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Results of Regional Spawning Ground Surveys and Estimates of Salmonid Redd Abundance in the South Fork Eel River, Humboldt and Mendocino Counties California, 2018-2019.

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ABSTRACT

The 2018-19 South Fork Eel River Adult Salmonid Redd Abundance Monitoring Project conducted 232 spawning ground surveys upon 38 spatially balanced and randomly selected sample reaches in the South Fork Eel River watershed between November 5, 2018 and, February 11, 2019. Each sample reach was surveyed an average of 4.9 times, and the average interval between surveys for all reaches was 19.9 days. The 2018-2019 survey observed 41 live coho salmon, 42 live Chinook salmon, 18 live steelhead,18 unidentified live salmonids, 4 coho salmon carcasses, and 10 Chinook salmon carcasses. A total of 246 redds were detected, and 15 of those redds were observed to be associated with a specific salmonid species digging or guarding the redd. The remaining 231 redds were assigned a species using a k-Nearest Neighbors algorithm analysis. The number of redds observed in the 38 sample reaches was expanded to estimate the number of redds constructed across the entire South Fork Eel River reach sample frame. Redd abundance estimates for the 2018-2019 spawning season in the South Fork Eel River sample frame area, including 95% confidence intervals, are: 990 (205, 1776) coho salmon redds, 404 (131, 676) Chinook salmon redds*, and 322 (168, 476) steelhead redds*

*The South Fork Eel River Salmonid Redd Abundance Monitoring Project is focused upon the temporal extent of coho salmon spawning and spatial extent of coho salmon spawning distribution within the South Fork Eel River. The project does not monitor the complete spatial extent of Chinook and steelhead spawning in the South Fork Eel River, and the redd abundance estimate for these species is limited to redds observed within the coho salmon focused reach sample frame.

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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 37160). 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 trends in California. In the CMP's Northern California area, adult salmonid population abundance will be monitored using extensive spawning ground surveys to estimate total redd escapement within a survey area/sample frame. 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 anadromous salmonid specie(s) within the designated study 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 to be expanded to estimate total redd escapement for the entire sample frame (Adams et al. 2011).

1.2 Study Area

The South Fork Eel River flows through Humboldt and Mendocino counties and is a significant tributary within California's third largest watershed (Figure 1). The South Fork Eel River'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 South Fork Eel River Basin is the second largest sub-basin in the Eel River Watershed and covers approximately 690 square miles. This consists of 19% of the Eel River Basin. The South Fork Eel River is approximately 105 miles long and the basin contains a total of 683 miles of perennial blue line 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. Under the federal Clean Water Act (Section 303(d)) in 1998 the State listed the South Fork Eel, along with many other water bodies, as water quality limited due to sediment and temperature concerns. (USEPA 1999)

Historically, the South Fork Eel River was the most productive tributary of the Eel River Basin for anadromous salmonids, supporting runs of coho salmon (*O.kisutch*), Chinook salmon (*O. tshawytscha*), and steelhead/rainbow trout (*O. mykiss*). An example of the historic abundance of coho salmon in the South Fork Eel River is exemplified by a high count of 25,289 adult coho salmon passing Benbow Dam (Taylor, 1978). However, Pacific salmon runs in the South Fork Eel River have markedly declined since the mid-twentieth century. In 1994, a status review of South Fork Eel River coho salmon estimated the returning population was 1,320 adults (Brown et al. 1994).

South Fork Eel River coho salmon are 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 South Fork Eel River 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 South Fork Eel River Watershed. This report presents the results of the 2018-2019 spawning survey season, the ninth year of the project. Previous annual reports for spawning years 2010/11 through 2017/18 are available in the CDFW Document Library: https://nrm.dfg.ca.gov/documents/.

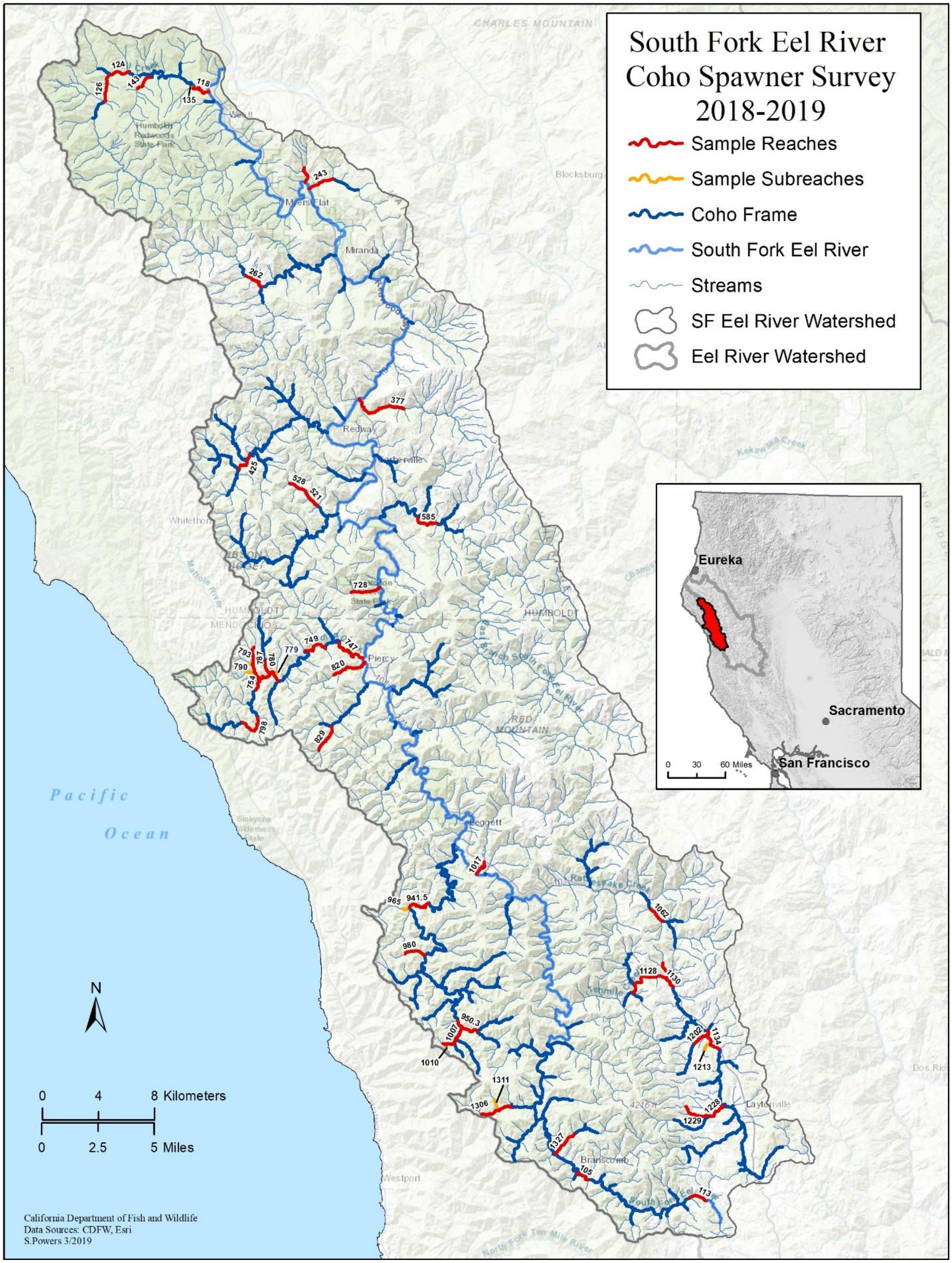

Figure 1. Map of the South Fork Eel River Watershed and reaches surveyed during the 2018-2019 adult coho salmon spawning survey season. The inset map depicts its location within the Eel River watershed and northern California.

2 METHODS

2.1 Sample Frame

A sample frame was established for South Fork Eel River 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). We compiled data in a Geographic Information System (GIS) to develop species-specific (coho, Chinook and steelhead) spawning distributions (sample frames).

As the focus of this project is adult coho salmon, streams within the identified coho-specific sample frame were segmented into one to three kilometer reaches. We established start and end points at identifiable landmarks (e.g. tributaries) and upstream extents at barriers to anadromy, both known and model-derived. We assigned a numeric identification, known as the location code, starting at the lower-most reach, and moving upstream from north to south. 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).

2.2 Sample Reach Selection

We conducted spawning ground surveys periodically on a spatially balanced, random sample of 38 stream reaches drawn from the coho-specific sample frame of 198 potential reaches. We used a Generalized Random Tessellation Stratified (GRTS) routine (McDonald 2003) to create a randomized reordering of the survey frame. Prior to the beginning of the 2017-18 survey season sample units selected by the GRTS sampling scheme were allocated to four panels that are assigned different visitation schedules (CDFW 2011). The four different visitation schedules for panels are as follows: one panel that will be visited every year (Panel 1), three panels that will be visited once every three years (Panels 2 through 4), 12 panels that will be visited once every 12 years (Panels 5 through 16), and 30 panels that will be visited once every 30 years (Panels 17 through 46), for the life of the project (Figure 2 for a visualization). 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 South Fork Eel River is under private ownership, a reach's inclusion on the list of 38 sample reaches is dependent on gaining stream access permission from the relevant landowners. If a landowner denies access or does not respond in time for the start of the spawning season, the reach is dropped from the panel for the year. The next reach in the sample draw is added to the survey list. Table 1 shows the list of stream reaches that are to be visited annually.

