 2025, surveys were not conducted during the weeks of December 30, 2024 through April 28, 2025 due to high flows and/or low visibility. Results were tabulated for each weekly stratum including the number of days required to complete the survey, secchi depth measurements, the minimum, maximum and mean of mean daily flows and water temperatures at the USGS Englebright Dam station and the number of Chinook salmon redds observed **(Table 3).**

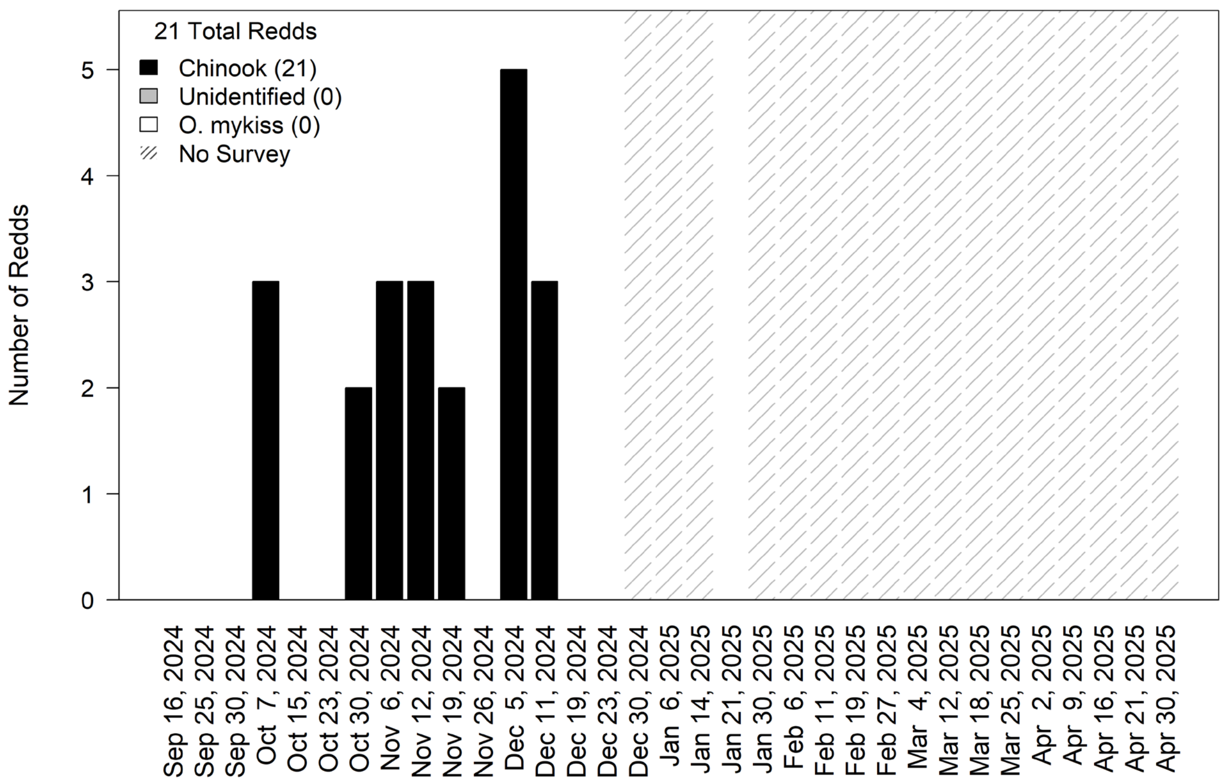
Table 3. Weekly survey results in the Englebright Dam study area of the lower Yuba River, CA from September 16, 2024 to April 28, 2025. Survey dates with an asterisk indicate no survey due to high flows (>1800 cfs) or turbidity (< 1.2 m secchi disk).

			Englebright Dam Flow (cfs)			Englebright Dam Temp. (°C)			Number of Redds Observed		
Week	Survey Days	Secchi Depth (m)	Min.	Max.	Mean	Min.	Max.	Mean	Chinook	Unknown Salmonid	O. mykiss
9/16/2024	1	4+	1082	1134	1096.3	12.5	13.0	12.8	0	0	0
9/23/2024	1	4+	1111	1188	1155.1	12.7	13.3	13.0	0	0	0
9/30/2024	1	4+	1082	1231	1147.0	12.2	13.0	12.5	0	0	0
10/7/2024	1	4+	1111	1134	1122.2	12.1	12.5	12.3	3	0	0
10/14/2024	1	4+	1111	1140	1125.1	12.0	12.6	12.3	0	0	0
10/21/2024	1	4+	1105	1129	1116.6	11.5	12.3	12.0	0	0	0
10/28/2024	1	4+	1111	1134	1121.8	11.2	11.9	11.6	2	0	0
11/4/2024	1	4+	1088	1129	1108.4	10.9	11.6	11.2	3	0	0
11/11/2024	1	4+	1088	1105	1094.2	10.6	11.2	10.8	3	0	0
11/18/2024	1	4+	1088	1686	1156.0	10.1	10.8	10.5	2	0	0
11/25/2024	1	4+	1082	1105	1095.4	9.9	10.5	10.2	0	0	0
12/2/2024	1	2	845	1100	902.2	9.7	10.1	9.9	5	0	0
12/9/2024	1	2.5	738	855	769.8	9.3	9.9	9.5	3	0	0
12/16/2024	1	2.5	747	761	752.7	9.1	9.5	9.2	0	0	0
12/23/2024	1	2	743	3200	1440.1	9.0	9.6	9.2	0	0	0
12/30/2024*	0	0.9	747	4035	1440.4	9.0	10.0	9.4	0	0	0
1/6/2025*	0	1	729	761	746.9	8.9	9.4	9.1	0	0	0
1/13/2025*	0	1	729	761	745.4	8.4	9.2	8.8	0	0	0
1/20/2025	1	1.5	743	765	753.6	8.1	8.7	8.3	0	0	0
1/27/2025*	0	2	747	15235	4513.9	7.9	8.4	8.1	0	0	0
2/3/2025*	0	0.5	9250	18664	12291.6	8.2	9.4	9.0	0	0	0
2/10/2025*	0	1.5	5948	11726	8170.2	8.2	8.9	8.5	0	0	0
2/17/2025*	0	1.5	4373	7150	4824.3	8.2	8.7	8.4	0	0	0
2/24/2025*	0	1.8	3954	4416	4289.5	8.2	8.8	8.5	0	0	0
3/3/2025*	0	2	4330	4744	4598.6	7.9	8.9	8.4	0	0	0
3/10/2025*	0	2.5	3927	5263	4427.4	7.9	8.8	8.2	0	0	0
3/17/2025*	0	2	4358	8254	5202.6	7.8	9.0	8.3	0	0	0
3/24/2025*	0	2	4387	6158	5456.9	8.4	10.0	9.2	0	0	0
3/31/2025*	0	1	5279	7291	6028.1	8.1	9.4	8.7	0	0	0
4/07/2025*	0	2	5295	6613	5976.2	8.6	10.2	9.4	0	0	0
4/14/2025*	0	2.5	5247	6558	5985.0	9.6	10.8	10.1	0	0	0

