State of California
Department of Fish and Wildlife

California Coastal Salmonid Monitoring Program Annual Report prepared in partial fulfillment of CDFW Fisheries Restoration Grant Program
Grantee Agreement Number: CMP-21R1001

Results of regional spawning ground surveys and estimates of total salmonid redd construction in the South Fork Eel River, Humboldt County California, 2021-2022

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October 27, 2022

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ABSTRACT

The Adult Salmonid Redd Abundance Monitoring Project develops annual salmonid redd abundance estimates in the South Fork Eel River (SFER) to inform conservation strategies for the state and federally threatened Southern Oregon/Northern California Coast Coho Salmon Evolutionarily Significant Unit (SONCC ESU)(Coho Salmon). The survey is designed to capture the entire spawning universe of Coho Salmon in the SFER and provides a complete estimate of the redd abundance for Coho Salmon. Other species such as Chinook Salmon and steelhead are incidentally observed during surveys and that data is used here to generate partial estimates of their respective redd abundances; however, due the spatial and temporal constraints of this survey these estimates do not reflect true abundance nor should be viewed as indices of abundance for these species. During year 2021- 2022 of the SFER Adult Salmonid Redd Abundance Monitoring Project, 265 spawning ground surveys were conducted over 36 spatially balanced and randomly reaches in the SFER watershed from October 27, 2021 to May 13, 2022. Each reach was surveyed an average of 7.36 times, and the average interval between surveys over all reaches was 16.95 days. Surveyors observed a total of 65 live Coho Salmon, 13 live Chinook Salmon, 23 live steelhead, and 11 unidentified salmonids42 Coho Salmon carcasses, 10 Chinook Salmon carcasses, three steelhead carcasses, and 11 unidentified salmonid carcasses. A total of 261 redds were detected, of which 17 redds were observed to be associated with a specific salmonid species. The remaining 244 redds were assigned a salmonid species using a k-Nearest Neighbors algorithm. The number of redds observed in randomly selected sample reaches was expanded to estimate the number of redds constructed across the entire SFER sample frame. Redd abundance estimates for the 2021 -2022 spawning season in the SFER, including 95% confidence intervals, were 941 (498 - 1380) Coho Salmon redds, 155 (44 - 266) Chinook Salmon redds, and 397 (187 - 607) steelhead redds.

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1 INTRODUCTION

1.1 BACKGROUND

Coho Salmon (*Oncorhynchus kisutch*) in the Southern Oregon/Northern California Coast (SONCC) Evolutionarily Significant Unit (ESU) were listed as threatened under the federal Endangered Species Act in 1997 (62 FR 24588); and their listing was reaffirmed in 2005 (70 FR 37159) and 2014 (79 FR 20802). The SONNC Coho Salmon ESU was also listed as threatened under the California Endangered Species Act in 2002 (CDFG 2002). Both the California Department of Fish and Wildlife (CDFW) and the National Marine Fisheries Service (NMFS) have developed recovery plans for Coho Salmon outlining recovery goals, prioritizing recovery actions, and offering criteria that must be met in order to delist the species (CDFW 2004, NMFS 2014). Long-term population monitoring is an essential component of these recovery plans, as metrics are needed to assess recovery actions and track the species' progress towards recovery.

The 2011 CDFW "*Fish Bulletin 180 California Coastal Salmonid Monitoring Plan*" (CMP) established the approach for monitoring ESA/CESA listed anadromous salmonid population(s) status and trend in coastal California (Adams et al 2011). In the CMP's Northern California area, adult salmonid population abundance can be monitored using extensive spawning ground surveys to estimate total redd escapement within a survey area/sample frame. Within the SFER, this method is logistically feasible and appropriate when focusing the surveys on Coho Salmon and thus the sample frame is defined for this species specifically. Each year spawning ground surveys are conducted on a random and spatially balanced sample of survey reaches, drawn from a survey frame encompassing all potential spawning habitat available to Coho Salmon within the designated survey area. Georeferenced live salmonids, salmonid carcasses, and redd observation data are collected in each reach. The number of redds per salmonid species identified by observation and data analysis within the sample reaches is then expanded to estimate total redd escapement for the entire sample frame (Adams et al 2011).

1.2 STUDY AREA

The South Fork Eel River (SFER) flows through Mendocino and Humboldt counties and is a significant tributary within California's third largest watershed (see Figure 1). The SFER's confluence with the Eel River is located approximately three miles north of the town of Weott, CA and approximately 40 river miles upstream from the Eel River's confluence with the Pacific Ocean, near the town of Loleta, CA. The SFER basin is the second largest sub-basin in the Eel River watershed and covers approximately 690 square miles, 19% of the Eel River Basin. The SFER is approximately 105 miles long and the basin contains a total of 683 miles of perennial streams according to the USGS

7.5 Minute U.S. Geological Survey (USGS) Quadrangle maps (CDFW 2014). The predominant land uses throughout the basin are timber harvest, livestock grazing, and dispersed rural development. In 1998, the SFER was listed as an impaired water body by the federal Environmental Protection Agency due to high levels of sedimentation and high water temperature (CDFW 2014).

Historically, the SFER was the most productive major tributary of the Eel River Basin for anadromous salmonids, supporting runs of Coho Salmon, Chinook Salmon (*O. tshawytscha*), and steelhead/rainbow trout (*O. mykiss*). In 1947, a high of 25,289 returning adult Coho Salmon were counted at the Benbow Dam, located at River Mile 40 (Taylor, 1978). However, Pacific salmon runs in SFER have markedly declined since the mid-twentieth century as depicted in Figure 1 below (SFER SHaRP Collaborative 2021). In a 1994 status review of SFER Coho Salmon, the estimated returning population was approximately 1,320 adults (Brown et al. 1994).