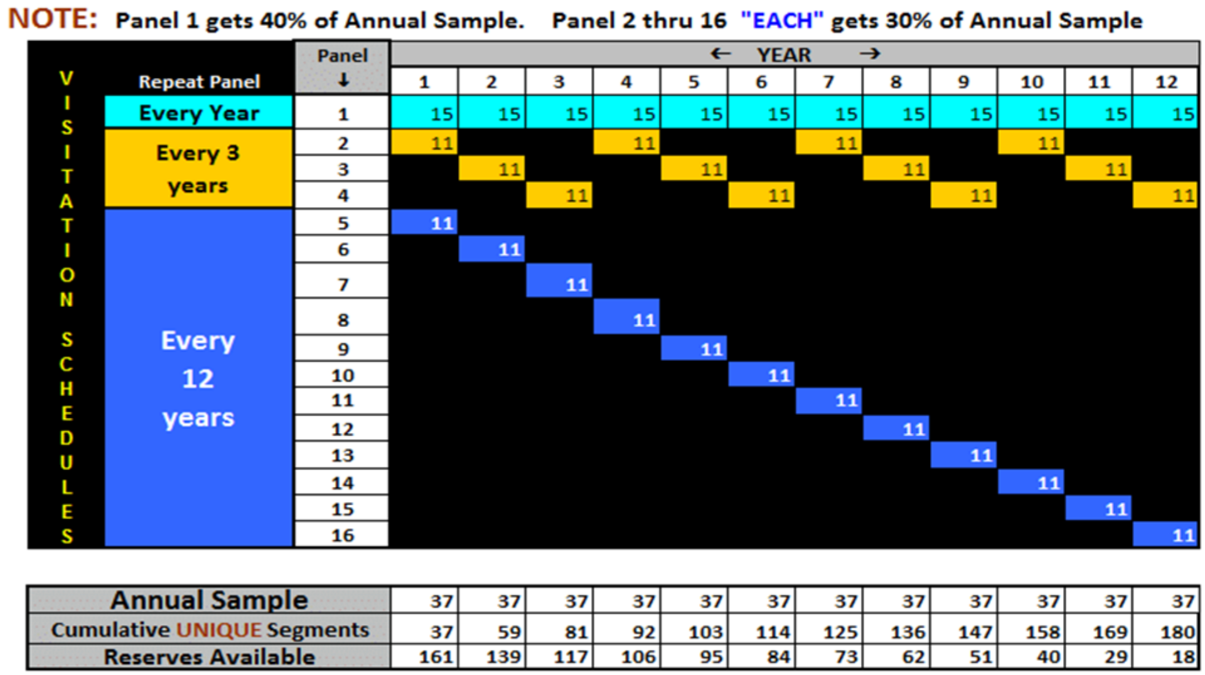

Figure 2. Example of rotating panel design.

Table 1. List of reaches in Panel 1 to be visited annually (bold indicates reaches that were surveyed in 2018-19).

Stream Name	*Drainage*	*Location Code*
South Fork Eel River	**Eel River**	**113**
Bull Creek	**South Fork Eel River (lower)**	**126**
Dean Creek	**South Fork Eel River(middle)**	**377**
Sproul Creek	South Fork Eel River (middle)	511
Sproul Creek	South Fork Eel River (middle)	514
East Branch South Fork Eel River	South Fork Eel River (middle)	582
Anderson Creek	**Indian Creek**	**798**
Hollow Tree Creek	**South Fork Eel River (upper)**	**950.3**
Foster Creek	Rattlesnake Creek	1070
Tenmile Creek	South Fork Eel River	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	**South Fork Eel River**	**1306**

2.3 Sample Frame Changes and Status

As of 2018-2019 we have surveyed or conducted reconnaissance on 166 of the 198 reaches in the South Fork Eel adult coho salmon sample frame. We will continue to refine this sample frame as new reaches are visited and will transfer updates of the sampling frame to the state-wide CMP Geo database in Sacramento and the luLocation table of the CMP Aquatic Survey's Survey Management Switchboard. The sample frame is static; however, updates will be made if reconnaissance reveals previously unknown barriers or if barriers such as impassible culverts are remediated or replaced. Previous sample frame updates included changes to reach lengths, start/stop locations, and total number of reaches. Reach additions resulted from the splitting of reaches on Hollow Tree Creek (Location Codes 943, 950) into multiple shorter reaches that better fit field protocols and reach length criteria for the CMP. The mainstem South Fork Eel River headwaters region above Dutch Charlie Creek was removed from the sample frame for the 2011-12 survey season then added back in for the 2012 and future years after physical access for survey crews was deemed available and reasonable using boating survey methods. Inaccessibility and surveyor safety concerns resulted in the removal of a reach in Rattlesnake Creek (Location Code 1060). There were additional instances of shortening reaches at the upstream extent of distribution. Smaller sub-reaches have been added and removed, but the manipulation of sub-reaches did not change the total number of main reaches in the sample frame. Reaches that have not been visited sometimes appear within the reach draw, which can result in observations of new barriers that were not recorded in previous years. Some reaches can include present barriers that have potential to change. One example is a bedrock cascade in Bear Creek a tributary to Hollow Tree Creek. The cascade precludes fish passage when a downstream log jam fractures and the impounded sediment degrades. The potential for the logjam to accumulate additional woody debris and impound enough sediment to allow fish passage will result in this reach remaining in the frame. An example of a permanent barrier discovered during reconnaissance is a 30-foot-tall dam on a sub reach to Tenmile Creek. GIS analysis indicated the sub-reach was ~ 800 meters in length, however the dam was located just 100 meters upstream. This permanent passage barrier to adult and juvenile salmonids will require adjustment to the sample frame. We reported this barrier to the California Passage Assessment Database (PAD). This is an example of reach modification as more reconnaissance is completed.

2.4 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) 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 are collected in degrees Celsius. We classified weather into five categories: (1) sunny, (2) cloudy, (3) overcast, (4) rain (5) snow. This season marked the first use of Apple iPads 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 (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 samples were sent to CDFW's Scale Library at the CDFW Arcata Office and tissue samples were delivered to the NOAA Southwest Fisheries Science Center.

If an identifiable fish is observed actively digging or guarding the redd we then assigned it to that species. If we did not observe fish guarding or constructing the redd, we left its species assignment as unidentified. We recorded the location of all newly observed redds with the GPS feature in Pendragon Forms and marked the redd with flagging. We labelled flagging with a unique record number, the distance from the flag to the redd, a compass bearing in relation to the flag, and the total length of the redd. We then assigned all new redds encountered an "age" of (1) new since last survey. On subsequent surveys, encountered flags are matched with their associated redds, which we re-assigned an age of (2) still visible and measurable, (3) visible, but not measurable, (4) not visible, or (5) unknown due to poor visibility. We then marked the redd age code on the existing flag. If a redd was given an age code of (4) a knot was tied in the flag to indicate that it was not to be recorded on future surveys. If a new redd was unattended or an old redd was not previously measured, we took physical measurements that included, length and width of pot and tail spill, substrate size of pot and tail spill, and depth of the pot relative to the surrounding substrate.

2.5 Estimation of Total Redd Abundance within Survey Frame

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 all redds are assigned a species then within reach-redd abundance is estimated, and lastly within reach-redd abundance is expanded to estimate total redd abundance across the entire survey frame.

2.5.1 Assigning Species to Unknown 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 l. When only Julien date is used n=1. When all three attributes are used n =3

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 of the 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).

2.5.2 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 $\widetilde{T_J}$ 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):

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

$\check{S}_p$ 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.

2.5.3 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:

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

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

We completed 232 spawning ground surveys from November 5, 2018 to February 11, 2019 over the 38 selected stream reaches within the South Fork Eel River Watershed (Table 2, Figure 3). We surveyed each reach between 3 and 7 times over the survey season. The average number of visits per reach was 4.9. The average interval between surveys over all reaches was 19.9 days. The period from January 28 to February 1 had the greatest number of surveys occur with 43. The most frequently surveyed reaches included Squaw Creek and Rattlesnake Creek with a total of seven surveys each. The least frequently visited stream was Upper Indian Creek with only three surveys. Rattlesnake Creek also holds the lowest value for average time between surveys with 13.2 days. The highest value for survey intervals is Upper Indian Creek with a mean of 24.5 days between surveys. (Table 2) The greatest discharge value recorded at the South Fork Eel USGS Leggett Gage during the season was 8540 Cubic Feet per Second (cfs) on January 21 (Figure 3). The lowest recorded discharge value of 13.5 cfs was recorded on November 21 (Figure 3).