4/21/2025*	0	3	3914	5913	4518.9	9.7	10.8	10.3	0
4/28/2025*	0	3.5	3900	3940	3912.1	9.8	11.1	10.4	0

4.3. Abundance

A total of 21 redds were observed during the survey period, all of which were positively identified as Chinook salmon redds, 0 were positively identified as a steelhead redd, and 0 were of unknown species origin (**Figure 9**). Peak observation of Chinook salmon redds occurred during the week of December 2, 2024 when five redds were observed.



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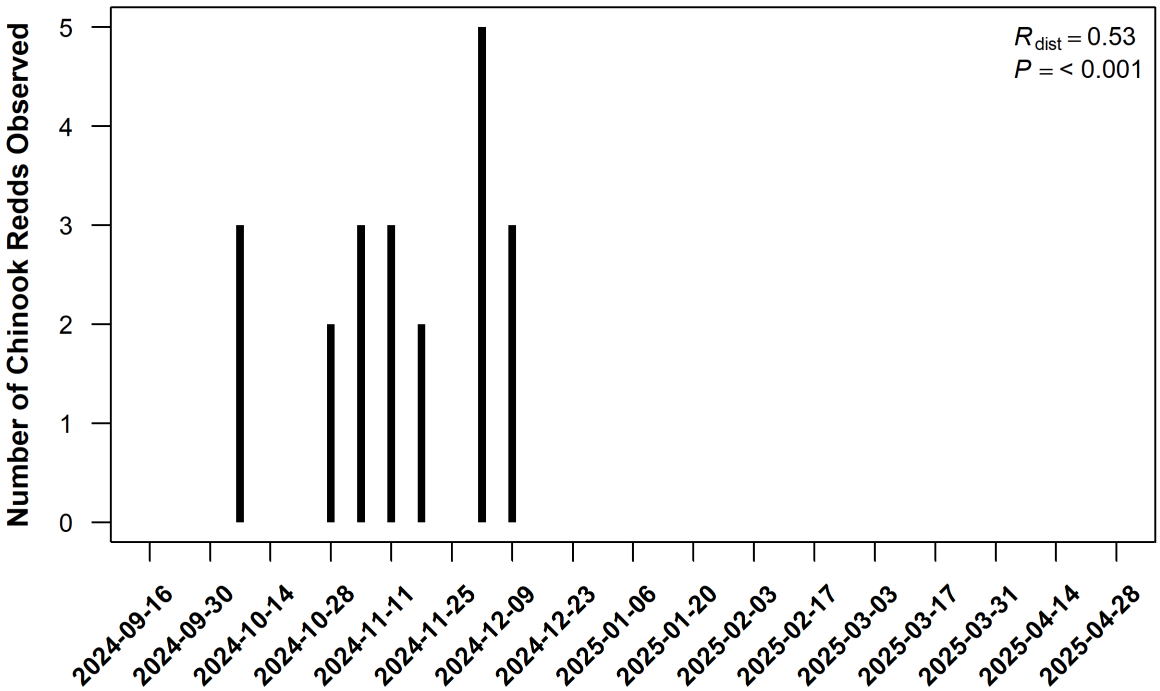

Figure 10. Distance correlation of the number of observed Chinook salmon redds by survey week in the Englebright Dam study area of the lower Yuba River, CA from September 16, 2024 to April 28, 2025.

Redd observations were concentrated primarily within the upper 2/3rds of the survey area, and did not occur beyond the mouth of Deer Creek (**Figure 11**).