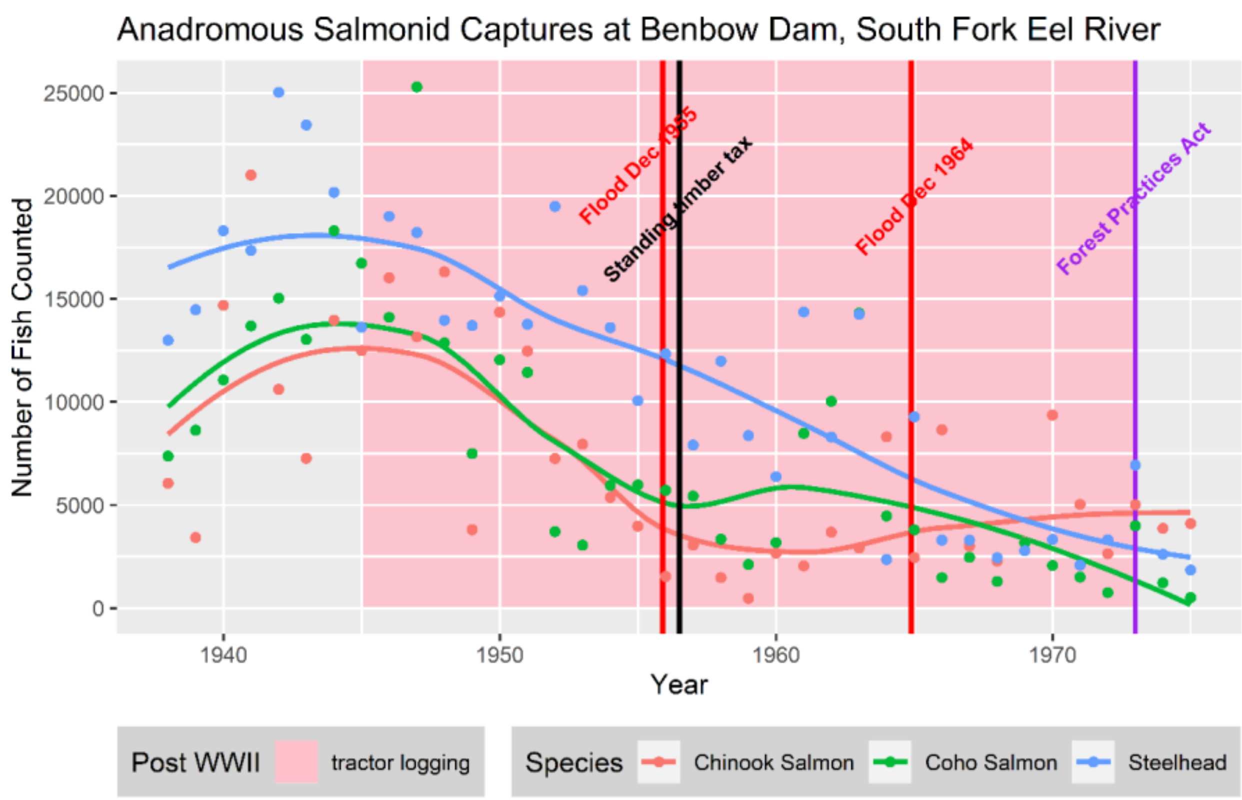

Figure 1. Counts and smoothed trend line of adult salmonids at Benbow Dam (river mile 40), SFER, 1938 - 1976. Shaded area indicates the period of increased post WWII tractor logging, and vertical lines indicate timing of major flood occurrences, and forest management legislation (SFER SHaRP Collaborative 2021).

SFER Coho Salmon are considered a core population under the federal SONCC Coho Recovery Plan and as such constitute an important demographic for long-term SONCC

Coho Salmon ESU monitoring needs (NMFS 2014). The SFER Adult Salmonid Redd Abundance Monitoring Project was initiated by the Pacific States Marine Fisheries Commission (PSMFC), in partnership with CDFW, in 2010 as a long-term effort to provide estimates of adult Coho Salmon redd abundance in the SFER Watershed. This report presents the results of the 2021 - 2022 spawning survey season, the 2021 year of the project. Previous annual reports for years 2010 through 2020 are available in the CDFW Document Library.

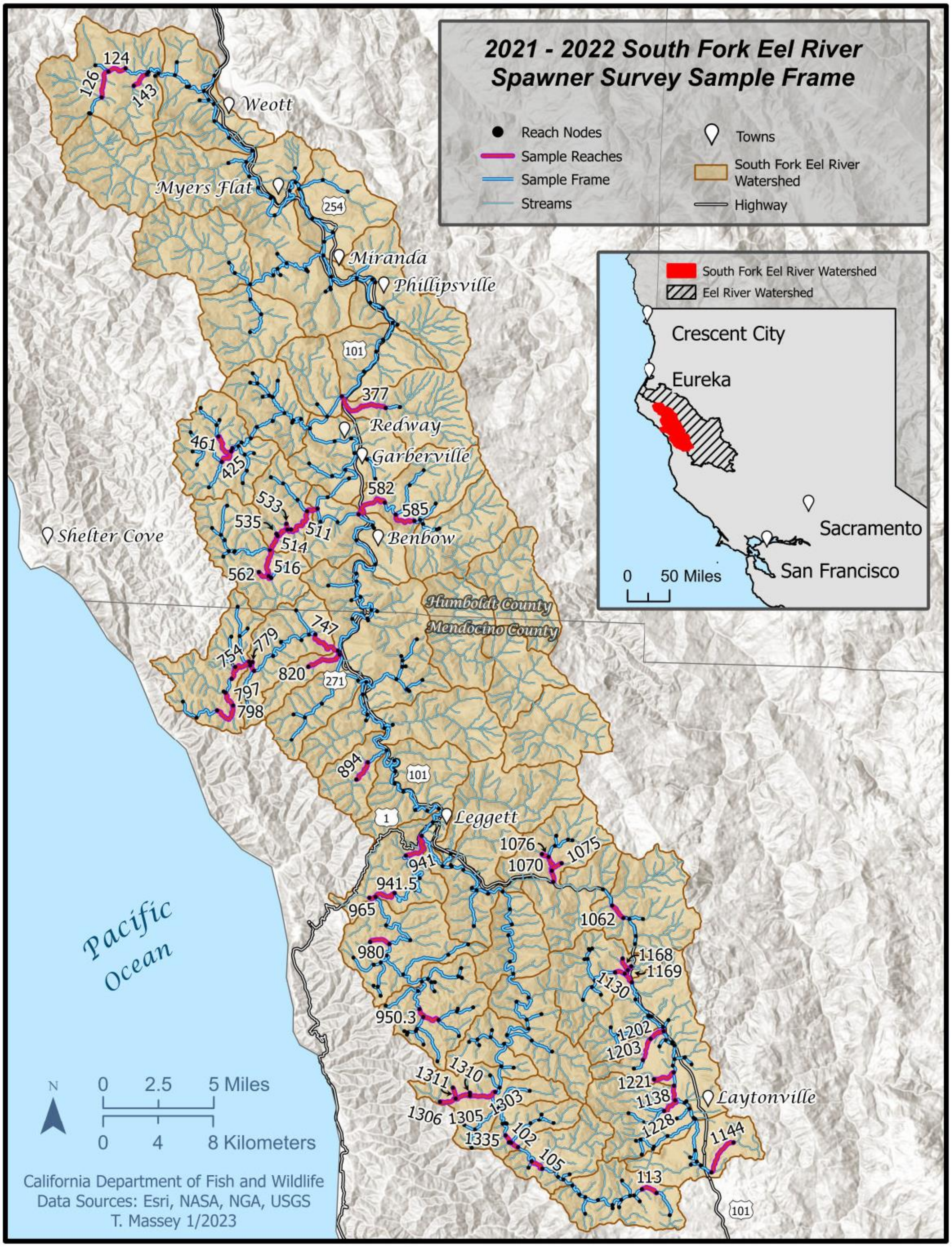

Figure 2. Map of the SFER and the reaches selected for sampling in 2021 - 2022. The inset map depicts the SFER (tan polygon) within the Eel River watershed (hashed black lines) in the northern California setting. Individual reaches of the survey frame are shown as enlarged line segments overlaying the stream lines and are separated by

black dots. Reaches surveyed during the 2022-2023 season are highlighted in pint and individually numbered.

2 METHODS

2.1 SAMPLE FRAME

A sample frame was established for SFER using five parameters: (1) documented salmonid distributions, (2) stream gradient and stream size where salmonid distributions are unknown, (3) fish passage barrier data, (4) expert knowledge of salmonid distribution and migration barriers, and (5) field reconnaissance (Garwood and Ricker 2011). These data were compiled within a Geographic Information System (GIS) to develop species-specific (coho, Chinook and steelhead) spawning distributions (sample frames).

Streams within the identified coho-specific sample frame were segmented into one to three kilometer reaches, with start and end points at identifiable landmarks (e.g. tributaries) and upstream extents at barriers to anadromy, both known and model-derived. The main focus of this survey is to obtain reliable and complete Coho Salmon redd abundance estimates and thus the frame was geographically limited to this species. Chinook Salmon and steelhead distributions overlap this frame substantially; however, it is too logistically challenging to encompass the geographic and temporal range of all three species. The resulting observations and redd abundance estimates for species other than Coho Salmon are thus incomplete. All reaches were assigned a numeric identification, known as the location code, starting at the lower-most reach and moving upstream from north to south (Figures 2 - 4). Reaches that are less than one kilometer long (sub-reaches) are surveyed together with the main reach that they flow into. All data collected in these sub-reaches are combined with that of their associated main reach (Garwood and Ricker 2011).