Table 2. Survey frequency by reach during the 2018-19 South Fork Eel River Adult Salmonid Redd Abundance Monitoring Project. Reaches are listed by stream name and 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 number of surveys. Totals represent the averages for each category. Subreaches with a different number of surveys and mean days between surveys from the main reach are indicated with parentheses.

Location Code (sub-reach)	Stream Name	Mean (Days)	Max (Days)	*N* (Surveys)
105	South Fork Eel River	15.4	24	6
113	South Fork Eel River	19.8	36	5
118 (135)	Bull Creek	21.8	32	5
124	Bull Creek	23.3	39	5
126	Bull Creek	23.3	36	5
143	Squaw Creek	15	27	7
238	Bridge Creek	19.2	34	6
243	Elk Creek	19.2	39	6
262	Salmon Creek	27	48	4
377	Dean Creek	19.3	29	5
425	Redwood Creek	19	30	6
521	Little Sproul Creek	18	38	6
528	Unnamed Trib to Little Sproul	21.3	33	4
585	East Branch S.F Eel River	21	28	5
728	Durphey Creek	17.8	25	6
747	Indian Creek	19.4	28	6
749	Indian Creek	20	24	4
754 (779)	Indian Creek	24.5	32	3
780	Sebbas Creek	17.3	24	4
787 (790,793)	Coulborn Creek	18.7 (28,18.7)	26 (48,26)	4 (3,4)
798	Anderson Creek	19.3	28	4
820	Piercy Creek	21.3	36	5
829	Standley Creek	23.2	27	4
941.5 (965)	Hollow Tree Creek	19.5 (26)	28 (50)	5 (4)
950.3	Hollow Tree Creek	17.3	26	5
980	Bear Creek	17.5	26	5
1007 (1010)	Huckleberry Creek	14.4	24	6
1017	Cedar Creek	15.8	23	6
1062	Rattlesnake Creek	13.2	22	7
1128	Tenmile Creek	16.5	25	5
1130	Tenmile Creek	16.5	25	5
1134 (1213,1214)	Tenmile Creek	24.3 (28)	29 (28.5)	4 (2,2)
1168 (1169)	Unnamed Trib to Tenmile Creek	19.3	27	4
1202	Big Rock Creek	20	28	5
1228	Little Case Creek	16	28	5
1229	Little Case Creek	21.3	38	4
1305	Dutch Charlie Creek	16	28	5
1306	Dutch Charlie Creek	16	28	5
1327	Kenny Creek	16.6	26	6
		19.9	30.4	4.9

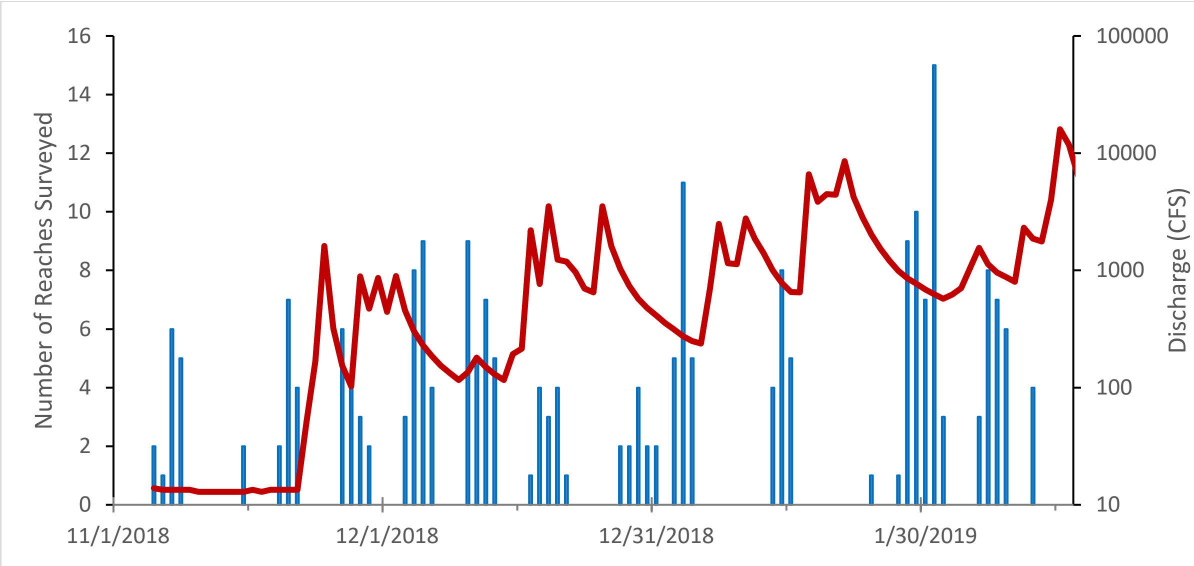

Figure 3. Spawning ground survey effort and timing in the South Fork Eel River compared to discharge (in cubic feet per second, cfs) measured at the USGS gauging station near Leggett, CA. Discharge values shown were recorded at midnight each day and are presented on the secondary y-axis (red line).

3.2 Fish Observations

We observed a total of 41 coho salmon, 42 Chinook salmon, 18 steelhead, and 18 unidentified anadromous salmonids over the survey period (Table 3, Figures 4-12). Four coho salmon carcasses, 10 Chinook salmon carcasses, and one steelhead carcass were collected throughout the season. (Table 3 and Figure 4).

We identified the first coho salmon of the season on December 17 and the last on February 6. The median date for these observations was January 11 (Table 4). The peak observation period for coho salmon was between December 17 and December 20 with 26 fish during this time (Figure 5). Huckleberry Creek was the reach with the greatest number of coho salmon observations with 12 individuals. We observed coho salmon on 9 of the 38 surveyed reaches (Table 3). The first coho salmon carcass was recorded on January 2 and the last on January 15 (Table 4). Coho salmon carcasses were found on four separate reaches (Table 3).

We observed the first Chinook salmon on December 4 and the last on January 2. The median date of observations was December 18 (Table 4). The peak observation period for Chinook salmon occurred from December 4 to December 9 with 23 fish (Figure 5). East Branch South Fork Eel River had the greatest number of Chinook salmon observed with 11. Overall, we recorded Chinook salmon on 10 of the 38 surveyed reaches. The first Chinook salmon carcass of the season was found on December 5 and the last was found on January 14 (Table 4). We collected Chinook salmon carcasses on a total of 8 reaches (Table 3).

We observed the first steelhead on January 28 and the last on February 11 with February 4 as the median date of observations. (Table 4). The peak of steelhead observations occurred between

January 28 and February 1 with 10 fish recorded during this period (Figure 5). Piercy Creek yielded the greatest number of steelhead observations with three individuals. Steelhead were recorded on 10 reaches and one sub-reach (Table 3). We recorded only one steelhead carcass, and this was on February 7 on Anderson Creek. Additionally, we recorded 18 unidentified salmonids throughout the survey on 9 separate reaches. The first of these was observed on November 27 and the last on January 30 (Table 4). The median date for these observations was December 29. The Upper South Fork Eel had the greatest number of unidentified fish observed with 5 (Table 3).

3.3 Redd Observations

We identified 11 known coho salmon redds, two known Chinook salmon redds, and two known steelhead redds (Table 3, Figures 6-9). Cross validation of the 15 known redds resulted in the kNN model correctly assigning all known redds to the respective species. Two hundred thirty-one redds were not field identified to species and kNN predictions of species likely to have constructed them were made. Percentage of known redds ranged from 10.7 % on the week of December 17 to 6.5 % during the week of January 7 (Figure 6). We observed very few known redds before and after these periods. We observed the first known coho salmon redd on December 17 and the last on January 14. The median date for these observations was December 31 (Table 4). We observed coho salmon redds on seven different survey reaches. Huckleberry Creek had the greatest number of known coho salmon redds with three (Table 3). We observed the first known Chinook salmon redd on December 5 and the last on December 20 (Table 4). There were only two redds observed with Chinook salmon actively digging or guarding them. These observations occurred on Tenmile Creek and Huckleberry Creek. (Table 3). The only known steelhead redds occurred on February 6 on Kenny Creek and on February 8 on Tenmile Creek (Tables 3 and 4). We observed the first unidentified redd on November 29 and the last on February 11. The median date for these observations was January 5 (Table 4). There were unidentified redds recorded on 31 main reaches and three sub-reaches. Upper Indian Creek had the greatest number of unidentified redds recorded with 38 (Table 3).

3.4 Total Redd Abundance

Sufficient flag marking and re-observation data was available to apply the within-reach estimation model in ten 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 28 reaches where no reach level expansion was available. The total redd abundance estimate for coho salmon for the 2018-2019 South Fork Eel River spawning season, with 95% confidence intervals, is 990. The total redd abundance estimates for Chinook salmon and steelhead are 404 and 322, respectively (Table 5). Table 6 represents the performance metrics for the kNN function.