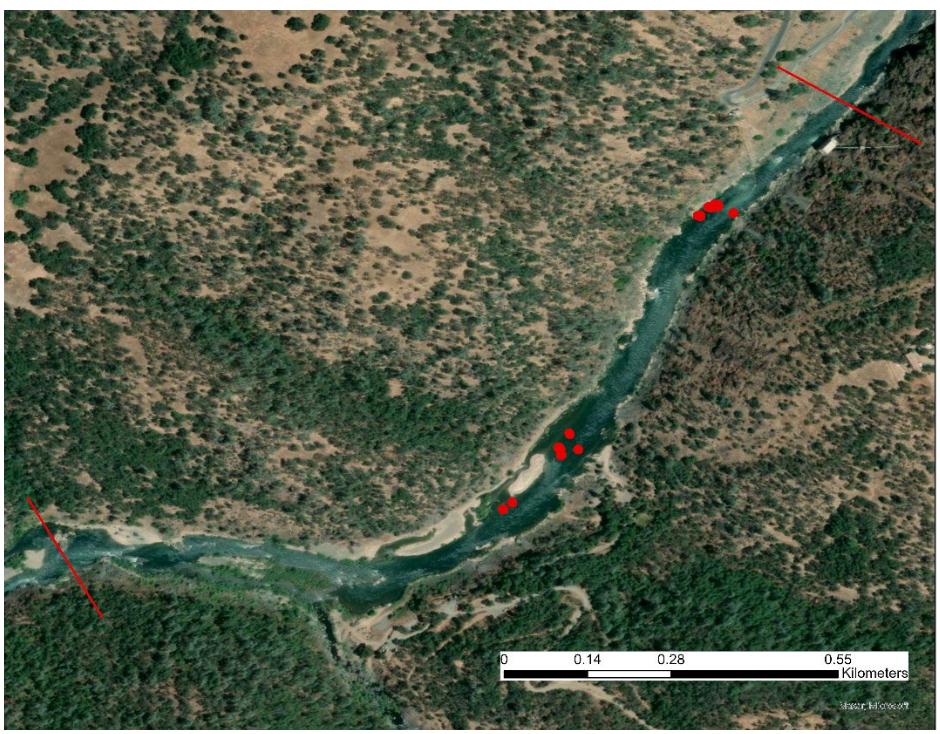

Figure 11. Aerial image of the survey area (between red boundary lines) with cumulative redd observations (red circles) from September 16, 2024 to April 28, 2025 in the Englebright Dam study area of the lower Yuba River, CA.

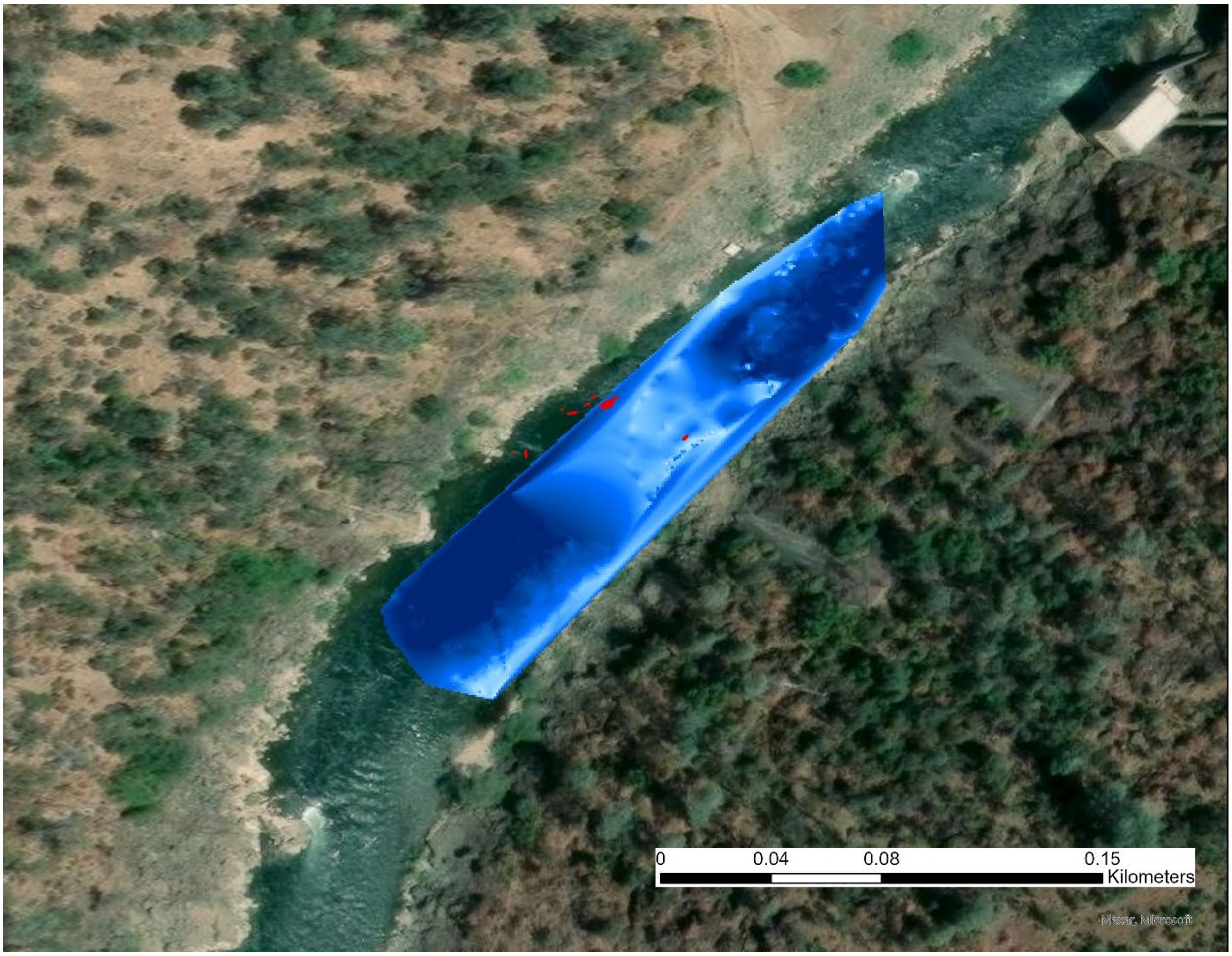

Figure 12. Mapped salmonid redds (pots and spill) in injection vicinity in the study area of the lower Yuba River below Englebright Dam, CA from September 16, 2024 to April 28, 2025. Blue shading indicates gravel elevation from post-injection gravel mapping in fall 2024.

A fitted asymmetric logistic function predicted that 50% of the Chinook salmon spawning was observed by the week of November 11, 2024, with 90% of the observations occurring by the week of December 02, 2024 (**Figure 13**).