Since the development of the sample frame, a few minor changes were made during the first few years of implementation and the frame has since remained static. Any changes made to reach delineations were documented and the GIS metadata and the corresponding annual report. Despite minor expansions of anadromy and/or the range of Coho Salmon in the SFER as the result of additional survey work or restoration actions, the sample frame has remained relatively unchanged to maintain the relevance of population estimates through time.

2.2 SAMPLE REACH SELECTION

The SFER spawning ground surveys are conducted using a spatially balanced, random sample of stream reaches drawn from the Coho Salmon- sample frame of 204 potential reaches. Sample units selected by a Generalized Random Tessellation Stratified (GRTS) sampling scheme (McDonald 2003) were allocated to four panels that are assigned different visitation schedules (Adams et. al 2011). The four visitation schedules for panels were as follows: one panel visited every year (Panel 1), three panels visited once every three years (Panels 2 through 4), 12 panels visited once every 12 years (Panels 5 through 16), and 30 panels visited once every 30 years (Panels 17 through 46), for the life of the project (Figure 2). Each panel contains multiple sample units. The panel sampled every year has ~40% of the total number of reaches visited every year. The panels sampled every 3, 12, and 30 years each have ~20% of the total annual number of reaches. Since much of the SFER is under private ownership, a reach's inclusion in the final annual list of sample reaches is dependent on gaining stream access permission from the relevant landowners. If permission was denied or if a landowner did not respond in time for the start of the spawning season, the reach was skipped for the year and the next stream in GRTS order was added to the survey list.

NOTE: **Panel 1 gets 40% of Annual Sample. Panel 2 thru 16 "EACH" gets 30% of Annual Sample**

VISITATION SCHEDULES

Repeat Panel	Panel ↓	← YEAR → 1	2	3	4	5	6	7	8	9	10	11	12
Every Year	1	15	15	15	15	15	15	15	15	15	15	15	15
Every 3 years	2	11			11			11			11		
	3		11			11			11			11	
	4			11			11			11			11
Every 12 years	5	11											
	6		11										
	7			11									
	8				11								
	9					11							
	10						11						
	11							11					
	12								11				
	13									11			
	14										11		
	15											11	
	16												11

	1	2	3	4	5	6	7	8	9	10	11	12
Annual Sample	37	37	37	37	37	37	37	37	37	37	37	37
Cumulative UNIQUE Segments	37	59	81	92	103	114	125	136	147	158	169	180
Reserves Available	161	139	117	106	95	84	73	62	51	40	29	18

Figure 3. Example of a rotating panel design. In this example, 15 reaches (aka segments) are sampled every year, 11 reaches are sampled every 3 years, and 11 reaches are sampled every 12 years. Each season, a combined total of 37 reaches are surveyed.

Table 1. List of reaches in Panel 1 to be visited annually.

Stream Name	*Drainage*	*Location Code*
SFER	Eel River	113
Bull Creek	SFER (lower)	126
Dean Creek	SFER(middle)	377
Sproul Creek	SFER (middle)	511
Sproul Creek	SFER (middle)	514
East Branch SFER	SFER (middle)	582

Stream Name	*Drainage*	*Location Code*
Anderson Creek	Indian Creek	798
Hollow Tree Creek	SFER (upper)	950.3
Foster Creek	Rattlesnake Creek	1070
Tenmile Creek	SFER (upper)	1144
Tributary to Tenmile Creek	Tenmile Creek	1168
Big Rock Creek	Tenmile Creek	1202
Little Case Creek	Tenmile Creek	1228
Tributary to Cahto Creek	Tenmile Creek	1260
Dutch Charlie Creek	SFER	1306

2.3 REACH SURVEY PROTOCOL

We conducted spawning ground surveys following the methods of ground survey and data capture outlined in Gallagher (et al. 2014) and Adams (et al. 2011). Surveys occur during the Coho Salmon and Chinook Salmon spawning season (roughly mid-November to late February/early March during an average rainfall year). This season also overlaps a portion of the steelhead spawning season (mid-January to late April). Surveys were conducted by a two-person team, either by foot in smaller streams, or by inflatable kayak in larger streams. Each reach is intended to be surveyed once every 7 to 14 days, or as weather, flow, and turbidity conditions allow. Before each survey we collected data on weather, air temperature, water temperature and turbidity. The turbidity threshold for acceptable survey conditions is 50 centimeters measured with a secchi disk. All air and water temperatures were collected in degrees Celsius. We classified weather into five categories: (1) sunny, (2) cloudy, (3) overcast, (4) rain, and (5) snow. Apple iPads were used as data collection devices with a Pendragon Forms® data collection application. We identified live fish and carcasses to species and sex if possible and acquired latitude and longitude for every fish observation using the GPS feature in Pendragon Forms. We measured the fork length of each complete carcasses and assigned a condition code based on the level of decomposition: (1) carcass, fresh, clear eye, (2) carcass, cloudy eye, low fungus, (3) carcass, cloudy or no eye, heavy fungus, (4) carcass, skin and bones with head, (5) carcass, skin and bones no head, and (6) loose tag no fish. We marked carcasses as “captured” with a uniquely numbered jaw tag. If a carcass was recovered with a jaw tag on a subsequent survey, it was considered “re-captured”. When viable, we collected biological samples of tissue and scales Scale and tissue samples were sent to CDFW’s Tissue Library in West Sacramento.

2.4 ESTIMATION OF TOTAL REDD ABUNDANCE WITHIN SURVEY FRAME

The redd data collected over the course of the spawning season was expanded to estimate total Coho Salmon redd abundance over the entire survey frame using the steps outlined in Ricker et al. 2014. To estimate total redd abundance, (1) all redds were assigned a species, (2) within-reach redd abundance was estimated, and (3) within-reach redd abundance was expanded to estimate total redd abundance across the entire survey frame.

2.4.1 Assigning Species to Redds

Only redds directly associated with a live fish building or guarding them, are considered unambiguously known to species. To assign a species to the redds labelled in the field as "unidentified species" we used a k-Nearest Neighbor (kNN) model to predict which species (Coho Salmon, Chinook Salmon, or steelhead) was most likely to have constructed the redd (Ricker et al. 2014). The k-Nearest Neighbors algorithm is a simple non-parametric form of machine learning where an object is classified by a majority vote of its k-nearest neighbors in Euclidean distance. Euclidean distance is a measure of distance between individuals and generalizes Pythagoras's theorem to multiple dimensions. We use location (latitude and longitude) and date as spatial and temporal dimensions and calculated Euclidean distance (d_{ij}) between redd x_i and x_j as:

$$d_{ij} = \sum_{k=1}^{n} \sqrt{\left(x_{ik} - x_{jk}\right)^2}$$

Fish and redd attributes are represented by n. When only Julien date is used $n = 1$. When all three attributes are used $n = 1$. The kNN model selects classes based on the shortest euclidean distance, and because the spatial distance is in meters, and the distance in time (number of days) are on distinctly different scales, we standardized attribute data values into z-scores by:

$$z_i = \frac{x_i - \mu}{\sigma}$$

The distance between the raw score and population mean μ is represented by z. We classified each redd by the majority vote of the three nearest neighbors ($k = 3$) based on the previous work of Ricker and Stewart (2011) who fit used values of k from 3 to 10 and found a k of 3 was the smallest number of neighbors that produced the highest percentage correct classification rate with the fewest ties. If ties were encountered in the vote, they were mitigated by using the majority vote of the entire data set (Ricker et al. 2013). Both known species redds and live fish observations are used as known elements in the training set of data in the kNN model. We used only known species fish and redds from the current survey year in the training data set available to make redd predictions.