Table 3. Counts of live fish and redds observed by reach in the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

Location Code	Stream Name	Live Chinook	Known Chinook Redds	Live Coho	Known Coho Redds	Live Steelhead	Known Steelhead Redds	Live Unidentified	Unidentified Redds
105	S.F Eel River	-	-	4	1	1	-	5	9
113	S.F Eel River	-	-	2	1	-	-	-	1
118	Bull Creek	-	-	-	-	-	-	1	-
135	Subreach to 118	-	-	-	-	-	-	-	1
124	Bull Creek	-	-	-	-	-	-	-	4
126	Bull Creek	3	-	-	-	-	-	1	14
143	Squaw Creek	2	-	-	-	-	-	-	5
238	Bridge Creek	-	-	-	-	-	-	-	-
243	Elk Creek	-	-	-	-	-	-	-	-
377	Dean Creek	1	-	-	-	-	-	-	3
425	Redwood Creek	-	-	2	1	2	-	-	10
521	Little Sproul Creek	-	-	-	-	-	-	-	2
528	Trib to Little Sproul	-	-	-	-	-	-	-	-
585	East Branch S.F Eel	11	-	-	-	-	-	-	1
728	Durphy Creek	-	-	-	-	-	-	-	-
747	Indian Creek	-	-	-	-	2	-	-	10
749	Indian Creek	-	-	-	-	1	-	-	3
754	Indian Creek	9	-	2	-	1	-	2	38
779	Subreach to 754	-	-	-	-	2	-	-	-
780	Sebbas Creek	-	-	-	-	-	-	-	1
787	Coulborn Creek	-	-	-	-	-	-	-	10
790	Subreach to 787	-	-	-	-	-	-	-	-
793	Subreach to 787	-	-	-	-	-	-	-	-
798	Anderson Creek	-	-	-	-	2	-	-	24
820	Piercy Creek	-	-	-	-	3	-	-	-
829	Standley Creek	-	-	-	-	-	-	-	-
941.5	Hollow Tree Creek	-	-	-	-	-	-	-	6
965	Subreach to 941.5	-	-	-	-	-	-	-	2
950.3	Hollow Tree Creek	-	-	1	-	-	-	-	20
980	Bear Creek	-	-	-	-	-	-	-	1
1007	Huckleberry Creek	3	1	12	3	-	-	3	9
1010	Subreach to 1007	-	-	-	-	-	-	-	-
1017	Cedar Creek	-	-	-	-	-	-	-	8
1062	Rattlesnake Creek	-	-	-	-	1	-	-	1
1128	Tenmile Creek	5	-	-	-	-	-	2	8
1130	Tenmile Creek	4	-	-	-	1	1	1	4
1134	Tenmile Creek	3	1	-	-	-	-	-	1
1168	Trib to Tenmile Creek	-	-	-	-	-	-	-	1
1169	Subreach to 1168	-	-	-	-	-	-	-	1
1202	Big Rock Creek	-	-	-	-	-	-	-	3
1228	Little Case Creek	1	-	-	-	-	-	1	11
1229	Little Case Creek	-	-	-	-	-	-	-	4
1305	Dutch Charlie Creek	-	-	6	2	-	-	-	2
1306	Dutch Charlie Creek	-	-	8	1	-	-	2	10
1327	Kenny Creek	-	-	4	2	2	1	-	3
Total:		**42**	**2**	**41**	**11**	**18**	**2**	**17**	**231**

Table 4. Counts of live fish, carcasses, and redds by first date observed, last date observed and median date of observation in the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

		Coho	Chinook	Steelhead	Unidentified
Live fish observations	*N*	41	42	18	18
	Median	11-Jan	18-Dec	4-Feb	29-Dec
	First	17-Dec	4-Dec	28-Jan	27-Nov
	Last	6-Feb	2-Jan	11-Feb	30-Jan
Redd observations	*N*	11	2	2	231
	Median	31-Dec	12-Dec	7-Feb	5-Jan
	First	17-Dec	5-Dec	6-Feb	29-Nov
	Last	14-Jan	20-Dec	8-Feb	11-Feb
Carcass observations	*N*	4	10	1	-
	Median	8-Jan	25-Dec	-	-
	First	2-Jan	5-Dec	7-Jan	-
	Last	15-Jan	14-Jan	-	-

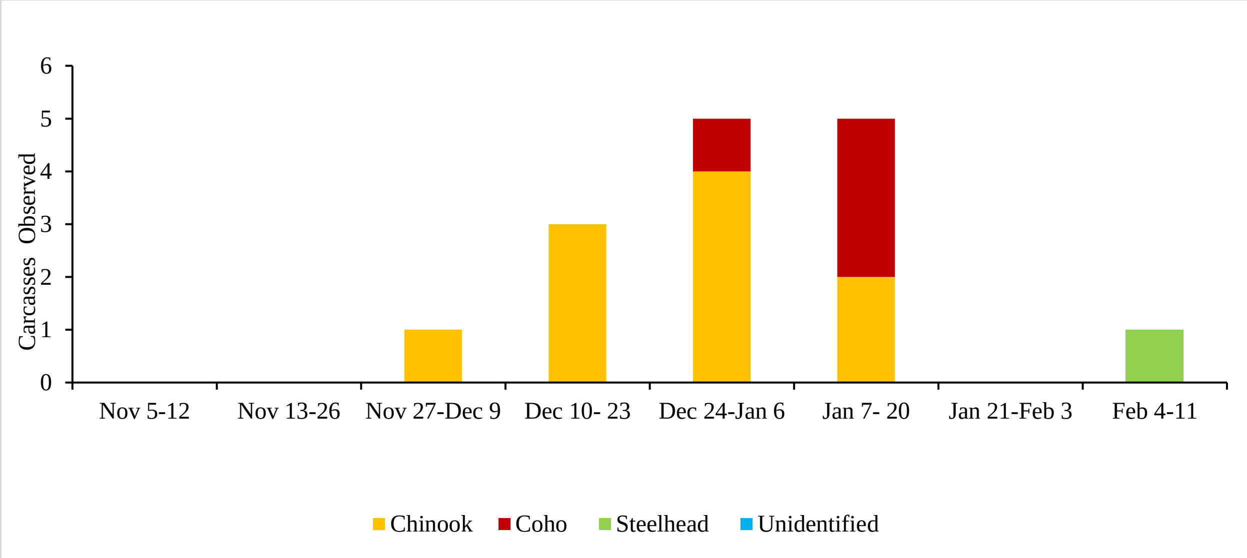

Figure 4. Stacked barplot of bi-weekly carcass observations in the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

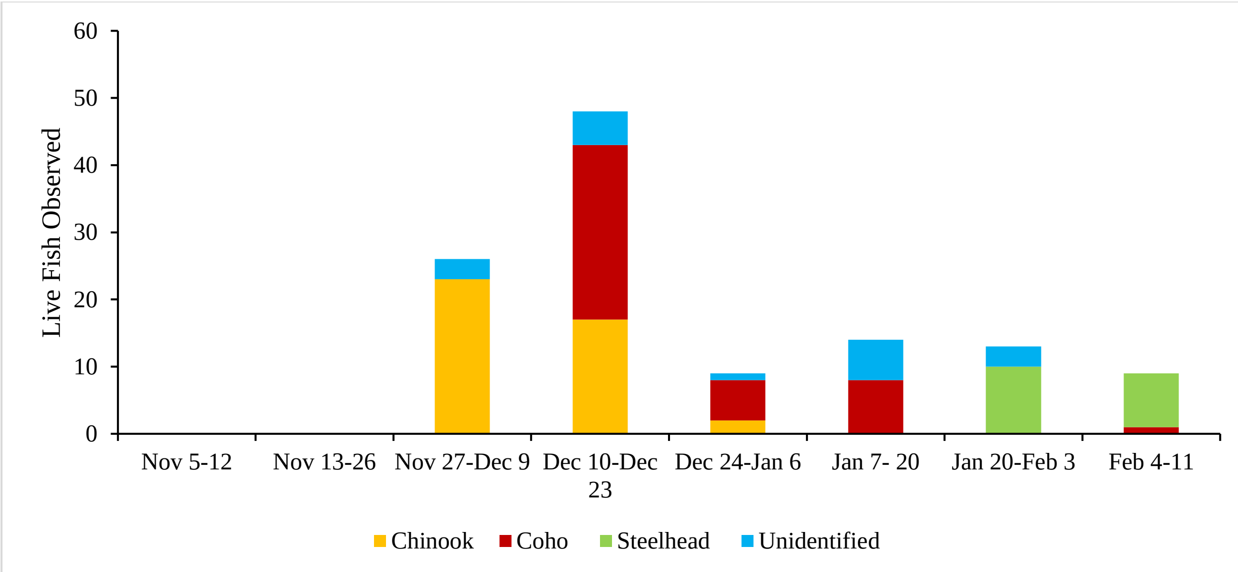

Figure 5. Stacked barplot of bi-weekly fish observations in the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