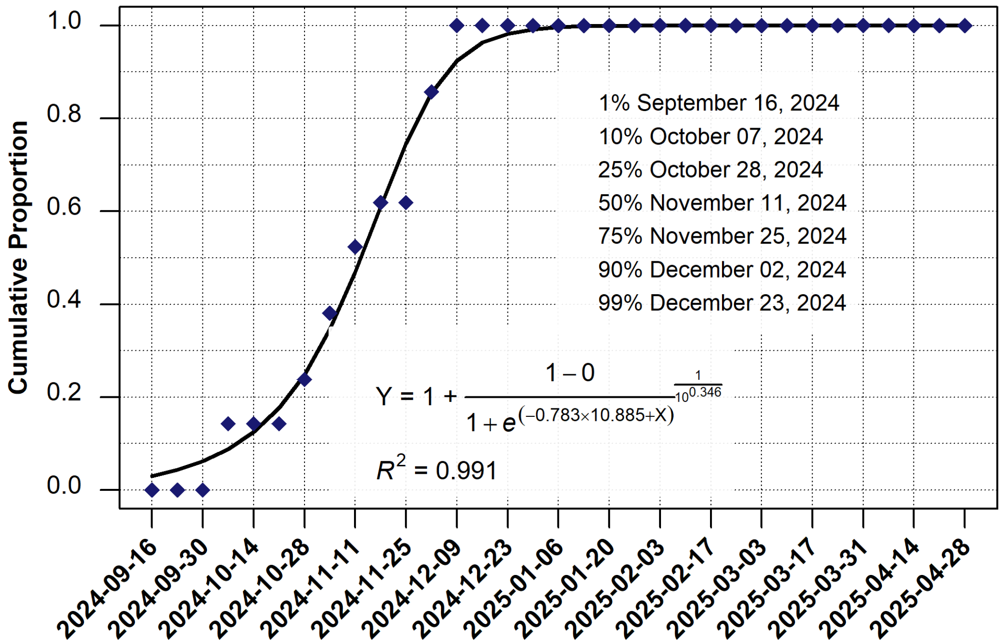

Figure 13. Cumulative weekly temporal distribution of observed Chinook salmon redd abundance in the Englebright Dam study area of the lower Yuba River, CA from September 16, 2024 to April 28, 2025.

Mean daily flow remained between 737.3 cfs and 14,907.7 cfs (**Table 3**) for the majority of redd observations. Redds were observed to be constructed between 9.1 °C and 13.1 °C (**Table 3**). Of the redds observed, 75% of them were found at temperatures between 10.0 °C and 13.1 °C (**Figure 14**).

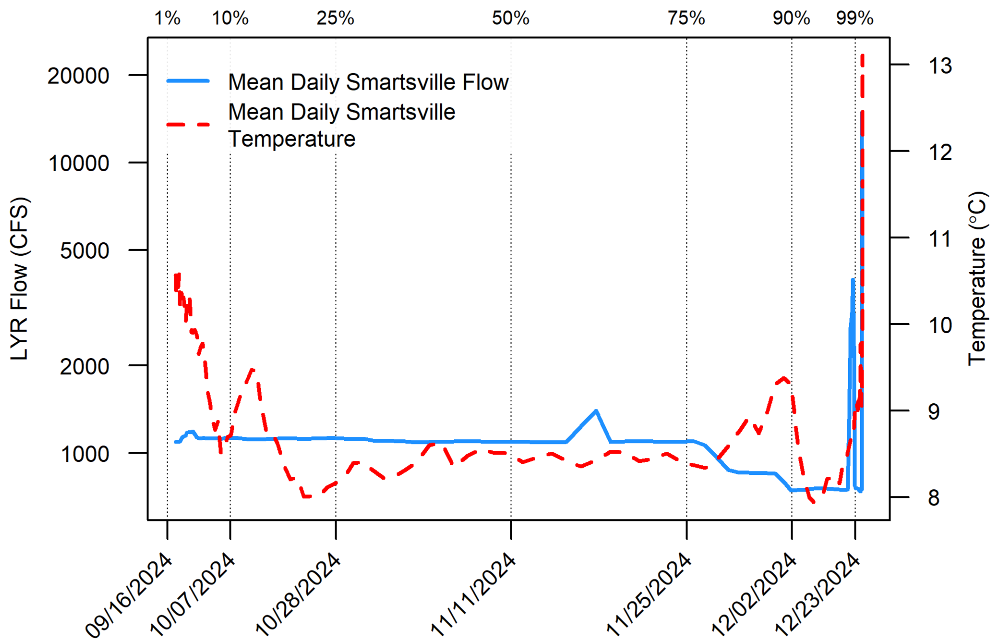

Figure 14. Mean weekly flow and mean weekly temperature (calculated from mean daily values) at the USGS Englebright Dam station through the percentile expressions (1%, 10%, 25%, 50%, 75%, 90% and 99%) for Chinook salmon redd abundance in the Englebright Dam study area of the lower Yuba River, CA from September 16, 2024 to the week of December 23, 2024 (last Chinook salmon redd observed in 2024).

Within stratum calculated egg pocket overlap occurred during the survey period (**Appendix A, Tables A1 – A9**). The calculated cumulative egg pocket impact indices ranged from 0.039 to 0.094 during the survey period (**Appendix B, Table B1)**. The cumulative mean egg pocket overlap remained a constant 4% (**Appendix B, Table B1**). Linear regression of the index of superimposition impact on survey week found a relatively strong relationship (R^2 = 0.129, P < 0.001). A third order polynomial regression was able to describe 42.7% of the information in the index of superimposition regressed on survey week (R^2 = 0.472, P < 0.001, **Figure 15).** Cumulative redd egg pocket impact analysis using ArcGIS demonstrated all 21 redds exhibited a very little degree of egg pocket overlap (**Appendix A, Tables A1 – A9; Appendix B**).