We used leave-one-out-cross-validation (LOOCV) of the known redds in the survey to evaluate the performance of the kNN model. LOOCV is an iterative process where each redd is removed in turn from the training data set of known species redds, the model re-fit to the data and the removed redd predicted to species. Known species redds were paired with the LOOCV prediction and confusion matrices tabulated, indexed by row of the true species of the redd and by columns of the predicted redd. From these matrices, the performances of the models are evaluated for each species by assessing their classification sensitivity, specificity, and accuracy. Values generated for these measures of model performance range from zero to one, with measures closer to one indicating better model performance. Sensitivity, or power, is the proportion of the total known redds of a particular species to the total number of redds classified as that species. High sensitivity indicates a low type ll error rate (e.g. a model is not predicting redds as species two when, in the training data set, they are known to be species one). Specificity, or confidence, is the proportion of redds that are known to be a different species, to the total number classified as different species. High specificity indicates a low type l error rate (a model is not incorrectly predicting a redd to be species two when it is known to be species one). Overall model accuracy (one minus the apparent error rate) is the proportion of the total number of predictions that are correct. Ninety-five percent confidence intervals of the accuracy rate were produced using an exact binomial test. Good classifiers have high accuracy, and both high sensitivity and high specificity (Ricker et al. 2013). All calculations are performed using the program R with the “class” package (Venables and Ripley 2002) and the “caret” package (Kuhn 2013).

2.4.2 Estimation of Within-Reach Abundance

High stream discharge and time between repeated surveys may scour or flatten redds and therefore obscure them from potential counting (Jones 2012). To account for the unseen fraction of redds constructed then subsequently obscured from view between repeated surveys, the total number of redds constructed within a survey reach is estimated using a flag-based mark-recapture model. The total count of individually observed and flagged redds for a given reach is divided by the square root of the seasonally pooled redd survival rate. We calculated redd survival as the fraction of re-observed and still identifiable flagged redds (“recaptures” assigned age 2 or 3) to the total number of flagged redds available to for potential re-observation (“marked”). Taking the square root of this fraction assumes the deposition of redds occurs at the midpoint between survey intervals (Schwarz et al. 1993). This function can be defined as:

$$\check{\tau}_J = B_0 + \frac{\sum_{i=2}^{k} B_i - 1}{\sqrt{\check{S}_p}}$$

where $\check{\tau}_J$ is the estimate of the total number of redds within a sample reach J; B_i is the number of new redds on the survey occasion; *k* is the total number of survey occasions; and B_0 is the number of redds observed on the first survey of the season. The numerator of the second term is then the sum of all new redds observed from the second occasion to the last occasion, divided by survival of flagged redds pooled across all survey occasions for which at least one new redd of the target species was observed (Ricker et al. 2013 and Walkey and Garwood 2015):

$$\check{S}_p = \frac{\sum_{i=1}^{k-1} R_{i+1}}{\sum_{i=1}^{k-1} M_i}$$

Where $\check{S}_p$is the pooled survival rate of flagged redd i, is the survey with k being the total number of surveys. The numerator is then the sum of recaptured redds from the second survey occasion to the last survey occasion, and the denominator is the sum of marked redds and recaptured redds that were still visible from the first occasion to the second to last occasion (Walkey and Garwood 2015, Ricker et al. 2013). A bootstrap resampling from an assumed binomial distribution is used to represent the uncertainty of the pooled seasonal redd survival term in the estimator of total number of redds within the reach. This can be defined as:

$$se(\check{T}) = N\sqrt{\left(1-\frac{n}{N}\right)\widetilde{\Theta_b}} + \frac{1}{N_n}\left(\sum_{i=1}^{n} \theta_w\right)$$

N accounts for the total number of sample reaches in the South Fork Eel sample frame and *n* is the number of reaches sampled. $\widetilde{\theta_b}$ accounts for the between reach variance of bootstrapped replicates and $\widetilde{\theta_w}$ represents within reach variance of bootstraps replicates. This is derived from methods found in Ricker et al (2014). The variance of the estimated total number of redds within a reach is calculated as the variance of the resultant bootstrap distribution (Manly 1997, Ricker et al. 2013).

Additional assumptions applied to this model are:

1. Surveyors correctly identify all redds and no redds are missed during each survey.
2. Once a redd has been classified as “not visible” it does not become visible at a later occasion.
3. All redd flags are re-observed, identifiable, and recorded.
4. All marked redds have the same probability of survival, regardless of species or age and across all occasions.
5. New redds are constructed at the mid-point between survey intervals.

2.4.3 Estimation of Total Redd Abundance

A Simple Random Sample estimator is used to expand the number of redds in the sample reaches to an estimated total over the entire sample frame. The estimated total is calculated as the product of the total number of reaches in the sample frame and the mean number of redds of the sample reaches. The total variance is the sum of the within reach variance of the sample reaches and the between sample reach variance (Adams et al. 2011). It is defined as:

$$\check{T} = N\left(\frac{\sum \frac{n}{j=1} \check{\tau}_j}{n}\right)$$

N is the number of reaches in the sample frame, *n* represents surveyed reaches, $\check{T}_j$ is the estimate of the total number of redds in a sample reach.

3 RESULTS

3.1 SURVEY STATISTICS

Surveys began on October 27, 2021 and ran through May 13, 2022. During this time, monitoring crews completed 265 spawning ground surveys of 36 randomly selected stream reaches with an additional 60 surveys conducted on 12 associated sub-reaches (Table 2, Figure 2). Each reach was surveyed between 3 and 14 times over the survey season and the average number of visits per reach was ~7 (Table 2). The average interval between surveys over all reaches was ~17 days (Table 2). The most frequently surveyed reach was Redwood Creek (425) with 14 surveys total between December 7, 2021 to April 27, 2022. The least frequently visited stream reach was Unnamed Tributary of Tenmile Creek (1221) with only three surveys completed (Table 2). The survey interval varied between reaches due to survey conditions and accessibility including reaches with poor water clarity or locations that are difficult and time consuming to access. SFER (113) held the lowest value for average time between surveys at 7 days (Table 2). The highest value for survey intervals is Dean Creek (377) with a mean of 28.5 days between surveys (Table 2). The greatest discharge value recorded at the South Fork Eel USGS Leggett Gage during the season was 14,400 Cubic Feet per Second (cfs) on October 24th. The lowest recorded discharge value of 118 cfs was recorded on April 10 (Figure 3). A prolonged dry spell between the first week of January and the first week of April resulted in exceptionally low flows during what is otherwise a peak migration and spawning season. These low flow conditions likely altered spawning distribution for Coho Salmon and steelhead; several concentrations of adult steelhead holding in mainstem pools were observed incidentally as well as mainstem steelhead redd construction.

Table 2. 2021 – 2022 survey frequency by reach. Reaches are listed by location code (location codes listed in parentheses are subreaches). Mean indicates the average number of days between surveys, Max is the maximum number of days between surveys, and N is the total number of surveys. Subreaches with a different number of surveys and mean days between surveys from the main reach are indicated with parentheses.