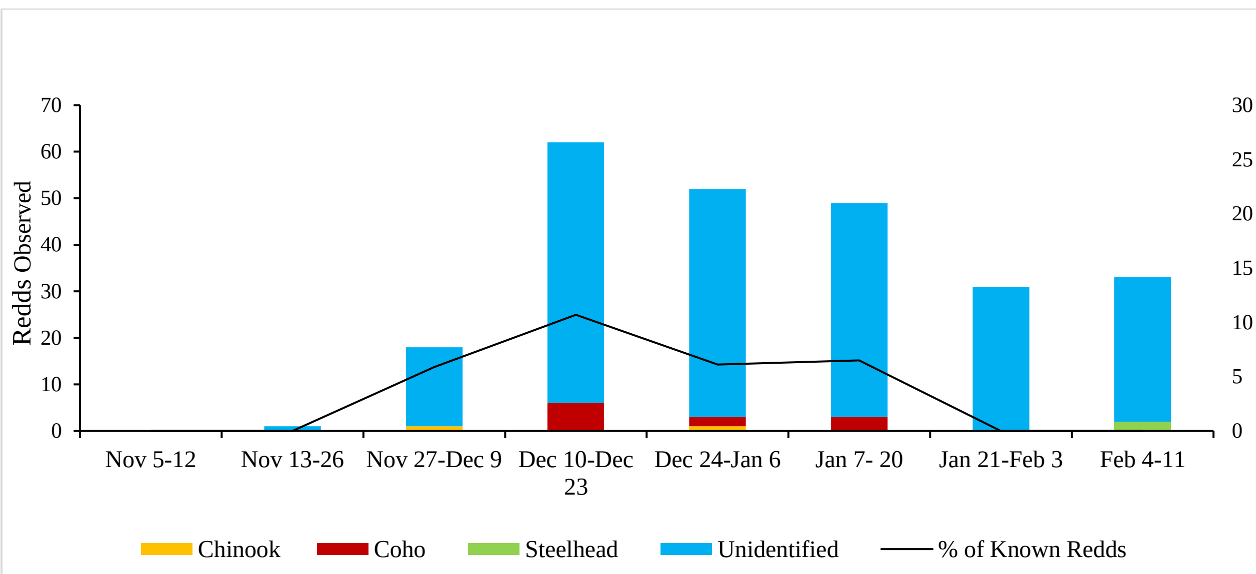

Figure 6. Stacked bar plot and line combination of bi-weekly redd observations in the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019. The left axis is number of redds while the right is the percentage of redds that were known.

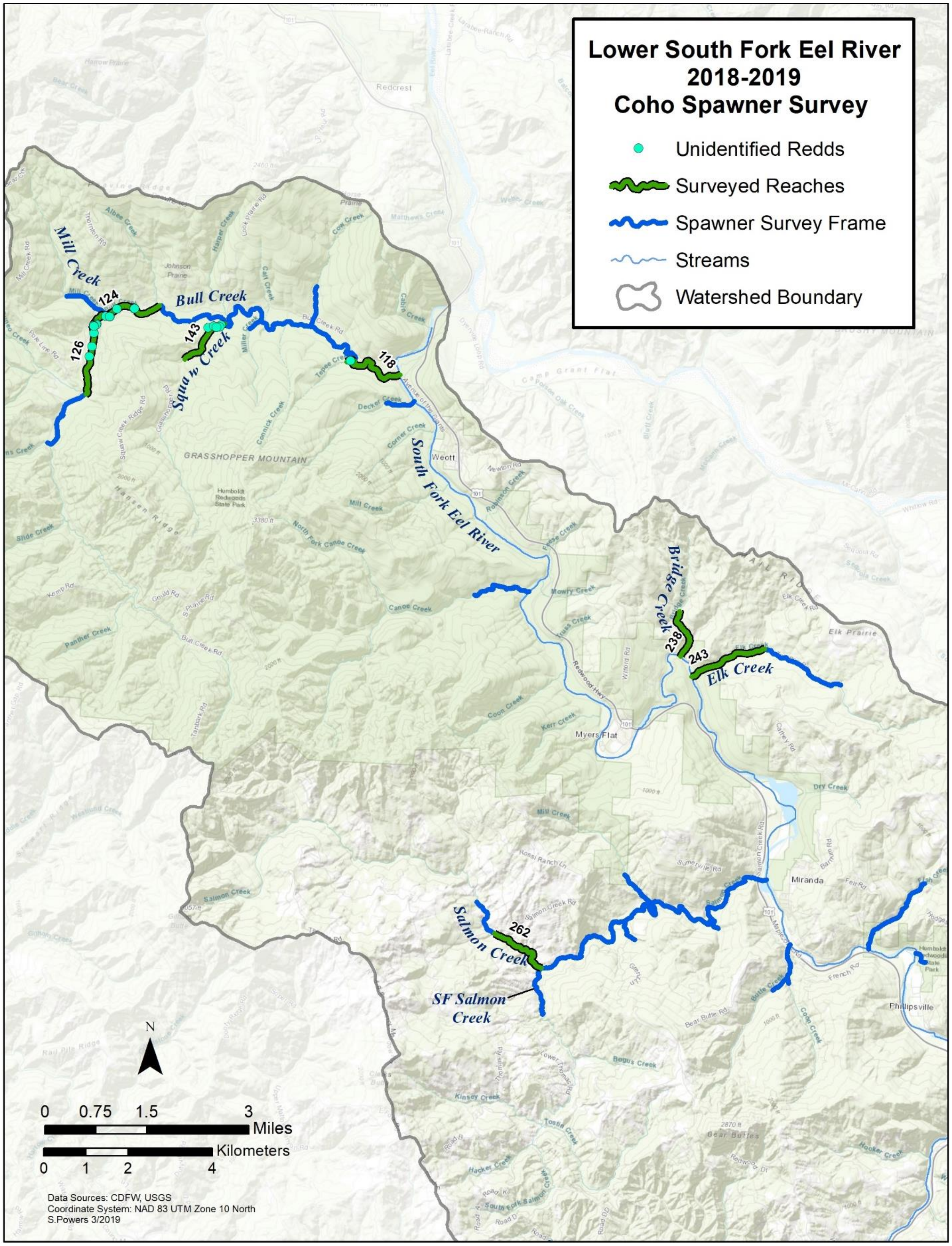

Figure 7. Distribution map showing the observation locations of unidentified anadromous salmonid redds in the lower portion of the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019. No adult coho salmon were observed in this area.

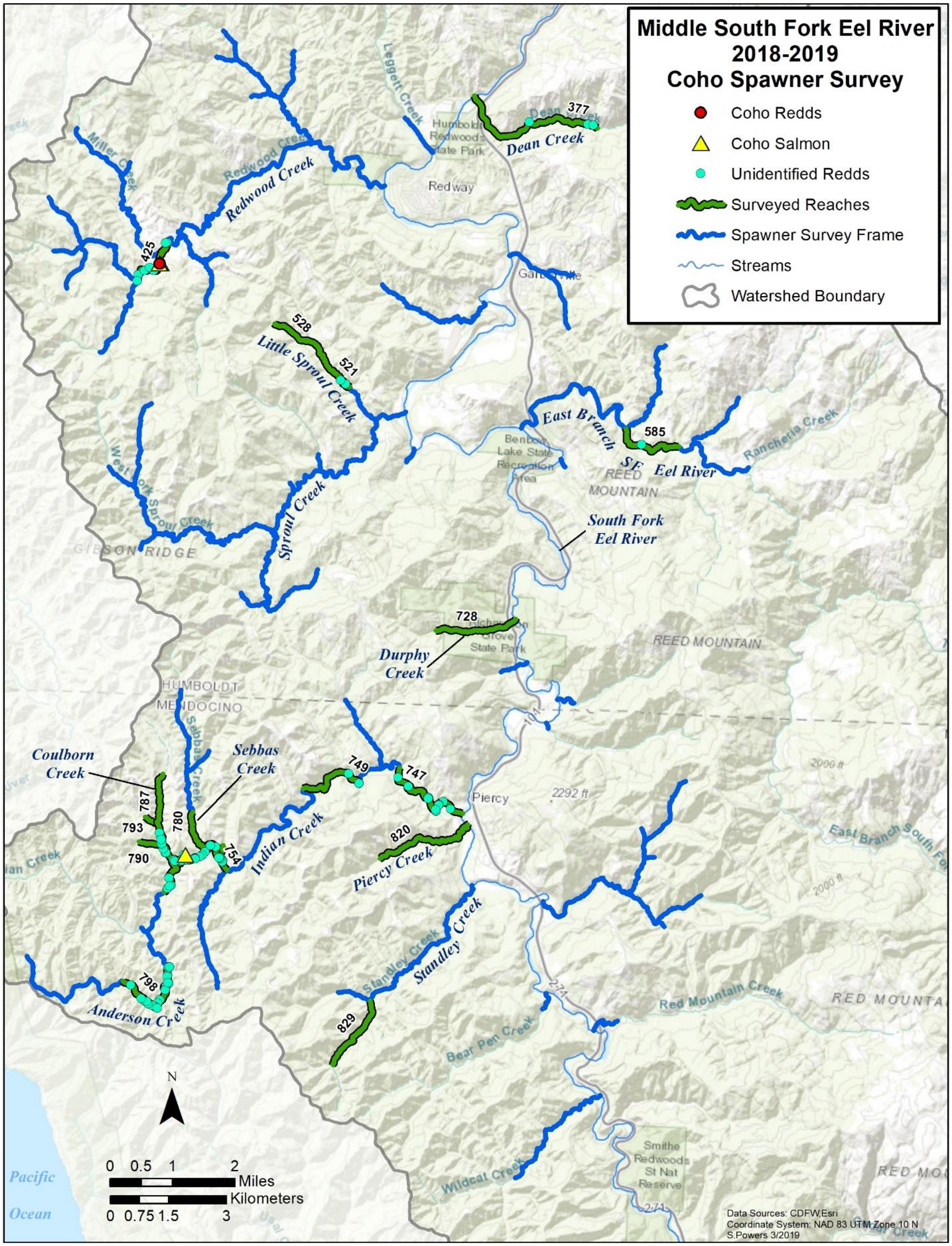

Figure 8. Distribution map showing the observation locations of live coho salmon, known coho salmon redds, and unidentified anadromous salmonid redds in the middle portion of the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