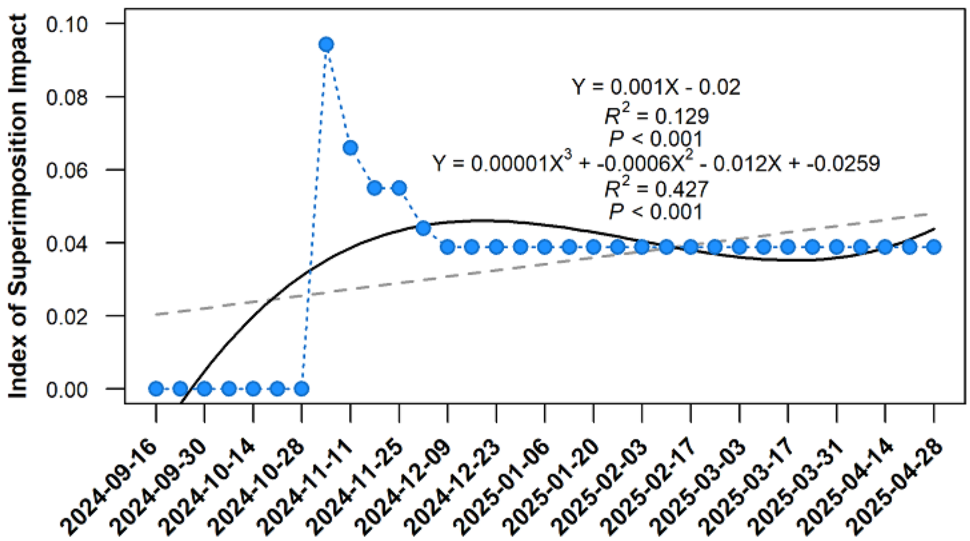

Figure 15. Linear Polynomial regression of the cumulative index of superimposition impact for all redds observed in the Englebright Dam study area of the lower Yuba River, CA from September 16, 2024 to April 28, 2025.

4.4. Diversity

The average dimensions of Chinook salmon redds observed in this survey (within a 95% confidence interval) were a mean pot length of 0.90 ± 0.19 m (2.95 ± 0.62 ft), a mean pot width of 0.76 ± 0.15 m (2.49 ± 0.49 ft), a mean tail-spill length of 1.30 ± 0.45 m (4.27 ± 1.48 ft), and mean tail-spill widths of 1.58 ± 0.31 m and 1.41 ± 0.29 m (5.18 ± 1.02 ft and 4.63 ± 0.95 ft). Additionally, Chinook redds were observed at an average depth of 0.51 ± 0.08 m (1.67 ± 0.26 ft), an observed average nose velocity of 0.65 ± 0.16 m/s (2.13 ± 0.52 ft/s), and an average mean column velocity of 0.50 ± 0.12 m/s (1.64 ± 0.39 ft/s) (**Figure 16, Table 4**).