Stream	Reach	N (surveys)	Mean	Max	SD
SFER	102	9	11.25	41	12.07
SFER	105	8	12.86	41	12.82
SFER	113	8	7	9	1.73
Bull Creek	124	7	24.17	49	15.96
Bull Creek	126	9	20.25	49	15.49
Grasshopper Creek	143	12	18	68	18.72
Dean Creek	377	5	28.5	70	27.72
Redwood Creek (Briceland)	425	14	10.85	29	6.12
Miller Creek	461	12	12.82	29	7.53
Sproul Creek	511 (533)	11 (8)	18.1	40	10.83
Sproul Creek	514 (535)	13 (8)	13	28	6.98
Sproul Creek	516 (562)	11 (5)	14.2	38	10.59

Stream	Reach	N (surveys)	Mean	Max	SD
East Branch SFER	582	8	22	60	22.48
East Branch SFER	585	8	22	60	22.48
Indian Creek	747	5	22.5	46	15.76
Indian Creek	754 (779)	5 (3)	20.5	33	8.96
Anderson Creek	797	5	20.75	34	9.07
Anderson Creek	798	5	20.75	34	10.28
Piercy Creek	820	5	24.25	46	15.11
Wildcat Creek	894	3	21	27	8.49
Hollow Tree Creek	941	6	17.8	43	14.32
Hollow Tree Creek	941.5 (965)	8 (6)	21.86	57	18.72
Hollow Tree Creek	950.3 (980)	8 (4)	19.71	55	17.92
Rattlesnake Creek	1062 (1106)	7 (4)	11.33	32	10.15
Foster Creek	1070 (1075, 1076)	5 (4, 3)	13	17	3.27
Tenmile Creek	1130	6	17.6	41	13.69
Tenmile Creek	1138	6	16.6	36	11.39
Tenmile Creek	1144	5	12	18	5.16
Unnamed Tributary	1168 (1169)	6 (4)	17.6	41	16.13
Big Rock Creek	1202	9	19.62	48	15.73
Big Rock Creek	1203	8	17	48	14.98
Unnamed Tributary	1221	3	7.5	8	0.71
Little Case Creek	1228	6	16.6	36	11.39
Dutch Charlie Creek	1303 (1310)	9 (7)	13.38	35	9.68
Dutch Charlie Creek	1305 (1311)	6 (4)	14.4	30	9.42
Dutch Charlie Creek	1306	4	9.67	15	4.62

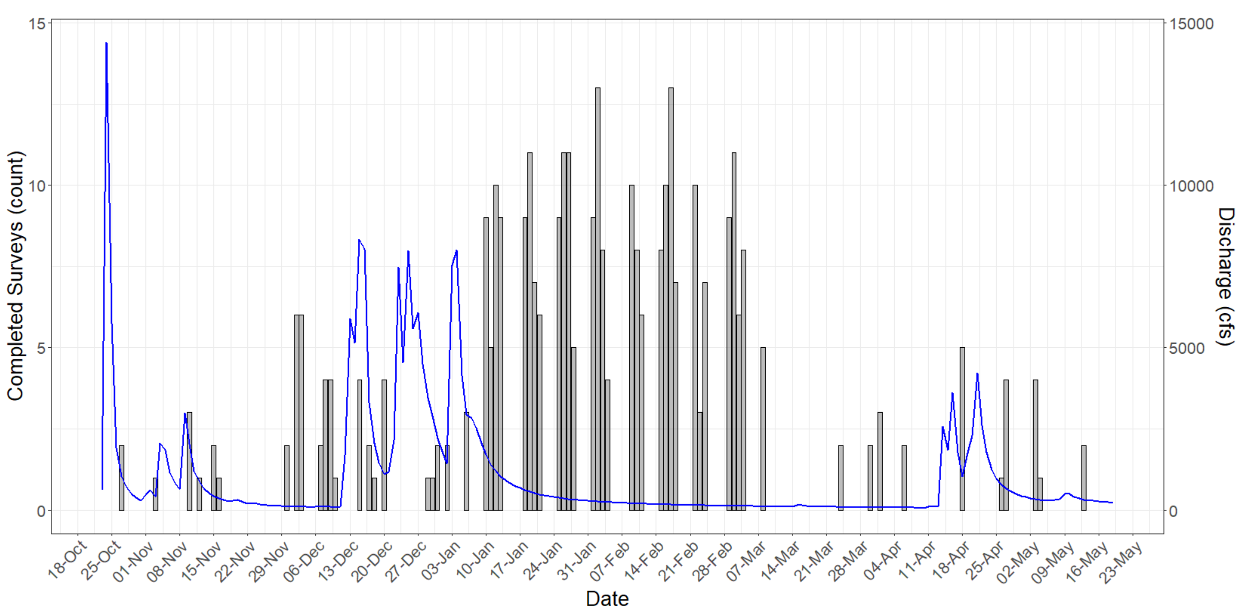

Figure 4. Daily spawning ground surveys completed (grey bars) in the SFER compared to discharge (in cubic feet per second, cfs) measured at the USGS gauging station near Leggett, CA between October 22th, 2021 and May 20th, 2022. Discharge values shown

were recorded at midnight each day and are presented on the secondary y-axis (blue line).

3.2 FISH OBSERVATIONS

A total of 60 live Coho Salmon, 13 Chinook Salmon, 22 steelhead and 11 unidentified anadromous salmonids were observed over the survey period (Table 3, Figure 5). 42 Coho Salmon carcasses, 10 Chinook carcasses, three steelhead carcasses and 18 unidentified carcasses were documented throughout the season (Table 4, Figure 5).

The first live Coho Salmon was identified on December 18th and the last on February 17th. Peak Coho Salmon observations occurred during the week of January 10th with a total of 35 live observations (Figure 5). Coho were observed on 10 out of the 36 surveyed reaches (Table 3). Anderson Creek (798) was the reach with the greatest number of Coho Salmon observations (n=14) throughout the season (Table 3). The first coho carcass was recorded on January 2nd and last on March 2nd (Table 4,Figure 5).

The first live Chinook was observed on December 2nd and the last on January 6th. Peak Chinook observations occurred on December 17th with 7 live fish observed in Grasshopper Creek (143) (Table 3, Figure 5). Chinook were observed on 5 of the 36 reaches (Table 3). The first Chinook carcass was recorded December 2nd on and the last on May 15th (Table 4,Figure 5).

The first live Steelhead was observed on January 13th and the last on April 18th. Peak steelhead observations occurred during the week of March 28th with 5 live observations (Table 3, Figure 5). Sproul Creek (514) yielded the greatest number of Steelhead observations (n=8), and steelhead were observed on 11 reaches (Table 3). The first of the three steelhead carcasses was recorded on February 16th and the last on March 30th (Table 4).

3.3 REDD OBSERVATIONS

Surveyors identified 12 known Coho Salmon redds, one known Chinook Salmon redd, and four known steelhead redds (Table 3). Cross validation of the known redds resulted in the kNN model correctly assigning a species to 15 of the 17 known redds for an overall accuracy of 88.23%. There were no live species associated with the remaining 244 redds observed, thus the kNN predictions were used to assign a species most likely to have constructed each redd. It should be noted that early season survey effort was minimal and may have missed some Chinook Salmon spawning activity, and for this reason the kNN model may be slightly biased towards Coho Salmon and Steelhead redd identification.