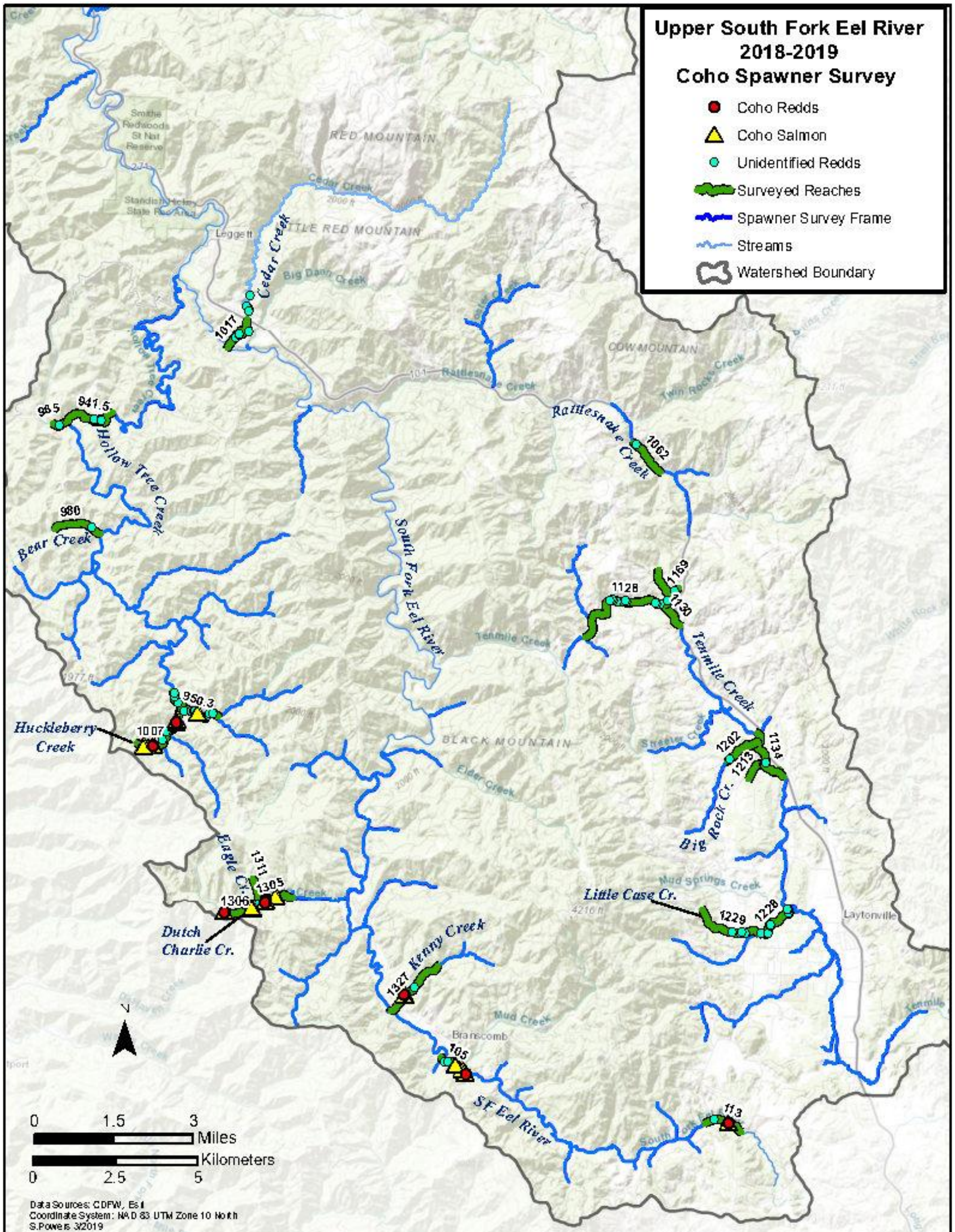

Figure 9. Distribution map showing the observation locations of live coho salmon, known coho salmon redds, and unidentified anadromous salmonid redds in the upper portion of the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

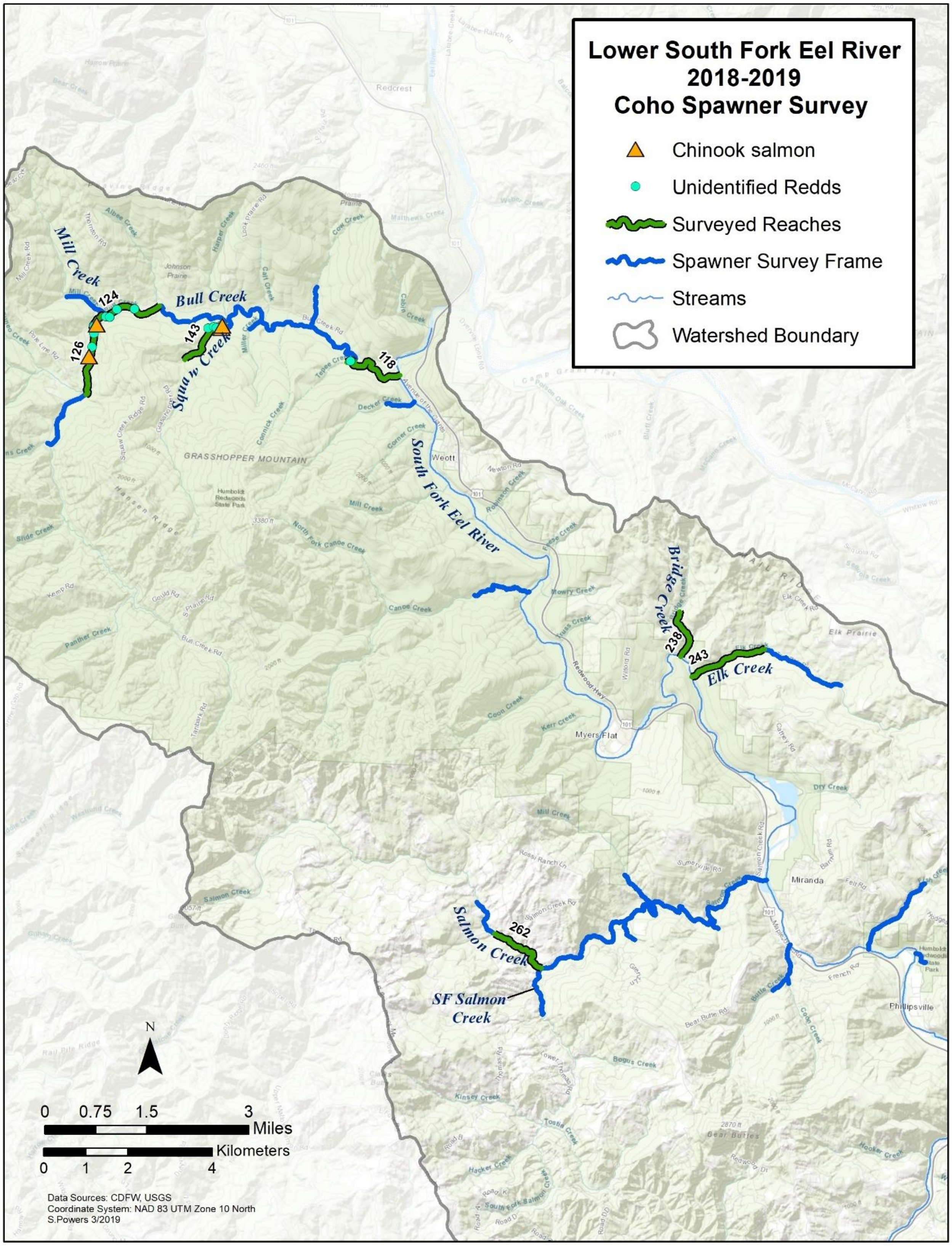

Figure 10. Distribution map showing the observation locations of live Chinook salmon, known Chinook salmon redds, live steelhead, known steelhead redds, and unidentified anadromous salmonid redds in the lower portion of the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