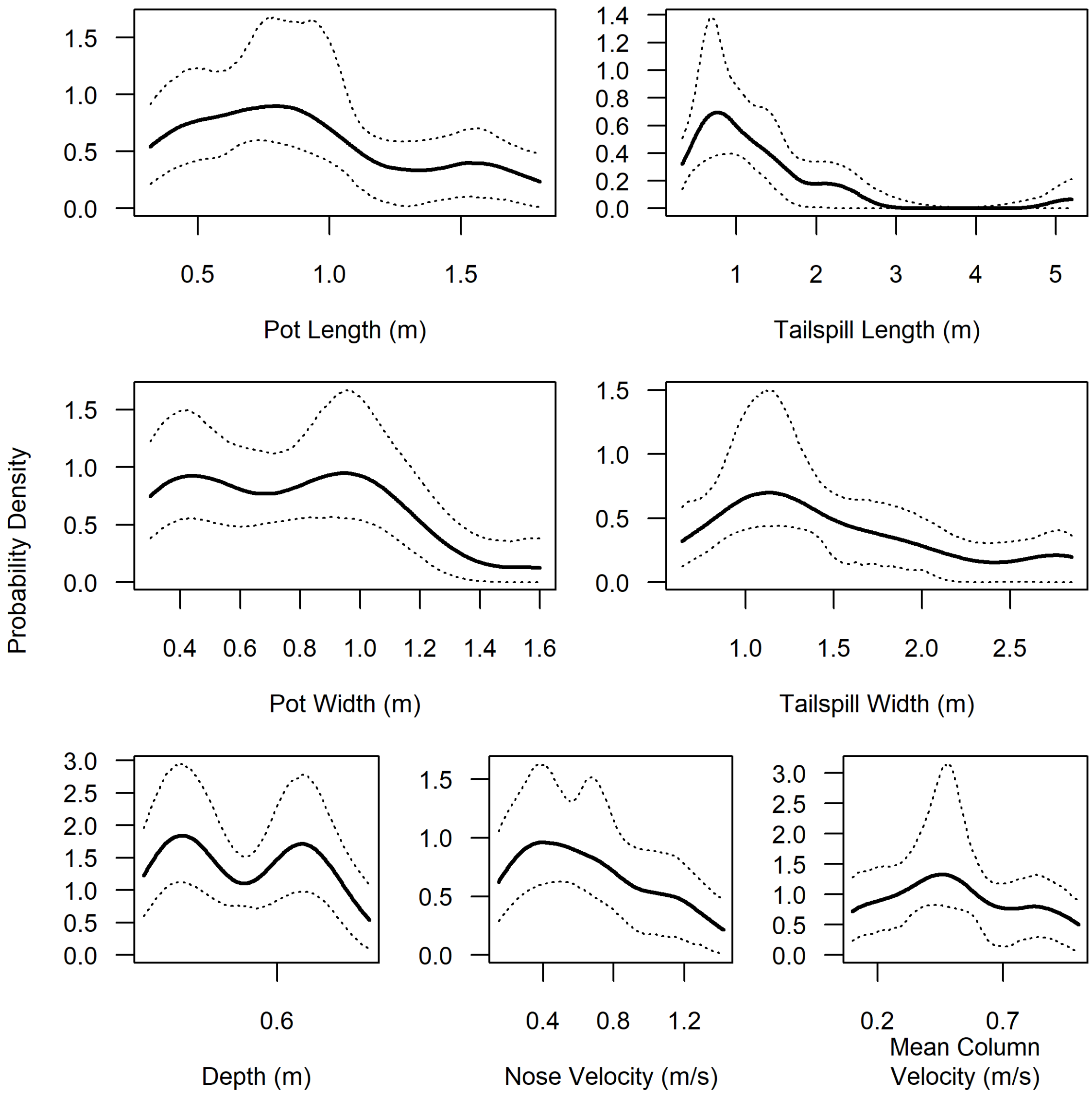

Figure 16. Probability density curves for measurements of redds constructed by Chinook salmon (n = 21). Dotted lines indicate 95% confidence intervals as determined by bootstrap sampling with 5,000 repetitions.

Table 4. Descriptive statistics for the physical size measurements (m) and microhabitat features of sampled Chinook salmon redds in the Englebright Dam study area of the lower Yuba River, CA.

	Pot Length	Pot Width	Tail Spill Length	Tail Spill Width 1	Tail Spill Width 2	Depth (m)	Nose Velocity (m/sec)	Mean Velocity (m/sec)
Sample Size	21	21	21	21	21	21	21	21
MIN	0.32	0.3	0.32	0.7	0.54	0.24	0.15	0.1
MAX	1.8	1.6	5.2	3	2.7	0.85	1.42	1
MEAN	0.90	0.76	1.30	1.58	1.41	0.51	0.65	0.50
MEDIAN	0.8	0.8	1	1.4	1.1	0.48	0.65	0.48
VARIANCE	0.19	0.12	1.12	0.52	0.45	0.04	0.14	0.08
SD	0.44	0.35	1.06	0.72	0.67	0.19	0.37	0.28
95% CONFIDENCE	0.19	0.15	0.45	0.31	0.29	0.08	0.16	0.12

Detailed breakdowns of substrate percentages are given in **Table 5.** Most Chinook salmon redds were constructed in substrates dominated by gravel (substrates 2 – 32 mm [0.079 – 1.260 in] mean diameter). No Chinook redds were observed to contain bedrock nor silt/clay (substrate <0.0625 mm [<0.002 in]) (**Figure 17**).

Table 5. Descriptive statistics for the substrate characterization percentages of sampled Chinook salmon redds in the Englebright Dam study area.

	Bedrock	Boulder >256mm	Lg. Cobble 128-256mm	Cobble 90-218mm	Fine Cobble 32-90mm	Gravel 2-32mm	Sand 0.0624-2mm	Silt/Clay <0.0625mm
Sample Size	21	21	21	21	21	21	21	21
MIN	Not Observed In Survey	0	0	0	10	0	0	Not Observed in Survey
MAX		20	30	30	80	90	10	
MEAN		5.48	6.90	9.05	17.38	60.48	0.71	
MEDIAN		0	5	10	10	60	0	
VARIANCE		52.26	76.19	86.55	239.05	637.26	5.71	
SD		7.23	8.73	9.30	15.46	25.24	2.39	
95% CONF		3.09	3.73	3.98	6.61	10.80	1.02	

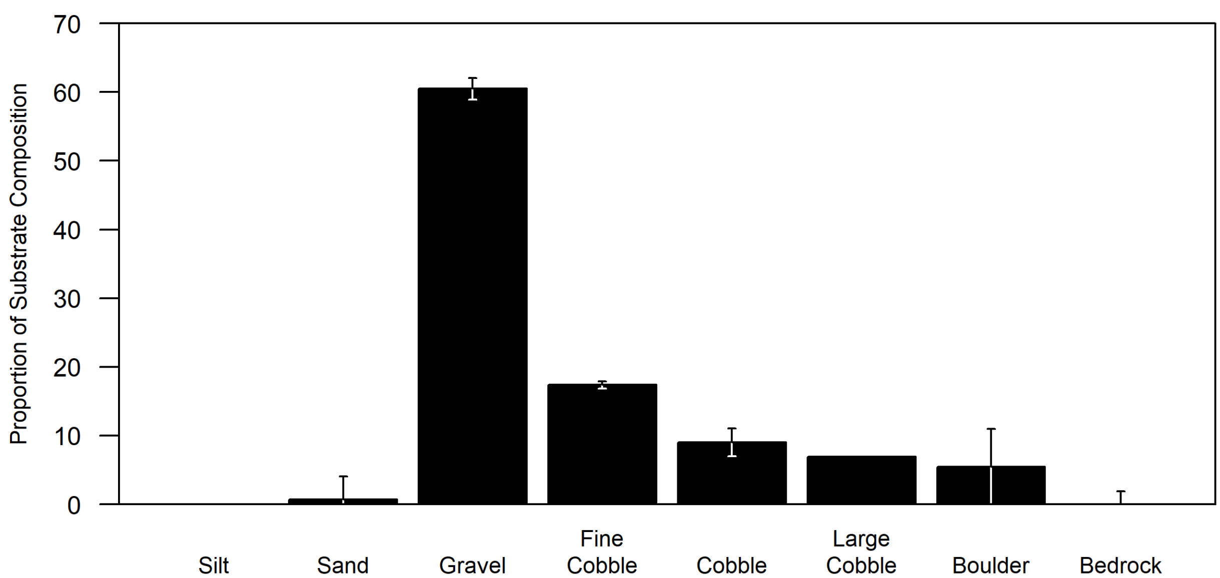

Figure 17. Mean substrate percentages observed for redds constructed by Chinook salmon (n = 21). Bars indicate ± 1 standard error.