3.4 TOTAL REDD ABUNDANCE

Sufficient flag marking and re-observation data was available to apply the within-reach estimation model in ten of the 32 randomly selected sample reaches where known or predicted Coho Salmon redds were observed. Aggregate counts of individual known and predicted redds by species were used in the remaining 12 reaches where no reach level expansion was available. The total redd abundance estimate for Coho Salmon for the 2021 - 2022 SFER spawning season, with 95% confidence intervals, is 941 (502, 1380) (Table 5). The total redd abundance estimates for Chinook Salmon and steelhead are 155 (44, 266) and 397 (187, 607), respectively (Table 5).

Table 3. Counts of observed live fish and redds by location code and species in the SFER over the course of the 2021-2022 spawning season.

Location Code	Live Chinook	Known Chinook Redds	Live Coho	Known Coho Redds	Live Steelhead	Known Steelhead Redds	Unk. Live Fish	Unk. Redds	Total Live Fish	Total Redds
102	2	-	-	-	-	-	-	3	2	3
105	-	-	-	-	-	-	-	5	-	5
113	-	-	4	2	1	-	-	7	5	9
124	-	-	-	-	1	1	-	-	1	1
126	-	-	-	-	3	-	-	3	3	3
143	7	1	-	-	-	-	-	5	7	6
377	-	-	-	-	-	-	-	-	-	-
425	-	-	2	-	-	-	1	6	3	6
461	-	-	6	1	-	-	-	11	6	12
511	-	-	1	-	-	-	1	7	2	7
514	-	-	2	-	8	1	-	15	10	16
516	1	-	7	-	-	-	-	12	8	12
582	-	-	-	-	1	-	-	-	1	-
585	-	-	-	-	-	-	-	-	-	-
747	-	-	-	-	1	-	-	2	1	2
754	-	-	-	-	-	-	-	33	-	33
797	2	-	-	-	-	-	-	16	2	16
798	-	-	14	4	-	-	1	20	15	24
820	-	-	-	-	3	1	4	7	7	8
894	-	-	-	-	-	-	-	4	-	4
941	-	-	-	-	1	-	-	3	1	3
941.5	-	-	-	-	-	-	2	6	2	6
950.3	-	-	8	1	-	-	-	23	8	24
1062	-	-	-	-	-	-	-	1	-	1
1070	-	-	-	-	1	-	1	3	2	3
1130	1	-	-	-	-	-	-	5	1	5

Location Code	Live Chinook	Known Chinook Redds	Live Coho	Known Coho Redds	Live Steelhead	Known Steelhead Redds	Unk. Live Fish	Unk. Redds	Total Live Fish	Total Redds
1138	-	-	-	-	-	-	-	9	-	9
1144	-	-	-	-	-	-	-	2	-	2
1168	-	-	-	-	-	-	-	-	-	-
1202	-	-	-	-	-	-	-	-	-	-
1203	-	-	-	-	-	-	-	-	-	-
1221	-	-	-	-	-	-	-	-	-	-
1228	-	-	-	-	1	1	1	1	2	2
1303	-	-	6	1	1	-	-	8	7	9
1305	-	-	10	1	-	-	-	4	10	5
1306	-	-	-	-	-	-	-	2	-	2
Total	13	1	60	10	22	4	11	223	106	238

Table 4. Carcasses observed per week during the 2021-2022 SFER spawning ground survey season.

Week Beginning	Chinook salmon	Coho salmon	Steelhead	Unidentified	Total
2021-11-29	2	-	-	-	2
2021-12-06	2	-	-	-	2
2021-12-13	-	-	-	-	-
2021-12-20	-	-	-	-	-
2021-12-27	-	2	-	-	2
2022-01-03	1	1	-	-	2
2022-01-10	2	11	-	2	15
2022-01-17	1	13	-	-	14
2022-01-24	-	4	-	-	4
2022-01-31	-	7	-	3	10
2022-02-07	-	2	-	7	9
2022-02-14	1	1	1	3	6
2022-02-21	-	-	-	1	1
2022-02-28	-	1	-	1	2
2022-03-07	-	-	-	-	-
2022-03-14	-	-	-	-	-
2022-03-21	-	-	1	1	2
2022-03-28	-	-	1	-	1
2022-04-04	-	-	-	-	-
2022-04-11	-	-	-	-	-
2022-04-18	-	-	-	-	-
2022-04-25	-	-	-	-	-
2022-05-02	-	-	-	-	-
2022-05-09	1	-	-	-	1
Total	10	42	3	18	73

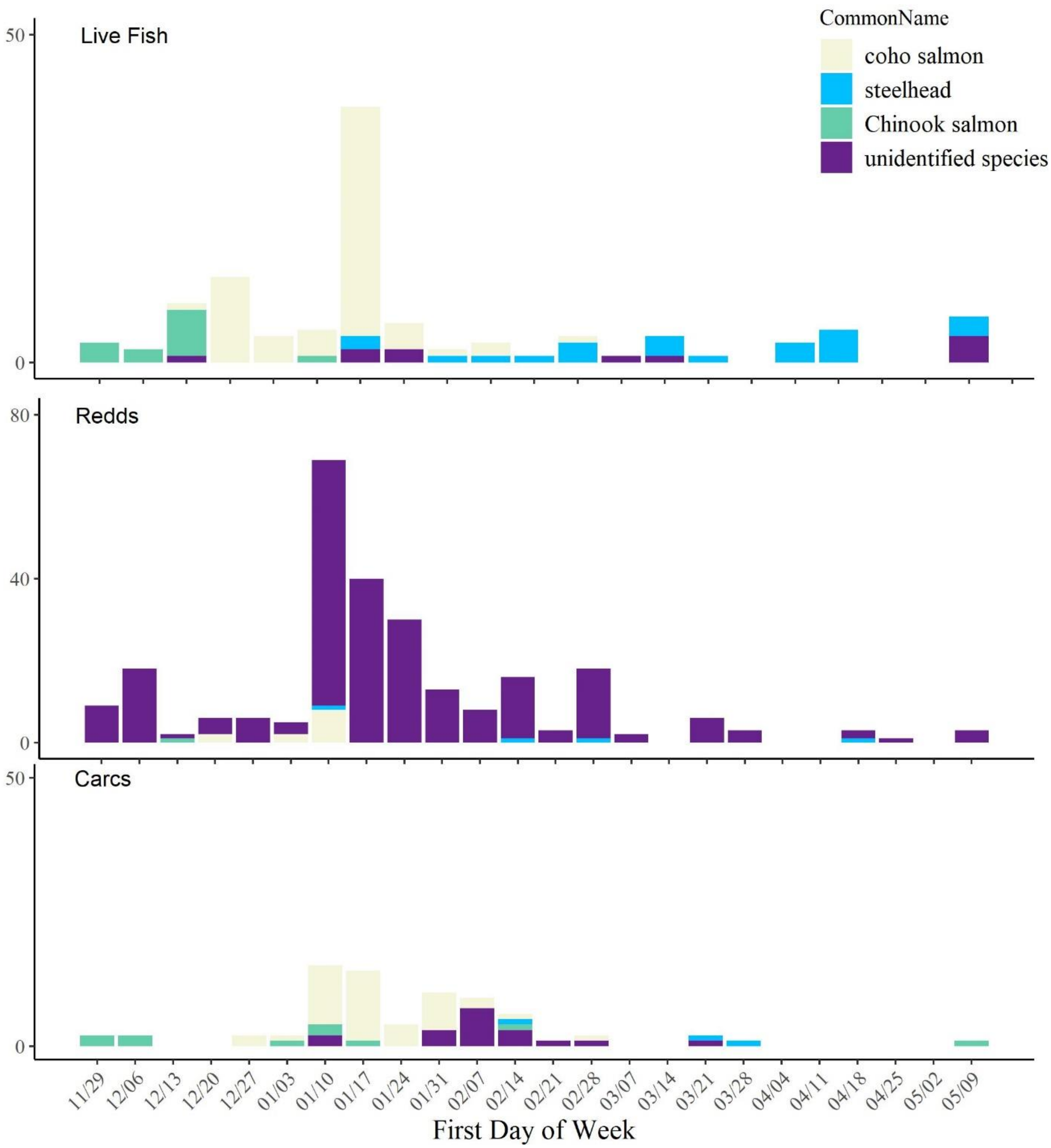

Figure 5. Observations per week of live adult salmonids (top), known and unknown redds (middle), and carcasses (bottom) throughout the 2021-2022 SFER spawning season.