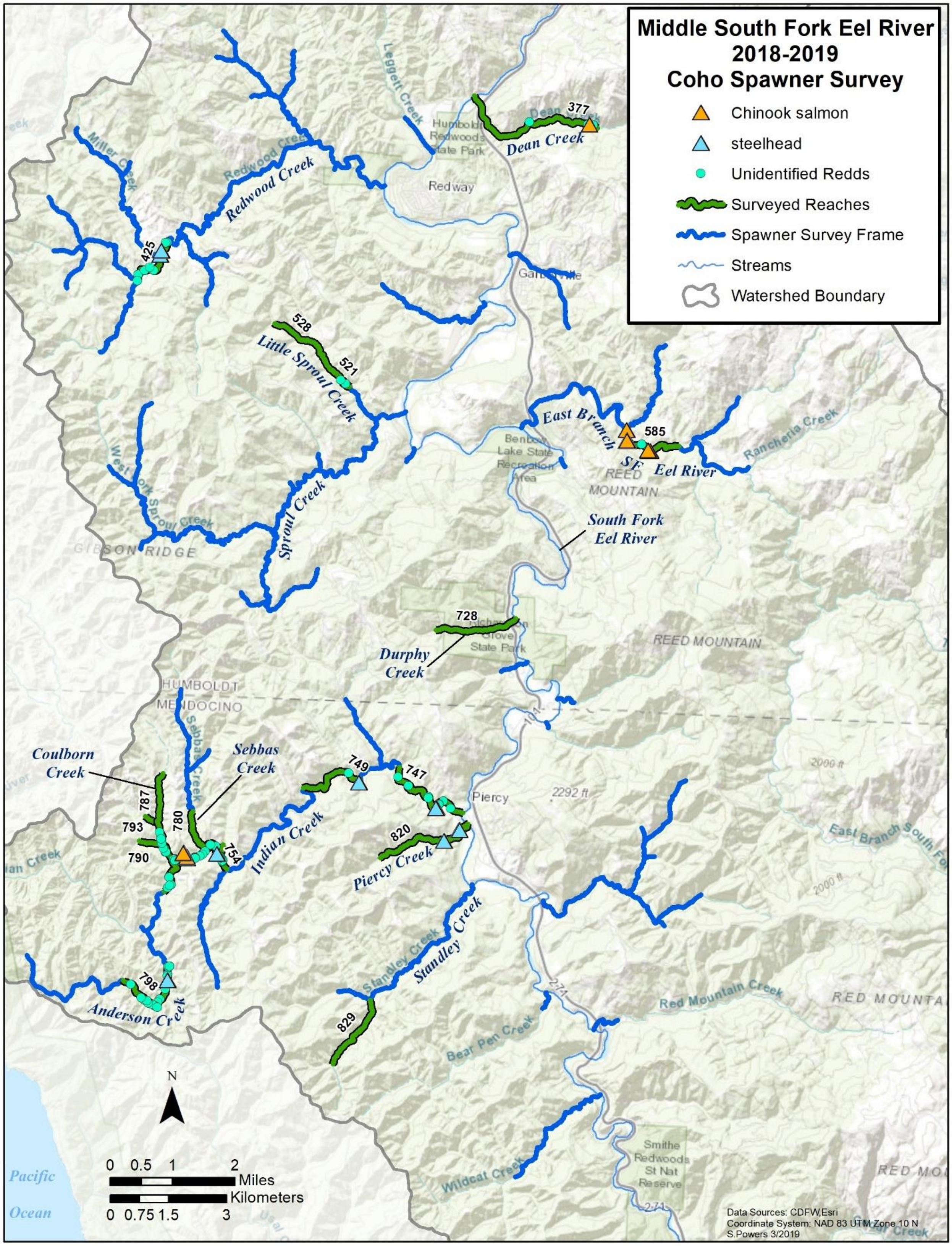

Figure 11. Distribution map showing the observation locations of live Chinook salmon, known Chinook salmon redds, steelhead, known steelhead redds and unidentified anadromous salmonid redds in the middle portion of the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

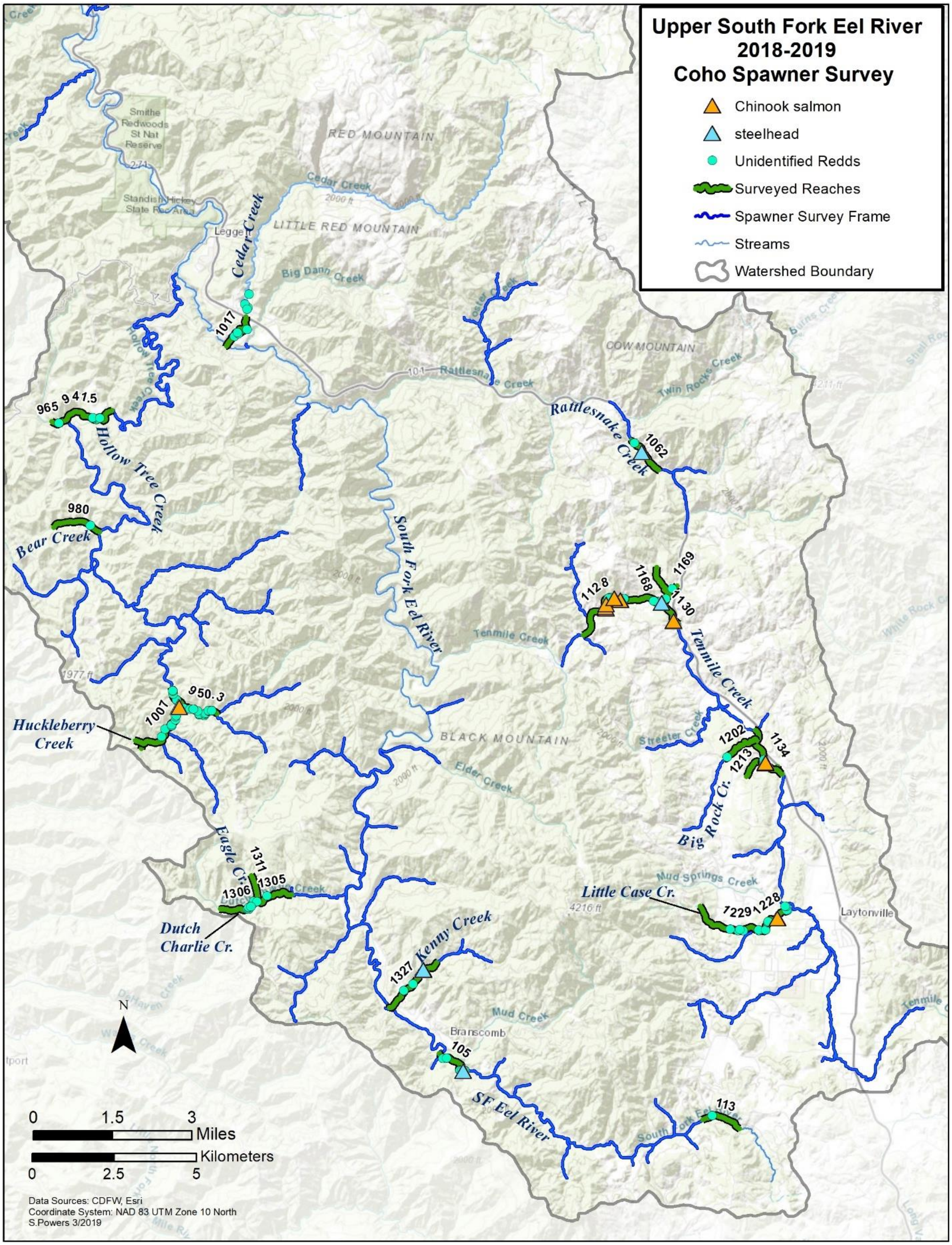

Figure 12. Distribution map showing the observation locations of live Chinook salmon, known Chinook salmon redds, live steelhead, known steelhead redds, and unidentified anadromous salmonid redds in the upper portion of the South Fork Eel River adult coho salmon spawning survey sample frame November 5, 2018 to February 11, 2019.

Table 5. Estimated total redd abundance by species with 95% confidence intervals for the 2018-2019 South Fork Eel River Adult Salmonid Redd Abundance Monitoring Project

	Chinook*	Coho	Steelhead*
Estimated number of redds	404	990	322
95% Confidence Intervals	(131, 676)	(205, 1776)	(168, 476)

Table 6. Confusion matrix, statistics, and number of redds by species for the 2018-2019 South Fork Eel River Adult Salmonid Redd Abundance Monitoring Project season. Redds were predicted with the kNN model using known species redds and live fish observations as the training dataset. We evaluated model performance using leave one out cross validation. Sensitivity indicates the probability of a type II error. Specificity indicates the probability of a type I error.