5. DISCUSSION

The 2024 redd survey season was punctuated by extensive periods of high flows and/or turbidity. As a result, sampling was not conducted from December 30, 2024 through the end of the survey, April 28, 2025 with the exception of the week of January 20, 2025. Likely, the majority of the Chinook fall spawning run had ended by the last conducted survey as is consistent with previous years' surveys. Redd construction occurred with global maxima of five redds on December 5, 2024 followed by extreme flows/turbidity rendering the survey area unmeasurable. As in previous surveys, redds were located in areas where suitable spawning gravels did not exist prior to USACE gravel injection, and additional concentrations of redd development occurred in the locations of Anadromous Fish Restoration Program (AFRP) habitat modification. (Campos et al. 2013, 2014; Stearman & Massa 2015; Kowalik & Massa 2018; Kowalik & Doughty, pers. obs).

Indices for superimposition impact potentials were tightly related with cumulative survey strata (i.e., modeled egg pocket overlap frequency increased as the spawning period progressed), suggesting a selective preference for aggregate spawning. Additionally, the cumulative index of superimposition remained below 10% for the entire survey, suggesting the potential for disruption and dislodgement of incubating eggs within individually constructed redds was small compared to previous survey seasons (Campos et al. 2013, 2014; Stearman & Massa 2015, 2016; Stearman et al. 2017). Similarly, the superimposition index remained well below the percentage of total redds showing at least some small degree of superimposition, and below the total percentage showing greater than 50% egg pocket overlap. Given a relatively low sample size ($n = 2$), these results suggest that aggregate spawning appears to have a low potential for impacting incubating eggs via encroachment into the egg pocket by adjacent redds.

A probability exists that these results underrepresented the actual potential for disruption and dislodgement to incubating eggs. Chinook salmon eggs incubating within redds constructed in the 2024/2025 survey period were not affected by superimposition, despite the truncated survey season, any further redds were likely to be unaffected as the juvenile alevins had likely emerged prior to subsequent superimposition. This conservative approach to superimposition analysis utilized all survey strata available, regardless of initial redd construction dates. Additionally, these methods simply employed a two-dimensional (2D) approach in identifying potential impacts to incubating eggs; excluding the depth at which the egg pockets occur relative to adjacent redd construction. Further investigations into the Z-plane (i.e., the depth of excavation by adjacent redd construction relative to egg pocket depth) may demonstrate that the actual potential for disruption or dislodgement of incubating eggs may be less than identified relative to this 2D approach. As provided, the methods and results defined in this 2D approach represent the most inclusive to date relative to redd superimposition, and demonstrate a moderate to high level of impact potential from aggregate spawning for Chinook salmon on the lower Yuba River.

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8. APPENDIX A

Table A1. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of September 16, 2024 and October 7, 2024.

Percentage of Redd Overlap	9/16/2024		9/23/2024		9/30/2024		10/07/2024	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%	0	0	0	0	0	0	0	0
5-10%	0	0	0	0	0	0	0	0
10-15%	0	0	0	0	0	0	0	0
15-20%	0	0	0	0	0	0	0	0
20-25%	0	0	0	0	0	0	0	0
25-30%	0	0	0	0	0	0	0	0
30-35%	0	0	0	0	0	0	0	0
35-40%	0	0	0	0	0	0	0	0
40-45%	0	0	0	0	0	0	0	0
45-50%	0	0	0	0	0	0	0	0
50-55%	0	0	0	0	0	0	0	0
55-60%	0	0	0	0	0	0	0	0
60-65%	0	0	0	0	0	0	0	0
65-70%	0	0	0	0	0	0	0	0
70-75%	0	0	0	0	0	0	0	0
75-80%	0	0	0	0	0	0	0	0
80-85%	0	0	0	0	0	0	0	0
85-90%	0	0	0	0	0	0	0	0
90-95%	0	0	0	0	0	0	0	0
95-100%	0	0	0	0	0	0	0	0
TOTALS	0	0	0	0	0	0	0	0

Table A2. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of October 14, 2024 and November 4, 2022.

Percentage of Redd Overlap	10/14/2024		10/21/2024		10/28/2024		11/04/2024	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%	0	0	0	0	0	0	0	0
5-10%	0	0	0	0	0	0	0	0
10-15%	0	0	0	0	0	0	1	1
15-20%	0	0	0	0	0	0	0	0
20-25%	0	0	0	0	0	0	0	0
25-30%	0	0	0	0	0	0	0	0
30-35%	0	0	0	0	0	0	0	0
35-40%	0	0	0	0	0	0	0	0
40-45%	0	0	0	0	0	0	1	1
45-50%	0	0	0	0	0	0	0	0
50-55%	0	0	0	0	0	0	0	0
55-60%	0	0	0	0	0	0	0	0
60-65%	0	0	0	0	0	0	0	0
65-70%	0	0	0	0	0	0	0	0
70-75%	0	0	0	0	0	0	0	0
75-80%	0	0	0	0	0	0	0	0
80-85%	0	0	0	0	0	0	0	0
85-90%	0	0	0	0	0	0	0	0
90-95%	0	0	0	0	0	0	0	0
95-100%	0	0	0	0	0	0	0	0
TOTALS	0	0	0	0	0	0	2	2

Table A3. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of November 11, 2024 and December 2, 2024.

Percentage of Redd Overlap	11/11/2024		11/18/2024		11/25/2024		12/02/2024	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%	0	0	0	0	0	0	0	0
5-10%	0	0	0	0	0	0	0	0
10-15%	0	1	0	1	0	1	0	1
15-20%	0	0	0	0	0	0	0	0
20-25%	0	0	0	0	0	0	0	0
25-30%	0	0	0	0	0	0	0	0
30-35%	0	0	0	0	0	0	0	0
35-40%	0	0	0	0	0	0	0	0
40-45%	0	1	0	1	0	1	0	1
45-50%	0	0	0	0	0	0	0	0
50-55%	0	0	0	0	0	0	0	0
55-60%	0	0	0	0	0	0	0	0
60-65%	0	0	0	0	0	0	0	0
65-70%	0	0	0	0	0	0	0	0
70-75%	0	0	0	0	0	0	0	0
75-80%	0	0	0	0	0	0	0	0
80-85%	0	0	0	0	0	0	0	0
85-90%	0	0	0	0	0	0	0	0
90-95%	0	0	0	0	0	0	0	0
95-100%	0	0	0	0	0	0	0	0
TOTALS	0	2	0	2	0	2	0	2

Table A4. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of December 19, 2022 and January 9, 2025.