Table 5. Estimated total redd abundance for the SFER by species with 95% confidence intervals created using a Simple Random Sample estimator (Adams et al. 2011).

Value	Chinook	Coho	Steelhead
Estimated number of redds	155	941	397
95% Confidence Intervals	44, 266	502, 1380	187, 607

4 DISCUSSION

The winter precipitation pattern for the 2021 - 2022 season allowed for broad distribution of earlier migrating salmonids (Chinook Salmon and Coho Salmon). The first significant rise in South Fork Eel River flows began on October 20th peaking at approximately 17,400 CFS at the USGS Miranda gage on October 24th. This storm ended up being the highest peak flow for the entire water year, an unusual event for October. A number of smaller rain events maintained a high base flow through most of November. Thereafter, a series of storms spanning mid-December through the first week of January sustained flows between 1700 CFS and 11,00 CFS. All of this precipitation allowed fall Chinook Salmon and the bulk of the Coho Salmon to access spawning habitat in tributaries (Figure 4) resulting in the highest counts of live fish and redds in the first three weeks of January (Figure 5). Although survey efforts were limited during November and December due to staffing limitations, surveyors were able to document live Chinook Salmon, carcasses, and redds throughout the SFER in a wide range of habitats including some of the smaller tributaries (e.g. Anderson Creek, Little Case Creek, Grasshopper Creek, and Dutch Charlie Creek). We believe the early effort placed across the landscape was sufficient to capture the general timing and spatial extent of spawning Chinook Salmon, Coho Salmon, and steelhead. However, it should be noted that only 6.5 % of redds were observed with a salmonid species, and this places a high reliance on the kNN assignment of species to unknown redds. This is not unique to this season and is rather an intrinsic characteristic of conducting spawner surveys. It is difficult to capture the cryptic and ephemeral behavior of spawning salmonids without an extremely high level of effort. It should be noted that the confidence intervals do not account for much of the uncertainty described here and rely on the variance of the sample data collected among reaches, which for 2021-2022 and many other seasons is relatively high. Due to the patchy and variable distribution of fish across the landscape the majority of redds were observed in a relatively small number of the total reaches thus inflating variance (Table 3, Table 6, Figure 8. South Fork Eel River Coho Salmon redd abundance estimates from 2010 to 2021. Each of the 3 cohorts are separated out across time and represent by an individual line and 95% confidence interval.).

From first week of January until early April no significant precipitation fell in the basin, and this resulted in unusually prolonged low flow conditions which likely challenged the remaining migrating adult salmonids and left several redds dewatered. Spawning activity continued throughout this period, however, there was a precipitous decline in new redds and live fish observed after the month of January. This was particularly concerning as the months progressed into peak steelhead season and flows continued to drop. Since many of the redds were built during the relatively high base flow of the early season, dropping water levels left many redds perched above the stream (Figure 6). At least 22 redds were noted as having some portion of their structure dried or separated from the stream and seven were noted as being completely dry with no visible surface water present between mid-January and the first week of April. The productivity of these desiccated redds is unknown, but it is unlikely some redds produced offspring due to the longevity of the dry period.

Normally, surveys would conclude sometime in early March after Coho Salmon have finished spawning, but the 2021 - 2022 season was anomalous with persistent January to March low flow conditions. Therefore, it was prudent to carry surveys forward till more rain fell allowing any holding adult salmonids to enter tributaries again. During the week of April 8th, precipitation finally occurred bringing with it nearly two weeks of passable flows. Subsequent surveys did not confirm any late arriving Coho Salmon, but there was a slight uptick in the number of steelhead and unidentified species arriving at this time. There was also an unseasonably late Chinook Salmon carcass found during the last week of surveys, but it is unclear if it was just an unusually well-preserved carcass or late migrant. During this low-flow period, many steelhead were observed holding in large pools of the South Fork Eel and Lower Eel River. Additionally, several redds were observed in pool tails and riffles of the mainstem South Fork Eel River, indicating that steelhead were spawning wherever they could while flows remained low.

The primary focus of this project is Coho Salmon and, as described earlier, spawning ground surveys are conducted over the spatial extent and time period deemed ideal for Coho Salmon data capture. Because the spatial extent of Chinook Salmon and steelhead spawning habitats are greater than the spatial extent of the Coho Salmon sampling frame, and because the duration of the steelhead spawning run extends beyond the Coho Salmon spawning run, estimates of total redd construction for Chinook Salmon and steelhead presented here are incomplete and likely an underestimate of these species' populations in the SFER. However, observations of Chinook Salmon and steelhead spawn timing and distribution are valuable to understanding the ecology of the basin. The relatively small number of steelhead observed on spawning grounds was somewhat alarming, especially after the April rise in stream flows. Snorkel counts from the following summer indicated that young-of-year Coho Salmon outnumbered young-of-year steelhead by nearly 2:1 (Loomis in prep); confirming our observations from the winter and spring and indicating there was not much additional spawning after surveys ended. While there is not a population estimate to reference for the SFER, sonar counts of steelhead on the mainstem Eel River were relatively low (Kajtaniak and Roberts 2022). These observations combined with other reports of low steelhead numbers across the west coast raise some cause for concern and perhaps more focused steelhead monitoring is warranted.

An interesting result of this unusually dry winter was that primary production seemed to ramp up earlier than usual as the standing crop of algae in the South Fork Eel was comparable to what is normally seen in late May or June (Figure 7). The lack of scouring flows combined with clear water conditions and sunny skies allowed algae to establish and grow quickly, potentially advancing invertebrate food production. Subsequent snorkel observations conducted in the SFER sample frame between June and September indicated that many young-of-year Coho Salmon were growing fast but there was also a high degree of variation in sizes. This could be due to the seasonally unusual spring-like conditions that early-emerging Coho Salmon encountered and lead to higher growth rates and an early competitive edge for a subset of the population. Variation in size could also be related low flow and delayed fry emergence. This variation was tracked through the subsequent winter and spring as the Coho Salmon began emigrating and smolting and were captured during monitoring events in the Eel River estuary as well as in downstream migrant traps in tributaries, such as Hollow Tree Creek and Indian Creek. These observations remain anecdotal as little data on salmonid growth and diet is available in the basin.

The SFER Adult Redd Salmonid Abundance Monitoring Project was initiated in 2010 and has now been operating for over a decade as a long-term effort to provide estimates of adult Coho Salmon redd abundance in the SFER Watershed (Table 6). As of this year, we now have four years of monitoring for each cohort of Coho Salmon in the South Fork, increasing our range of inference on population. To illustrate this data, the time series of population estimates for each cohort is plotted in Figure 8. Although a thorough trend analysis has not been conducted on this data, preliminary data exploration reveals a weak overall negative trend in the population and a strong cohort effect. This is probably driven greatly by cohort A which has taken a sharp decline since monitoring began in 2010 with the lowest ever redd abundance estimate of 138 redds in 2019. All three cohorts were likely impacted in some way by the multiple years of extreme drought and marine heatwaves between 2014 and 2016, but cohort A likely was hit the hardest as their young of year were born into the beginning of a difficult three-year dry period which also include marine heatwaves for ocean rearing life stages. The other two cohorts were somewhat stable overall and weathered the drought without significant decline, though the high degree of uncertainty in the population estimates indicated by the 95% confidence intervals complicates interpretation of these trends. With no clear signal of population recovery in SFER and amid extreme environmental stochasticity it should be recognized that there is a long road to recovery ahead for Coho Salmon and their ecosystems.