		Reference Chinook salmon	 coho salmon	 steelhead
Prediction	Chinook salmon	2	0	0
	coho salmon	0	11	0
	steelhead	0	0	2
	Sensitivity	1	1	1
	Specificity	1	1	1
	Accuracy		1 (0.78-1)	
Number of Redds	Known Species	2	11	2
	kNN Predicted	402	979	320
	Total	404	990	322

*The South Fork Eel River Salmonid Redd Abundance Monitoring Project is focused upon the temporal extent of coho salmon spawning and spatial extent of coho salmon spawning distribution within the South Fork Eel River. The project does not monitor the complete spatial extent of Chinook and steelhead spawning in the South Fork Eel River, and the redd abundance estimate for these species is limited to redds observed within the coho salmon focused reach sample frame.

4 DISCUSSION

The 2018-2019 South Fork Eel spawning ground survey season began November 5, 2018. The first two weeks of the season consisted of reach reconnaissance and crew training. All stream reaches were at fall baseflow conditions and we did not record any fish, redds or carcasses. The first significant increase in discharge measured at the South Fork Eel USGS Leggett Gage began on November 21 and peaked on November 25 at 1200 cfs. This event allowed all survey reaches to become accessible to anadromous salmonids. Several heavy precipitation events characterized the 2018-19 survey season. From January 7 to the 21 some of the highest discharges were recorded on the Leggett Gage. There were no surveys conducted during the week of January 7 because of poor conditions. Although this week did not have the greatest measured discharge of the year, it still resulted in the lack of acceptable survey conditions. This attests to the dynamic nature of the South Fork Eel River Watershed's geology. We continued to conduct surveys into the first week of February with one coho salmon observed during this time. Another precipitation event was followed by a subsequent rotation through the survey frame the following week in which we recorded only steelhead. The lack of coho observations resulted in conclusion of the survey season on February 11.

The 2018-2019 season experienced several limitations with the primary being poor survey conditions. Frequent storms often caused excessive turbidity throughout the watershed. The South Fork Eel River is a large and complex system. As such, survey intervals and the number of visits per reach are more influenced by the unique discharge and turbidity characteristics of the individual reaches than by conditions basin wide. For example, Hollow Tree Creek and Indian Creek have low turbidity rates during storm events and tend to present a trend of dynamic behavior with the quick rise and fall of stream flows, making it easier to conduct surveys within three to five days after a significant rain event. Bull Creek is a system with very high turbidity and it can take weeks before conditions are clear enough to survey. Consequently, some reaches within the sample frame are more frequently sampled during a season. Efforts are being made to create a more extensive set of turbidity data points to compare with discharges observed on gages within the South Fork Eel River. Collecting this information will improve survey planning and result in more efficient use of time and resources. Providing landowners with a secchi disk and basic training on taking visibility readings could be an effective way to build this dataset while getting them involved and invested in the project. The considerable amount of private land in the South Fork Eel makes maintaining and improving relationships with landowners a critical point of successfully collecting data.

The season also consisted of area specific limitations. We were not able to survey reaches in the Upper Indian Creek drainage until the week of December 10. All-Terrain Vehicles (ATVs) are required to access these reaches and were not available due to mechanical issues. Utilizing ATVs to gain access instead of trucks in some remote areas is critical to maintaining a good working relationship with landowners by preventing road damage. Staffing was yet another challenge during this survey season. To cover a full rotation of the frame every two weeks the entire crew was required to survey a minimum of 5 reaches per day. Missed time due to illness and other factors resulted in several weeks where this was difficult to achieve even though there were an adequate number of technicians assigned to the project. Options for improving scheduling and staffing to increase survey coverage are being examined. The use of volunteers could be a way to mitigate for missing survey staff. Drive times are a further difficulty encountered every season. The South Fork Eel is a large watershed and reaches in the upper portion near Branscomb are over 110 miles from the Fortuna office; the duty station for surveyors. California State Parks has graciously opened housing at Richardson Grove which has greatly reduced drive times. Despite this, there are still survey reaches that can take over 2 hours to access from this point therefore this ongoing cooperation will be critical to the future success of this project. Access is a constant issue within the South Fork Eel due to the large amount of private land. There are six reaches in the yearly index panel where landowner permission was not gained. This was typically due to lack of correspondence from these landowners. No replacement reaches were selected however; attempts at gaining access are to be made for future survey years. Access was obtained in 9 out of 15 index reaches for the 2018-19 season. This is a significant improvement from the previous season when only 6 of the 15 index reaches were surveyed. This change conveys the potential to gain access to the remaining index reaches through landowner engagement and changes in parcel ownership.

4.1 Coho Salmon Observations

The coho salmon season was marred by a general trend of poor survey conditions due to flow and turbidity restraints resulting in undesirable survey intervals throughout the season. Frequent rain events likely resulted in missed observations of coho salmon digging or guarding redds. The majority of coho salmon observations occurred in the upper extent of the South Fork Eel watershed that is centered geographically near Branscomb, CA. On December 16 through December 19 a rain induced increase in discharge allowed coho salmon to gain access to these upper reaches. We recorded the first coho salmon of the survey season on Dutch Charlie Creek and the Upper South Fork Eel. There were also a high number of observations in Huckleberry Creek a tributary of Hollow Tree Creek. Huckleberry Creek and Dutch Charlie Creek have similar characteristics in terms of habitat features, land use and gradient. They also exhibit some of the highest numbers of coho salmon observations throughout the nine seasons of the project. This is evidence of the role these streams play as strongholds of coho salmon in the South Fork Eel River drainage though it will take further data collection to confirm this. Evaluation for restoration potential of these watersheds is currently underway.

The South Fork Eel River Adult Salmonid Redd Abundance Monitoring Project has now carried out 9 seasons of data collection. This has begun to allow for observation of population trends for three separate brood years of SONCC coho salmon. There appears to be a dominant brood year that was first observed during the 2010-2011 season with 1873 estimated redds. Returns of mature adults from this brood year continued in the 2014 -2015 season with 2069 estimated redds which is the greatest estimate throughout the nine survey seasons. The next round of adults from this brood year (2017-18) had the third highest number of redds estimated with 1633. (Table 7). Known redds and live fish observations in these years appear to support the redd estimates though it should be noted that two out of these three years also had among the greatest number of surveys performed and favorable survey intervals compared to other years. Returns of spawning adults in the 2018-2019 surveys corresponded to the 2015-16 season which had the lowest number of estimated redd among nine seasons. This particular brood year was impacted by drought while rearing as juveniles. However, the 990 estimated redds this season is a significant increase from the 416 estimated during the 2015-16 season (Table 7.) The 2018-19 season had more surveys conducted and favorable survey intervals when compared to 2015-16 (Table 2). Overall, there will need to be further data collected to produce a robust analysis of population trends.

4.2 Chinook Salmon Observations

The first confirmed observations of adult Fall Run Chinook salmon occurred in Tenmile Creek. We also observed eleven live fish on the East Branch South Fork Eel River this same week. Both reaches exhibit channel width and substrate that is indicative of Chinook salmon spawning activity. There were also instances of Chinook salmon on Little Case Creek as well. This is a smaller drainage that appears more representative of supporting all three anadromous salmonid species found in the watershed. These observations show that the coho salmon spawner survey frame covers a significant amount of Chinook salmon spawning in terms of habit and run timing. It is likely that live fish and redd observations were missed due to the lack of access in the Upper Indian Creek area between flow events. These reaches have had high numbers of observations in past years of the survey so there is the possibility of an underrepresentation of Chinook salmon activity because of this. The last Chinook salmon observation of the season occurred on January 2 in the upper extent of the Dean Creek. This is the only observation of Chinook salmon on this reach throughout the nine-season duration of the South Fork Eel River Adult Salmonid Redd Abundance Monitoring Project. The number of Chinook salmon and redds resulted in some of the lowest of seasonal totals from the nine years surveys. This can be contributed to the previously stated equipment issues and overall poor survey conditions throughout the year.

4.3 Steelhead Observations

Initial observations of live steelhead occurred on January 28 on the Upper South Fork Eel River. We confirmed in live fish in several different sub-watersheds including Indian Creek (Anderson Creek and Upper Indian Creek) and Redwood Creek. One notable observation during the season was the presence live adult steelhead on a small sub reach of Upper Indian Creek. Surveys were concluded on February 11 and live steelhead were still present around this time. The survey does not cover the temporal and spatial extent of steelhead but overall does provide information on steelhead distribution relative to the coho salmon specific frame and season.

Table 7. Summary of South Fork Eel River Adult Salmonid Redd Abundance Monitoring Project redd estimates and 95% confidence intervals for survey years 2010-2011 through 2018-2019.

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)
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)

*The South Fork Eel River 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 South Fork Eel River. The project does not monitor the complete spatial extent of Chinook spawning in the South Fork Eel River, 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 South Fork Eel River, and the Steelhead redd abundance estimate is limited to redds observed within the Coho focused reach sample frame and November to February survey period.

5 ACKNOWLEDGEMENTS

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