Percentage of Redd Overlap	12/09/2024		12/16/2024		12/23/2024		12/30/2024	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%	0	0	0	0	0	0		
5-10%	0	0	0	0	0	0		
10-15%	0	1	0	1	0	1		
15-20%	0	0	0	0	0	0		
20-25%	0	0	0	0	0	0		
25-30%	0	0	0	0	0	0		
30-35%	0	0	0	0	0	0		
35-40%	0	0	0	0	0	0		
40-45%	0	1	0	1	0	1		
45-50%	0	0	0	0	0	0		**No Survey**
50-55%	0	0	0	0	0	0		**Conducted**
55-60%	0	0	0	0	0	0		
60-65%	0	0	0	0	0	0		
65-70%	0	0	0	0	0	0		
70-75%	0	0	0	0	0	0		
75-80%	0	0	0	0	0	0		
80-85%	0	0	0	0	0	0		
85-90%	0	0	0	0	0	0		
90-95%	0	0	0	0	0	0		
95-100%	0	0	0	0	0	0		
TOTALS	0	2	0	2	0	2		

Table A5. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of January 16, 2025 and February 6, 2025.

Percentage of Redd Overlap	01/06/2025		01/13/2025		01/20/2025		01/27/2025	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%					0	0		
5-10%					0	0		
10-15%					0	1		
15-20%					0	0		
20-25%					0	0		
25-30%					0	0		
30-35%					0	0		
35-40%					0	0		
40-45%					0	1		
45-50%		No Survey			0	0		No Survey
50-55%		Conducted			0	0		Conducted
55-60%					0	0		
60-65%					0	0		
65-70%					0	0		
70-75%					0	0		
75-80%					0	0		
80-85%					0	0		
85-90%					0	0		
90-95%					0	0		
95-100%					0	0		
TOTALS					0	2		

Table A6. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of February 3, 2025 and February 24, 2025.

Percentage of Redd Overlap	02/03/2025		02/10/2025		02/17/2025		02/24/2025	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%	No Survey Conducted							
5-10%								
10-15%								
15-20%								
20-25%								
25-30%								
30-35%								
35-40%								
40-45%								
45-50%								
50-55%								
55-60%								
60-65%								
65-70%								
70-75%								
75-80%								
80-85%								
85-90%								
90-95%								
95-100%								
TOTALS								

Table A7. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of March 3, 2025 and March 24, 2025.

Percentage of Redd Overlap	03/03/2025		03/10/2025		03/17/2025		03/24/2025	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%	No Survey Conducted							
5-10%								
10-15%								
15-20%								
20-25%								
25-30%								
30-35%								
35-40%								
40-45%								
45-50%								
50-55%								
55-60%								
60-65%								
65-70%								
70-75%								
75-80%								
80-85%								
85-90%								
90-95%								
95-100%								
TOTALS								

Table A8. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA between the weeks of March 31, 2025 and April 21, 2025.

Percentage of Redd Overlap	03/31/2025		04/07/2025		04/14/2025		04/21/2025	
	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative	Within Stratum	Cumulative
0-5%	No Survey Conducted							
5-10%								
10-15%								
15-20%								
20-25%								
25-30%								
30-35%								
35-40%								
40-45%								
45-50%								
50-55%								
55-60%								
60-65%								
65-70%								
70-75%								
75-80%								
80-85%								
85-90%								
90-95%								
95-100%								
TOTALS								

Table A9. Redd egg pocket overlap magnitude within each stratum including cumulative totals in the Englebright Dam study area of the lower Yuba River, CA for the week of April 28, 2025.

Percentage of Redd Overlap	04/28/2025				
	Within Stratum	Cumulative			
0-5%					
5-10%					
10-15%					
15-20%					
20-25%					
25-30%					
30-35%					
35-40%					
40-45%					
45-50%		No Survey			
50-55%		Conducted			
55-60%					
60-65%					
65-70%					
70-75%					
75-80%					
80-85%					
85-90%					
90-95%					
95-100%					
TOTALS					

9. APPENDIX B

Table B1. Cumulative redd counts, cumulative number of superimposed redds, average egg pocket ellipse overlaps and cumulative index of redd superimposition impact in the Englebright Dam study area of the lower Yuba River, CA from September 16, 2024 to April 28, 2025.

Week	Number of Redds in Analysis	Cumulative Number Superimposed	Average Egg Pocket Ellipse Overlap	Cumulative Index of Superimposition Impact
9/16/2024	0	0	0	0
9/23/2024	0	0	0	0
9/30/2024	0	0	0	0
10/7/2024	3	0	0	0
10/14/2024	3	0	0	0
10/21/2024	3	0	0	0
10/28/2024	4	0	0	0
11/4/2024	7	2	0.330008	0.094288
11/11/2024	10	2	0.330008	0.066002
11/18/2024	12	2	0.330008	0.055001
11/25/2024	12	2	0.330008	0.055001
12/2/2024	15	2	0.330008	0.044001
12/9/2024	17	2	0.330008	0.038825
12/16/2024	17	2	0.330008	0.038825
12/23/2024	17	2	0.330008	0.038825
12/30/2024	**No Survey Conducted**			
1/6/2025				
1/13/2025				
1/20/2025				
1/27/2025				
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