Figure 6. A redd constructed during higher flows is left perched above the stream on January 19th as flows dropped during a prolonged dry period in the winter of 2022. The pot of the redd is still wetted in the foreground while the tail spill is high and dry between the center of the frame and the bank.

Figure 7. Algal growth in the South Fork Eel River on February 10th, 2022 near Piercy, CA. Photo credit: Gabe Rossi.

Table 6. Summary of SFER Adult Salmonid Redd Abundance Monitoring Project redd estimates for survey years 2010 - 2011 through 2021 - 2022. 95% confidence intervals are included in parentheses after each respective point estimate.

Survey Year	Number of reaches surveyed	Total Number of Surveys	Average Survey Interval	Average number of surveys per reach	Estimated number of coho redds	Estimated number of Chinook redds *	Estimated number of steelhead redds *
2010 - 2011	31	151	21	5	1284 (159, 2543)	1829 (679, 2980)	288 (35, 255)
2011 - 2012	40	204	22	5	1873 (1253, 2493)	68 (15, 148)	379 (58, 818)
2012 - 2013	40	229	16	6	1340 (658, 2022)	855 (293, 1418)	761 (471, 1051)

Survey Year	Number of reaches surveyed	Total Number of Surveys	Average Survey Interval	Average number of surveys per reach	Estimated number of coho redds	Estimated number of Chinook redds *	Estimated number of steelhead redds *
2013 - 2014	39	247	27	6	939 (304, 1574)	223 (40, 423)	1055 (359, 1751)
2014 - 2015	40	248	19	6	2069 (1342, 2795)	781 (310, 1253)	967 (541, 1393)
2015 - 2016	40	190	26	5	416 (117, 715)	418 (76, 892)	1125 (686, 1563)
2016 - 2017	40	227	20	6	465 (98, 831)	1458 (923, 1992)	54 (9, 111)
2017 - 2018	37	249	16.8	6.7	1,633 (793, 2473)	867 (454, 1279)	5 (1, 15)
2018 - 2019	38	232	19.9	4.9	990 (205, 1776)	404 (131, 676)	322 (168, 476)
2019 - 2020	36	317	12.4	8.9	138 (34, 243)	135 (34, 277)	607 (381, 834)
2020 - 2021	30 (18)**	442	8.6	10.9	1700** (616, 3897)	14** (2, 31)	232** (106, 359)

Survey Year	Number of reaches surveyed	Total Number of Surveys	Average Survey Interval	Average number of surveys per reach	Estimated number of coho redds	Estimated number of Chinook redds *	Estimated number of steelhead redds *
2021 - 2022	36	265	17	7	941 (502, 1380)	155 (44, 266)	397 (187, 607)

*The SFER Salmonid Redd Abundance Monitoring Project is focused upon the temporal extent of Coho Salmon spawn timing and spatial extent of Coho spawning distribution within the SFER. The project does not monitor the complete spatial extent of Chinook Salmon spawning in the SFER, and the Chinook redd abundance estimate is limited to redds observed within the Coho focused reach sample frame. The project does not monitor the complete spatial and temporal extent of steelhead spawning areas and spawning period in the SFER, and the steelhead redd abundance estimate is limited to redds observed within the Coho focused reach sample frame and November to February survey period.

**Due to logistical complications related to COVID-19, a limited number of random reaches could be surveyed during the 2020 - 2021 winter survey season. A second stage of sampling was conducted during the subsequent summer to enumerate young-of-year throughout the basin and expand reach estimates of redd escapement using a juvenile:redd relation. This exercise could be completed reliably for Coho Salmon but not for Chinook Salmon or steelhead. Please refer to the 2020-2021 season report for more information.

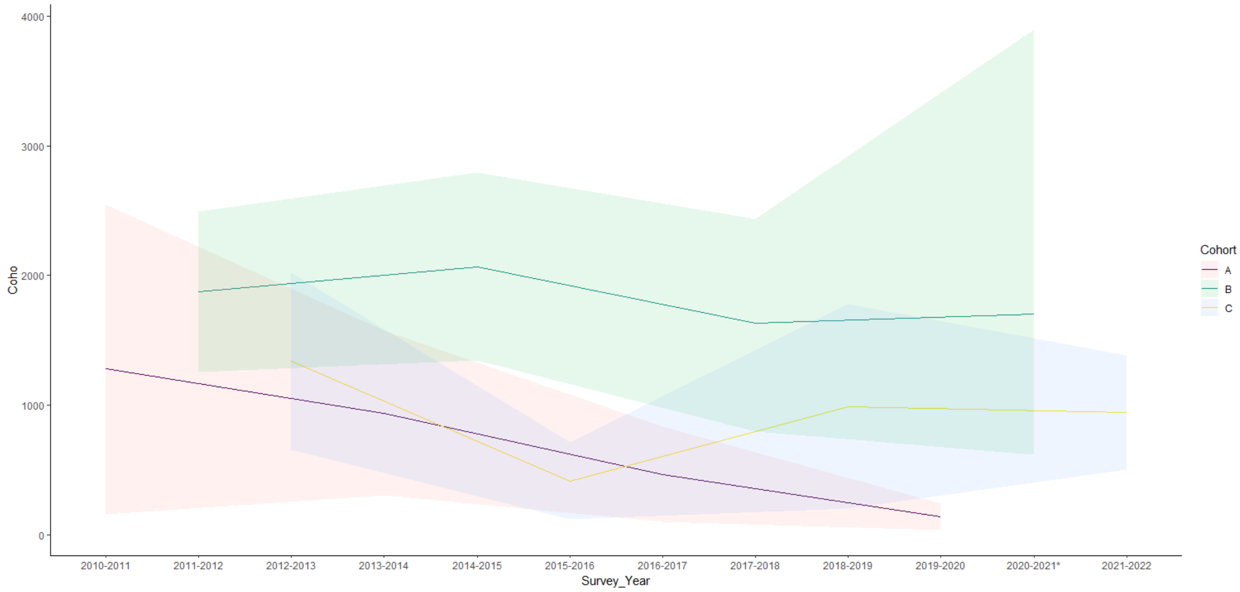

Figure 8. South Fork Eel River Coho Salmon redd abundance estimates from 2010 to 2021. Each of the 3 cohorts are separated out across time and represent by an individual line and 95% confidence interval.

5 ACKNOWLEDGEMENTS

Funding for the 2021 - 2022 SFER Adult Salmonid Redd Abundance Monitoring Project was provided by the Pacific Coastal Salmon Recovery Fund: Grantee Agreement CMP-18R1001.

We would like to thank our project partners: the California Conservation Corps AmeriCorps Watershed Stewards Program, especially Shannon Filbey. Thank you to the CDFW scientific aids: Kari Bencomo, Stacy Giraldo, Marisa McGrew, Shayda Abidi, Logan McDiffitt, Bryce Ryals, and Skylr Lopez.

This project was possible thanks to the many willing landowners who granted the project team access to their land and throughout the SFER Watershed.

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